

# Introduction to C

CSC100 Introduction to programming in C/C++ Spring 2023

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## **1 What will you learn?**

- What is C?
- What is its origin?
- What is its importance?
- What's the difference to C++?
- Why are we not just learning C++?
- What are C's strengths and weaknesses?
- Why are you learning C from me?
- What's next in the course?

Source:

- Textbook King (2008) ch.1<sup>1</sup>
- See also slides (GDrive)

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<sup>1</sup>All sources are referenced at the end of the script, followed by the footnotes, which do unfortunately not render as links on GitHub. The book by King (2008) does not cover a few recent updates to the ANSI standard for C, like C11, and the current standard C17. The next major C standard revision (C23) is expected for 2023. Gustedt (2019) is a good (but quite difficult) book on "modern C".

## 2 What is C?

- C is a programming language created in the early 1970s.
- It grew out of the development of the UNIX operating system
- In turn, UNIX grew out of a space travel game (Brock, 2019).

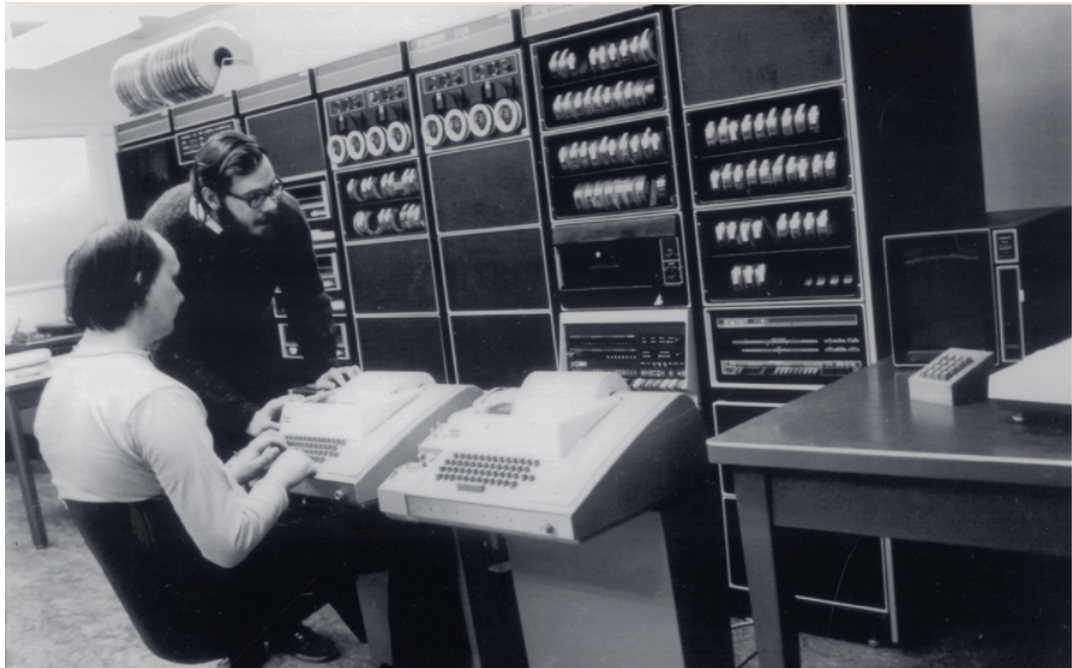


Figure 1: Thompson & Ritchie & DEC PDP-11, 1970. (Brock, 2019)

## 3 How popular is C?

- C consistently ranks among the top 3 programming languages.
- TIOBE Language of the year 2008, 2017, 2019
- Popularity contest: cp. TIOBE Index<sup>2</sup>

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<sup>2</sup>Since 2000, C has consistently ranked among the top two languages in the TIOBE index (based on searches).

