The Design of C: A Rational Reconstruction: Part 1

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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

"When someone says, 'I want a programming language in which I need only say what I want done,' give him a lollipop."

-- Alan Perlis

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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 & members of standardization committees

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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!

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Agenda

Data Types

Operators

Statements

I/O Facilities

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Primitive Data Types

What primitive data types should C provide?

Thought process

- C will be used primarily for **system** programming, and so should handle:
  - Integers
  - Characters
  - Character strings
  - Logical (alias Boolean) data
- C might be used for **application** programming, and so should handle:
  - Floating-point numbers
- C should be small/simple

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Primitive Data Types

Decisions
- Provide **integer** data types
- Provide **floating-point** data types
- **Do not** (really) provide a **character** data type
- **Do not** provide a character **string** data type
- **Do not** provide a **logical** data type

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Integer Data Types

What integer data types should C provide?

Thought process
- For flexibility, should provide integer data types of various sizes
- For portability at **application** level, should specify size of each data type
- For portability at **system** level, should define integer data types in terms of **natural word size** of computer
- Primary use will be **system** programming

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Integer Data Types

Decisions
- Provide four integer data types: `char`, `short`, `int`, and `long`
- Type `char` is 1 byte
  - But number of bits per byte is unspecified!
- Do not specify sizes of others; instead:
  - `int` is natural word size
  - 2 <= (bytes in `short`) <= (bytes in `int`) <= (bytes in `long`)

On FC010
- 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

How should C represent integer literals?

Thought process
- People naturally use decimal
- System programmers often use binary, octal, hexadecimal

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Integer Literals

Decisions
- Use decimal notation as default
- Use "0" prefix to indicate octal notation
- Use "0x" prefix to indicate hexadecimal notation
- Do not allow binary notation; too verbose, error prone
- Use "L" suffix to indicate `long` literal
- Do not use a 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

Should C have both signed and unsigned integer data types?

Thought process
- Signed types are essential
  - Must represent positive and negative integers
- Unsigned types are useful
  - Unsigned data can be twice as large as signed data
  - Unsigned data are good for bit-level operations (common in system programming)
- Implementing both data types is complex
  - Must define behavior when expression involves both

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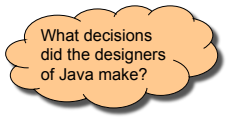
Unsigned Integer Data Types

Decisions

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



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Unsigned Integer Literals

How should C represent unsigned integer literals?

Thought process

- "L" suffix distinguishes **`long`** from **`int`**
- Also could use a suffix to distinguish signed from unsigned

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Unsigned Integer Literals

Decisions

- Default is signed
- Use "U" suffix to indicate unsigned literal

Examples

- **`unsigned int`**:
  - **`123U`**, **`0173U`**, **`0x7BU`**
- **`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

What character data types should C have?

Thought process

- The most common character codes are (were!) ASCII and EBCDIC
- ASCII is 7-bit
- EBCDIC is 8-bit

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Character Data Types

Decision

- Use type **`char`**!

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Character Literals

How should C represent character literals?

Thought process

- Could represent character literals as `int` literals, with truncation of high-order bytes
- More portable & readable to use single quote syntax (`'a'`, `'b'`, etc.); but then…
- Need special way to represent the single quote character
- Need special ways to represent unusual characters (e.g. newline, tab, etc.)

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Character Literals

Decisions

- Provide single quote syntax
- Use backslash (the **escape character**) to express special characters

Examples (with numeric equivalents in ASCII):

```
'a'     the a character (97, 01100001B, 61H)
'\o141' the a character, octal character form
'\x61'  the a character, hexadecimal character form
'b'     the b character (98, 01100010B, 62H)
'A'     the A character (65, 01000001B, 41H)
'B'     the B character (66, 01000010B, 42H)
'\0'    the null character (0, 00000000B, 0H)
'0'     the zero character (48, 00110000B, 30H)
'1'     the one character (49, 00110001B, 31H)
'\n'    the newline character (10, 00001010B, AH)
'\t'    the horizontal tab character (9, 00001001B, 9H)
'\\'    the backslash character (92, 01011100B, 5CH)
'\''    the single quote character (96, 01100000B, 60H)
```

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Strings and String Literals

How should C represent strings and string literals?

Thought process

- 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?
- C should be small/simple

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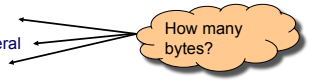
Strings and String Literals

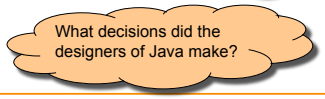
Decisions

- 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





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Logical Data Type

How should C represent logical data?

Thought process

- Representing a logical value (TRUE or FALSE) requires only one **bit**
- Smallest entity that can be addressed is one **byte**
- Type `char` is one byte, so could be used to represent logical values
- C should be small/simple

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Logical Data Type

Decisions

- Don't define a logical data type
- Represent logical data using type `char`
  - Or any integer type
  - Or any primitive type!!!
- Convention: 0 => FALSE, non-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

What floating-point data types should C have?

Thought process
- System programs use floating-point data infrequently
- But some application domains (e.g., scientific) use floating-point data often
- C should support system programming primarily
- But why not allow C to support application programming?
- For portability at **application** level, should specify size of each data type
- For portability at **system** level, should define floating point data types as natural for underlying hardware

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Floating-Point Data Types

Decisions
- Provide three floating-point data types: `float`, `double`, and `long double`
- Don't specify sizes
- bytes in `float` <= bytes in `double` <= bytes in `long double`

On FC010
- `float`: 4 bytes
- `double`: 8 bytes
- `long double`: 16 bytes

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Floating-Point Literals

How should C represent floating-point literals?

Thought process
- Convenient to allow both fixed-point and scientific notation
- Decimal is sufficient; no need for octal or hexadecimal

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Floating-Point Literals

Decisions
- Allow fixed-point and 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
- **C**: Sizes of all types except `char` are system-dependent

Type char
- **Java**: `char` consists of 2 bytes
- **C**: `char` consists of 1 byte

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Continued next lecture

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