Princeton University

Computer Science 217: Introduction to Programming Systems

The C Programming Language

Part 1

For Your Amusement

"C is quirky, flawed, and an enormous success. While accidents of history surely helped, it evidently satisfied a need for a system implementation language efficient enough to displace assembly language, yet sufficiently abstract and fluent to describe algorithms and interactions in a wide variety of environments."

– Dennis Ritchie

Goals of this Lecture

Help you learn about:

- The decisions that were made by the designers* of C
- **Why** they made those decisions

… and thereby…

- The fundamentals of C

Why?

- Learning the design rationale of the C language provides a richer understanding of C itself
- A power programmer knows both the programming language and its design rationale

* Dennis Ritchie, then later, members of standardization committees

Historical context - 1972

Operating systems were programmed in assembly language (i.e., in machine instructions)

[Efficient; expressive; easy to translate to machine language; but not portable from one computer instruction set to another; hard to write programs, hard to debug, maintain…]

Application programs were in "high-level" languages such as Algol, COBOL, PL/1, (newly invented) Pascal

Goals of these languages: Ease of programming, expressiveness, structured programming, safety, data structures, portability

Not fully achieved: safety, expressiveness, portability

Not even attempted: modularity

Goals for C language - 1972

Program operating-systems in a "high-level" language

Need: ease of programming, (reasonable) expressiveness, structured programming, data structures, **modularity,** compilable on a 64-kilobyte computer

Don't even attempt: safety

When possible, have a bit of: portability

Goals for C language - 1972

Program operating-systems in a "high-level" language

Need: ease of programming, (reasonable) expressiveness, structured programming, data structures, **modularity,** compilability

Don't even attempt: safety

When possible, have a bit of: portability

Goals for Java language - 1995

(reasonable) ease of programming, (reasonable) expressiveness, structured programming, data structures,

modularity, safety, portability, automatic memory management

It's not that Java was particularly innovative (in these respects). By 1995, decades of computer-science research had made it straightforward to achieve all these goals at once. In 1972, nobody knew how.

Goals of C

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

Conflicting goals on multiple dimensions!

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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)

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Integer Data Types

- integer data types: **`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 type is not fully specified but *constrained:*
  - **`int`** is natural word size
  - 2 ≤ sizeof(**`short`**) ≤ sizeof(**`int`**) ≤ sizeof(**`long`**)

On CourseLab

- Natural word size: 4 bytes (but not really!)
- **`char`**: 1 byte
- **`short`**: 2 bytes
- **`int`**: 4 bytes
- **`long`**: 8 bytes

What decisions did the designers of Java make?

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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`**

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Unsigned Integer Data Types

Both signed and unsigned integer data types

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Unsigned Integer Data Types

Both signed and unsigned integer data types

- signed integer types: `int, short, long`
- unsigned integer types: `unsigned char`, `unsigned short`, `unsigned int`, and `unsigned long`
- `char` might mean `signed char` or `unsigned char;`
- Define conversion rules for mixed-type expressions
  - Generally, mixing signed and unsigned converts signed to unsigned
  - See King book Section 7.4 for details

What decisions did the designers of Java make?

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Unsigned Integer Literals

Decisions
- 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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Signed and Unsigned Integer Literals

The rules:

The type is the first one that can represent the literal without overflow

Literal	Data Type
dd…d	int long unsigned long
0dd…d 0xdd…d	int unsigned int long unsigned long
dd…dU 0dd…dU 0xdd…dU	unsigned int unsigned long
dd…dL 0dd…dL 0xdd…dL	long unsigned long
dd…dUL 0dd…dUL 0xdd…dUL	unsigned long

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Character Data Types

Back in 1972, some computers had 6-bit bytes, some had 7-bit bytes, some had 8-bit bytes; the C language had to accommodate all these

By 1985, pretty much all computers had 8-bit bytes
- The ASCII character code fits in 7 bits
- One character per byte
- It would be a very strange 21st-century C compiler that supported other than 8-bit bytes

The C character type
- `char` can hold an ASCII character
- `char` might be signed or unsigned, but since 0 ≤ ASCII ≤ 127 it doesn't really matter
- if you're using these for *arithmetic,* you might care to 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, 01100001_B, 61_H)
`'\o141'`	the a character, octal character form
`'\x61'`	the a character, hexadecimal character 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)

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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 before 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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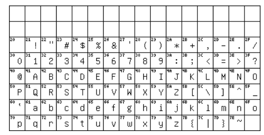
Unicode and UTF-8

Back in 1970s, English was the only language in the world, 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:

Unicode and UTF-8

But Unicode characters are 24 bits; how to encode them in 8-bit bytes?

Obvious solution: 3 bytes per char.

Problem 1: Then, '\n'=0x0a might not mean newline (if it's one of the bytes of a 3-byte sequence)

Problem 2: wastes a lot of space for English text

Solution: UTF-8 encoding of Unicode

http://www.cprogramming.com/tutorial/unicode.html

(This won't be on the exam...)

Logical Data Types

- no logical or Boolean data type
- Represent logical data using type `char`
  - Or any integer type
  - Or any primitive type!!!
- Convention: 0 ⇒ FALSE, ≠0 ⇒ TRUE
- Convention used by:
  - Relational operators (`<`, `>`, etc.)
  - Logical operators (`!`, `&&`, `||`)
  - Statements (`if`, `while`, etc.)

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Aside: Logical Data Type Shortcuts

Note

- Using integer data to represent logical data permits shortcuts

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

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Aside: Logical Data Type Dangers

Note

- The lack of 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?

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Floating-Point Data Types

Back in 1972, each brand of computer had a different (and slightly incompatible) representation of floating-point numbers

This was standardized in 1985; now practically all computers use the IEEE 754 Floating Point standard, designed by Prof. William Kahan of the Univ. of California at Berkeley

- 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)

- `float`: 4 bytes
- `double`: 8 bytes
- `long double`: 16 bytes

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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`

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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

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Continued next lecture

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