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
- **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, stay tuned for "number systems" lecture next 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`

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"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`

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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, 01100001₂, 61₈)
'\141' the a character, octal form
'\x61' the a character, hexadecimal form
'b'    the b character (98, 01100010₂, 62₈)
'A'    the A character (65, 01000001₂, 41₈)
'B'    the B character (66, 01000010₂, 42₈)
'\0'   the null character (0, 00000000₂, 0₈)
'0'    the zero character (48, 00110000₂, 30₈)
'1'    the one character (49, 00110001₂, 31₈)
'\n'   the newline character (10, 00001010₂, A₈)
'\t'   the horizontal tab character (9, 00001001₂, 9₈)
'\\'   the backslash character (92, 01011100₂, 5C₈)
'\''   the single quote character (96, 01100000₂, 60₈)
```

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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?

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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?

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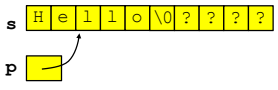
Arrays of characters



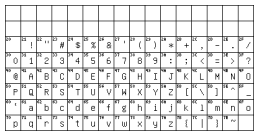

```
char s[10] = {'H','e','l','l','o',0};
```
(or, equivalently)
```
char s[10] = "Hello";

char *p = s+2;

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

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

prints **Jello!**

Unicode

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

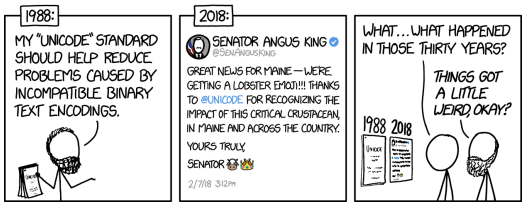


ASCII: American Standard Code for Information Interchange

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

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

What happens in Java?

What happens in C?

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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

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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`

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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

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