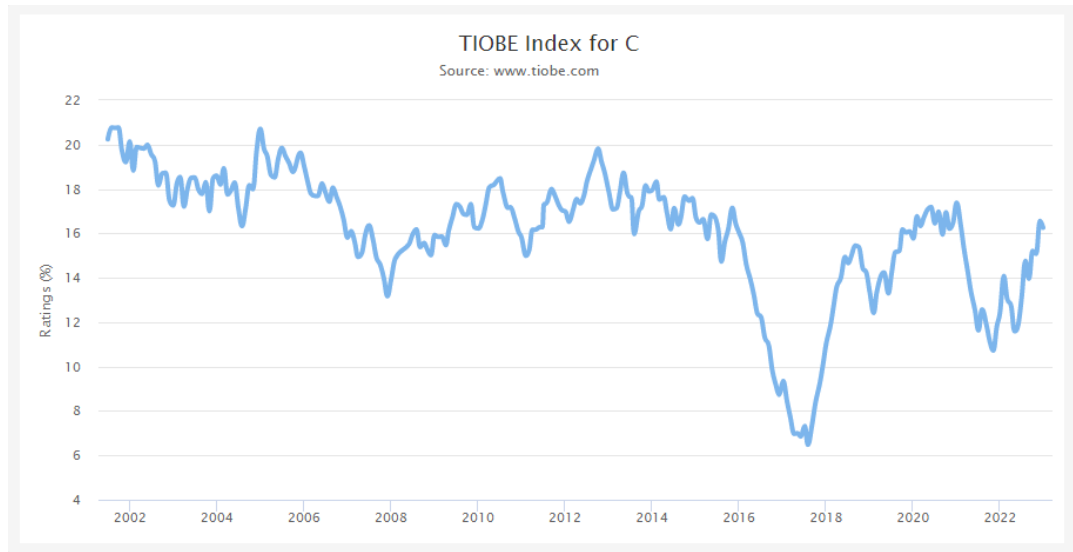


Figure 2: TIOBE Index for C, 2002-2023 (Source: TIOBE)


Jan 2023	Jan 2022	Change	Programming Language	Ratings	Change
1	1		 Python	16.36%	+2.78%
2	2		 C	16.26%	+3.82%
3	4	▲	 C++	12.91%	+4.62%
4	3	▼	 Java	12.21%	+1.55%
5	5		 C#	5.73%	+0.05%
6	6		 Visual Basic	4.64%	-0.10%
7	7		 JavaScript	2.87%	+0.78%
8	9	▲	 SQL	2.50%	+0.70%
9	8	▼	 Assembly language	1.60%	-0.25%
10	11	▲	 PHP	1.39%	-0.00%

Figure 3: TIOBE Index ranking 1-10 (tiobe.com)

- Of the top 10 languages, 7 are direct descendants of C - only Visual Basic, SQL and Assembly language are not C-type languages

## 4 How important is C?

Some well-known programs written in C:

- The Linux kernel (and therefore, Android)
- UNIX operating system (core of MacOS)
- Windows 1.0 to Windows XP
- Doom (early video game)
- Wolfenstein 3D
- Git version control system
- C compilers (Clang, GCC/MinGW)
- Any software that crosses platforms easily (portable)

See also: "Why C programming is awesome" (Hawkes, 2016).

## 5 What is a programming language?

"A programming language is a *formal language* comprising of a set of *strings* that produce various kinds of *machine code* output. Programming languages are one kind of computer language, and are used in computer programming to implement algorithms." (Source: Wikipedia)

- **Formal** language?
- Set of **strings**?
- **Machine** code?
- **Algorithm**?

Fortunately, computer (and data) science isn't really a science at all! (it's more of a craft like mining, knitting, or pottering.)

Rank	Language	Type	Score
1	Python	  	100.0
2	Java	  	96.3
3	C	  	94.4
4	C++	  	87.5
5	R		81.5
6	JavaScript		79.4
7	C#	   	74.5
8	Matlab		70.6
9	Swift	 	69.1
10	Go	 	68.0

Figure 4: IEEE index (Source: Cass, 2019)



Figure 5: Real world applications of C (Source: DataFlair)

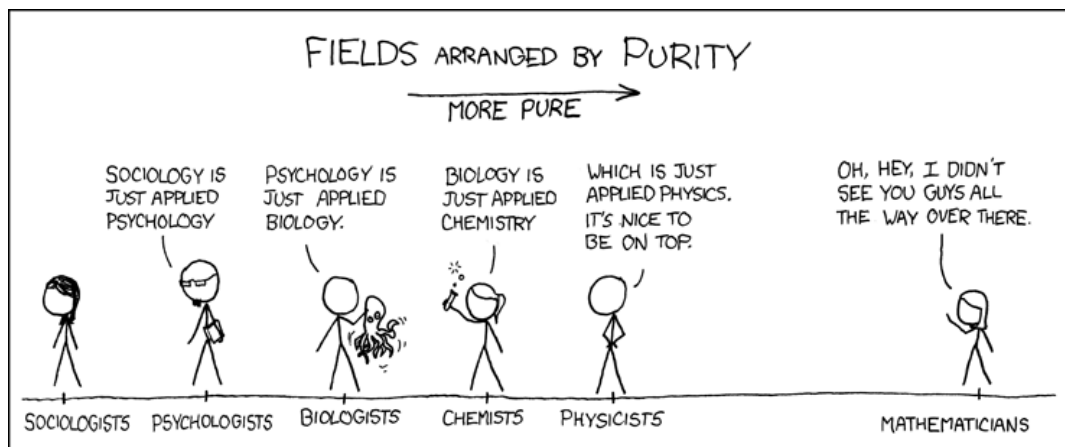


Figure 6: Scientific fields arranged by "purity" (xkcd)

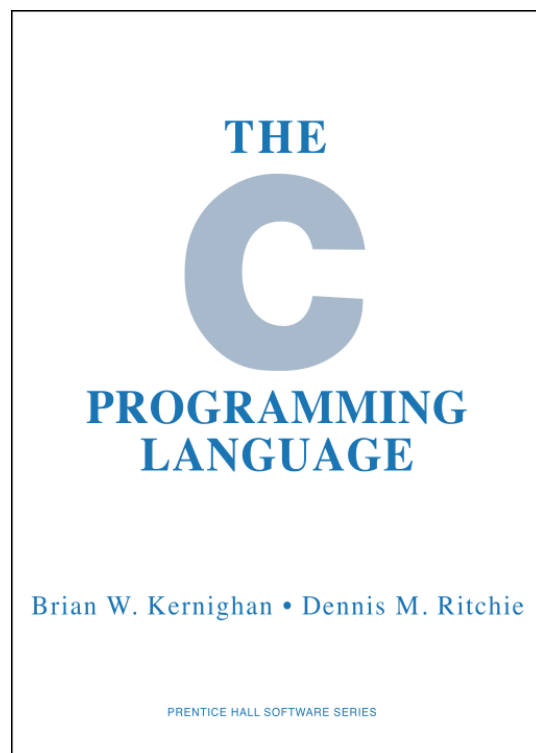


Figure 7: "K&R" (Kernighan/Ritchie, 1978)



## 6 Where does C come from?

- By-product of the UNIX operating system 1969 <sup>3</sup>
- Developed on DEC PDP-7 (computer with 8K words of main memory)
- Written originally in assembly language
- UNIX rewritten in C by 1973 for DEC PDP-11
- Standardization of C, 1973-2018

**Challenge:** what does "8K words of main memory" mean? <sup>4</sup>

See also: C Programming Language | Brian Kernighan & Lex Fridman

- Text processing problems were inherited from Unix
- Examples should be realistic, useful and representative
- If you're the first in anything, everybody else has to follow

## 7 Standardization

Details: see ANSI (American National Standards Institute)

## 8 How computers work

Well, at least this is one way of looking at it.

The "hard disk" can also be a Solid State Drive (SSD) or some other form of Non-Volatile Memory (NVM) - i.e. it doesn't disappear when the power goes out.

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<sup>3</sup>The motivation to create Unix, according to Wikipedia, was to port Thompson's space travel video game to the PDP-7 mainframe computer. So in a way we owe modern computing to gaming.

<sup>4</sup>How many bits can be stored in memory of 8K words depends on the bit length of a word (or byte). One byte holds  $8 = 2^3$  bits (binary digits, or memory locations capable of storing 2 states). 8K byte correspond to  $8 * 2^{10} = 8 * 1,024 = 8,192$  bits. By comparison, the main memory of my laptop is  $16\text{GB} = 16 * 2^{30} = 3.2\text{E}+31$  bits. It follows from these memory restrictions that UNIX (and C) had to be designed to be very small, or space effective.

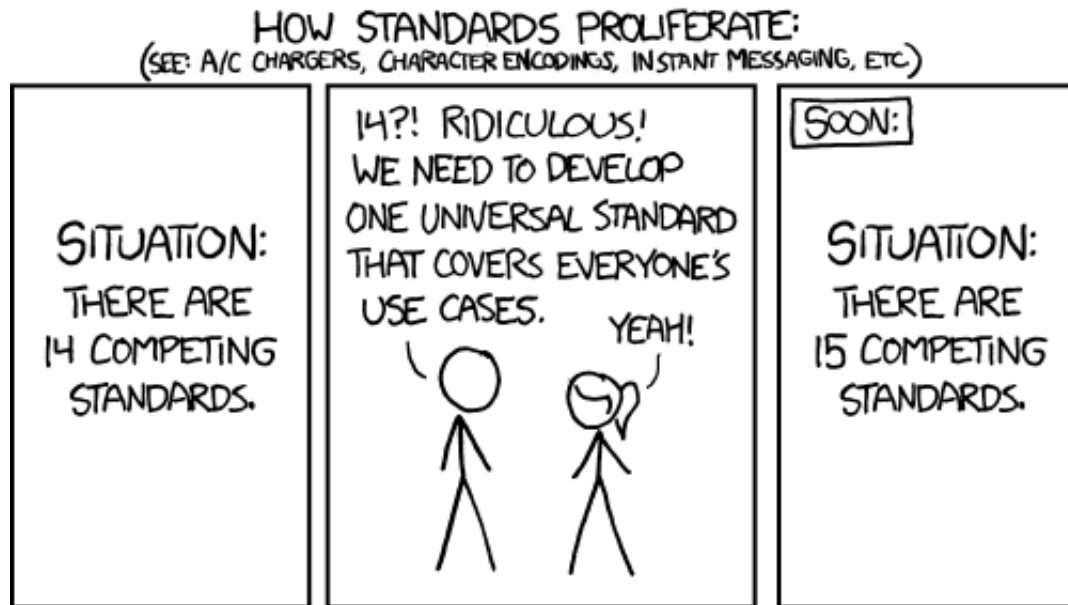


Figure 8: How standards proliferate (Source: xkcd)

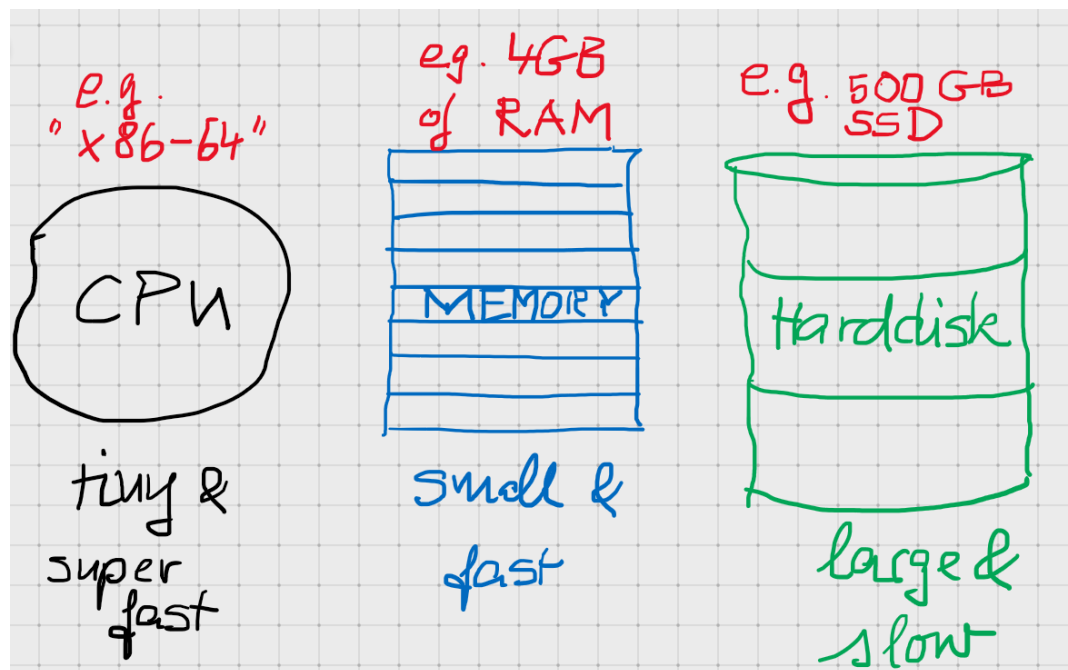


Figure 9: Computer architecture (simplified)

## 9 How programs are processed

### 9.1 Simplified process

1. **WRITE** source code in an editor (NVM)
2. **COMPILE** source code to machine code (RAM)
3. **RUN** program (CPU)
4. **DISPLAY** results (RAM)
5. **SAVE** result (NVM)

### 9.2 Complete process

Specifically for C and our compiler GCC, this process looks technically like this:

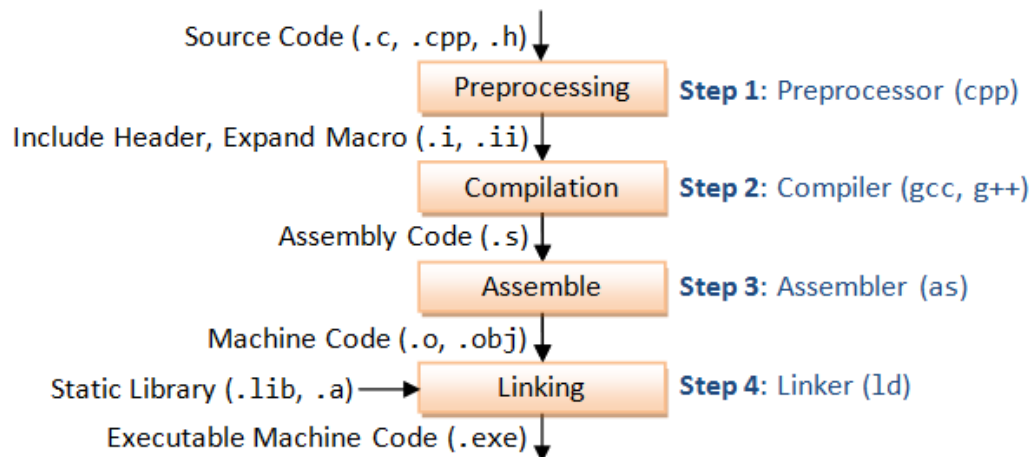


Figure 10: GCC compilation process (Source: Hock-Chuan, 2018).

## 10 Looks matter

She's a beauty.

Challenge: was C the first programming language? <sup>5</sup>



Figure 11: PDP-11/70

## 11 The Latin of programming languages

The following languages are C-based:

- C++ (OOP extension of C, games)
- Java (OOP, VM-portable, and no pointers)
- C# (Microsoft, games)
- Perl (scripting, text mining)

"C is to programming languages what Latin is to Western natural languages." (Anonymous)

- C is lightning fast and terribly tiny

"C is fast because it's the speed of light, and relativity?"<sup>6</sup>  
(Stackoverflow)

## 12 Benchmarking

- Excerpts for parsing and printing a *Mandelbrot* set
- *Benchmarks* depend on algorithm implementation
- C always wins the size battle (*memory allocation*)
- Some very *specialized* languages are even faster

## 13 Strengths and weaknesses of C

STRENGTH	WEAKNESS
Efficiency	Permissiveness (Error-prone)
Portability	Terseness and Understanding
Power	Large program maintenance
Flexibility	
Standard library	
Integration with UNIX	

<sup>5</sup>Answer: no. By 1966, there were already ca. 700 programming languages (Chatley et al, 2019), today there are almost 9,000. C descends from ALGOL60, other important languages are Lisp (functional language), SIMULA (first OOP language), and PROLOG (logic language).

<sup>6</sup>This is a joke based on someone mixing up *c* (speed of light constant) and C (the programming language).

Language	Time, s	Memory, MiB	Energy, J
C++/g++	11.561 $\pm$ 0.257	2.53 $\pm$ 00.89 + 1.37 $\pm$ 00.86	198.02 $\pm$ 10.79
C/gcc	12.638 $\pm$ 0.191	0.63 $\pm$ 00.00 + 1.00 $\pm$ 00.04	271.04 $\pm$ 04.12
Rust	13.468 $\pm$ 0.603	1.99 $\pm$ 00.07 + 0.31 $\pm$ 00.03	260.96 $\pm$ 26.40
C/clang	14.006 $\pm$ 0.558	0.69 $\pm$ 00.00 + 0.95 $\pm$ 00.03	277.62 $\pm$ 28.40

Figure 12: Image source: Kostya benchmark, GitHub, Nov 2021

Python/pypy	65.668 $\pm$ 2.354	63.37 $\pm$ 00.05 + 47.76 $\pm$ 00.05	1333.51 $\pm$ 81.90
Julia	75.405 $\pm$ 1.755	200.84 $\pm$ 00.22 + 0.61 $\pm$ 00.00	1569.12 $\pm$ 122.00
Ruby/truffleruby (-jvm)	120.743 $\pm$ 5.839	581.66 $\pm$ 04.97 + 539.81 $\pm$ 13.64	2466.87 $\pm$ 108.51
Ruby/truffleruby	131.313 $\pm$ 4.944	445.97 $\pm$ 01.32 + 574.91 $\pm$ 13.29	2693.24 $\pm$ 211.06
Haskell	220.958 $\pm$ 4.270	3.81 $\pm$ 00.02 + 26.13 $\pm$ 00.00	4785.77 $\pm$ 295.26

Figure 13: Image source: Kostya benchmark, GitHub, Nov 2021

## 14 What is the difference between C and C++?

C++ is a superset of C.



Figure 14: C/C++ logos

WHAT	C	C++
TIME	Thompson/Ritchie 1970s	Stroustrup 1980s
TYPE	Imperative procedural	Object-oriented
GOOD	System programming	Games and graphics
USED	Internet of Things	Flight Software

Source: Lemonaki, 2021.

## 15 Why are we not just learning C++?

- Object-orientation is a difficult paradigm (C++)
- System programming is pure power (C)
- C is simpler, smaller, and faster

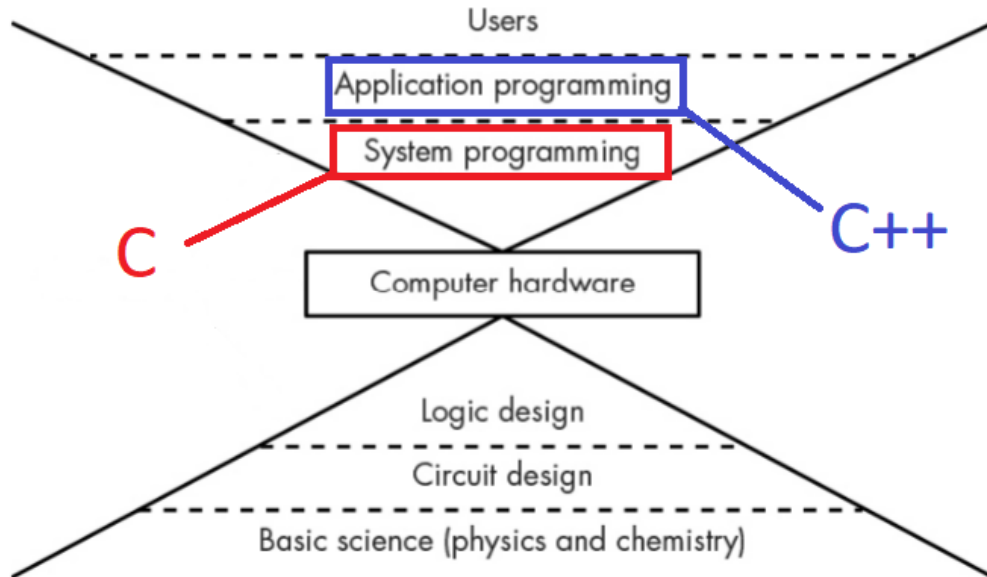


Figure 15: Computer Landscape. (Modified from: Steinhart, 2019)

- Bjarne Stroustrup (2011): "C is obsolete"<sup>7</sup>
- Linus Torvalds (2007): "C++ is a horrible language"<sup>8</sup>.

Also, there's this:

"Languages are tools. Memorizing them no more makes you a computer scientist than studying hammers makes you a carpenter." -Nielsen

- It's easy to pick up additional languages
- Data structures and algorithms are key to understanding
- First language could be anything<sup>9</sup>

<sup>7</sup>However, he is biased, since he is the creator of C++. The title of the video is misleading: Stroustrup believes that every C program should rather be a proper C++ program. However, he also concedes that C++ is still too complex for many ("We have to clean it up").

<sup>8</sup>Torvalds (who wrote the Linux kernel in C) argues here in favor of writing his hugely successful version control program `git` in C instead of C++. He highlights some of the strengths of C: efficient, system-level, portable code.

<sup>9</sup>My first real programming language was FORTRAN (specialized on scientific com-



## 16 Why am I teaching C/C++?

It's personal.

I used C++ during my PhD studies at DESY, Germany, to write a library of multigrid functions (numerical method for lattice gauge theory simulations in theoretical particle physics).<sup>10</sup>

## 17 What will happen to C/C++ in the next 20 years?

Whatever happens, good new for learning C.

I increasingly see propaganda for replacing C++ by Rust (Kirsh, 2021), another relatively new language with OOP support and better security properties.

## 18 Summary

1. The C programming language was created 50 years ago
2. C is small, simple, very fast, and close to the computer
3. Linux (and Android) are largely written in C
4. The object-oriented programming (OOP) language C++ contains C
5. System programming is a powerful skill set

## 19 Glossary

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puting), then C++. Recently, I picked up R (for data science). In between I've sampled (not mastered) many others, including: Python, Lisp, PROLOG, C, PHP, SQL, SQLite etc.

<sup>10</sup>I changed my name from 'Speh' to 'Birkenkrahe' when I got married.

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## The C++ Virtual Library

[Recent Changes](#) -- Mail additions to this list to <lilje@desy.de>

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[The HTML formatted version](#) on the draft C++ standard.

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### [Getting Start\(l\)ed](#)

Documents and sources on [C++](#) and [OOP](#). The draft C++ standard is now generally available.

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**To report errors, use this form to contact [Lutz](#), please.**

Last updated October 25th, 1995

[Lutz Lilje](#)

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**Big thanks to Marcus for starting up all this!**

[Info about Marcus Speh](#)

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Figure 16: The C++ Virtual Library, 1993-1995 (DESY)



**Wouter Van Ooijen**

Head Lecturer Computer Engineering · Updated 11mo



### **What will happen to C/C++ in the next 20 years?**

Note: there is no such thing as C/C++! Stop using that term!

If the recent past is any guide:

- the C language will remain mostly stable and unchanged
- The C++ language will adopt many new things, in 20 years it will probably be from 2 to 10 times as complex as it is now
- Some alternative programming languages will rise for the domain that is now dominated by C and C++, but they will not get much traction. The successful ideas from these languages will be incorporated in C++ (and a few unsuccessful ones too), but will be ignored by C.

C will remain dominant in Electrical Engineering curricula and careers (and in the Linux kernel). C++ will become dominant in low-level/high-performance/resource-constrained programming that is not intimately tied to electronics.

Hardware will continue to evolve, hence things that are now done in C and C++ will be done in other, more programmer-friendly but less performant (less CPU-friendly) languages. New application areas will arise that require performant languages to get the most out of the hardware, these things (gadgets? wearables? intelligent dust? who knows) will be programmed in C or (I hope!) C++.

This is my somewhat tongue-in-cheek but reasonably probable answer. For a better answer, please direct me to the nearest crystal ball repair shop.

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737



17



81



Figure 17: One expert's opinion (Source: Quora)

CONCEPT/TOPIC	DEFINITION
DEC PDP-11	1970s mainframe computer
UNIX	Operating system (ca. 1969)
ANSI	American National Standard Institute
String	A data type representing text
Assembler	Machine code (hard to write/read)
Algorithm	Fixed process or set of rules
Linux	Operating system (ca. 1991)
C	Imperative, procedural programming language
compiler	Software to translate source into machine code
C++	Object-oriented (OO) superset of C
Clang	C/C++ compiler
gcc	GNU compiler bundle (incl. C/C++)
Java,C#	OO programming language
Perl	Scripting language
Git	Software version control system
GitHub	Developer's platform (owned by Microsoft)
Library	Bundle of useful functions and routines
Portability	Ability of software to run on different hardware
Efficiency	Software speed of execution and memory requirements
Permissiveness	Degree to which a language tolerates ambiguities
Object-orientation	Ability to define abstractions
System programming	Programming close to the machine
Application programming	Programming close to the user

## 20 What's next?

- Getting started: Infrastructure (Lab)
- MinGW (compiler) + Emacs (editor) + GitHub (collaboration)
- First program: "hello world" (Lecture + Lab)

`../img/1_river.gif`

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