Advanced Programming

ACSE-5: Lecture 1

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Why programming?

- “Our civilization runs on software” Bjarne Stroustrup
- Code runs on a variety of hardware (not only PCs)

The Aims

- Learning objectives
  - Fundamental programming concepts
  - Key useful techniques
  - Basic Standard C++ facilities
- After the course, you should be able to
  - Write small colloquial C++ programs
  - Read much larger programs
  - Learn the basics of many other languages by yourself
- After the course, you will ***not*** (yet) be
  - A C++ language expert
  - An expert user of advanced libraries
  - But you will be on your way!

The Means

- Lectures
  - Do Attend
  - Few slides, and lots of live coding
  - Teaching 30 min, Break 5 min
  - Try to follow what is being done, you will get the final code after class, ask and interrupt if you want more/other details or don't follow or understand! Either through chat or by raising your hand.
- Notes/Chapters
  - Extra mile: Read a chapter per day
    - Bjarne Stroustrup: Programming -- Principles and Practice Using C++
  - Feedback is welcome (typos, suggestions, etc.)
- Assignments + Homeworks
  - "That's where the most fun and the best learning takes place"
  - One Assignment (groups of three) Feb 7th, 50%
  - One in-class Coursework (individual): Feb 1st, 50%

Cooperate on Learning

Except for the work you hand in as individual contributions, we ***strongly*** encourage you to collaborate and help each other

But don’t copy code from the internet, try to write it yourself

Course Outline (1)

- Introduction: C++, gcc/Intel compilers, MSVC IDE, compiling and linking, executables. Data types. (Adriana Paluszny)
- Functional programming. Functions: passing by value and reference. Recursion vs. iteration. Input/output. Pointers and References. Introduction to containers. (Steven Dargaville)
- Standard template library (STL). Introduction to objects (using objects). STL Containers: vectors, lists, maps. MSVC Debugger. Plotting with C++ (Gnuplot). (Adriana Paluszny)
- Object oriented programming (creating objects). Classes, constructor, destructor, copy constructor, members, Boolean operators, mutators, accessors. Introduction to Inheritance, Polymorphism & Encapsulation in C++. Making objects STL compatible. (Adriana Paluszny)
- C++ History Trip. C++18/20. The Standards Committee. Programming paradigms. Agile. Introduction to UML. Roles in programming teams (Architect vs. Programmer). (Adriana Paluszny)

Course Outline (2)

- Memory management with C++. Safety and housekeeping. Applied to linear systems and matrices. BLAS/LAPACK. Second Assignment. (Steven Dargaville)
- Memory management and optimisation. Scaling. Overwriting. Introduction to templates. (Steven Dargaville)
- Polymorphism in C++. Sparse CSR Formats. Introduction to PETSc. (Steven Dargaville)
- Templates. Reference Counting. Dense and iterative methods for matrix inversion. (Steven Dargaville)
- Computer-based programming in-class assignment.
- Wavelets (Steven Dargaville). Deep dive into STL. (Adriana Paluszny)

Course outline (3)

- Throughout
  - Program design and development techniques
  - C++ language features
  - Background and related fields, topics, and languages
  - Two instructors (Adriana and Steven)
  - GTAs – morning 8:00-9:00 am and 1:00-4:00pm sessions, except for Feb 26th, as you have an afternoon course

Feedback request

- Please mail questions and constructive comments to

  apaluszn@imperial.ac.uk

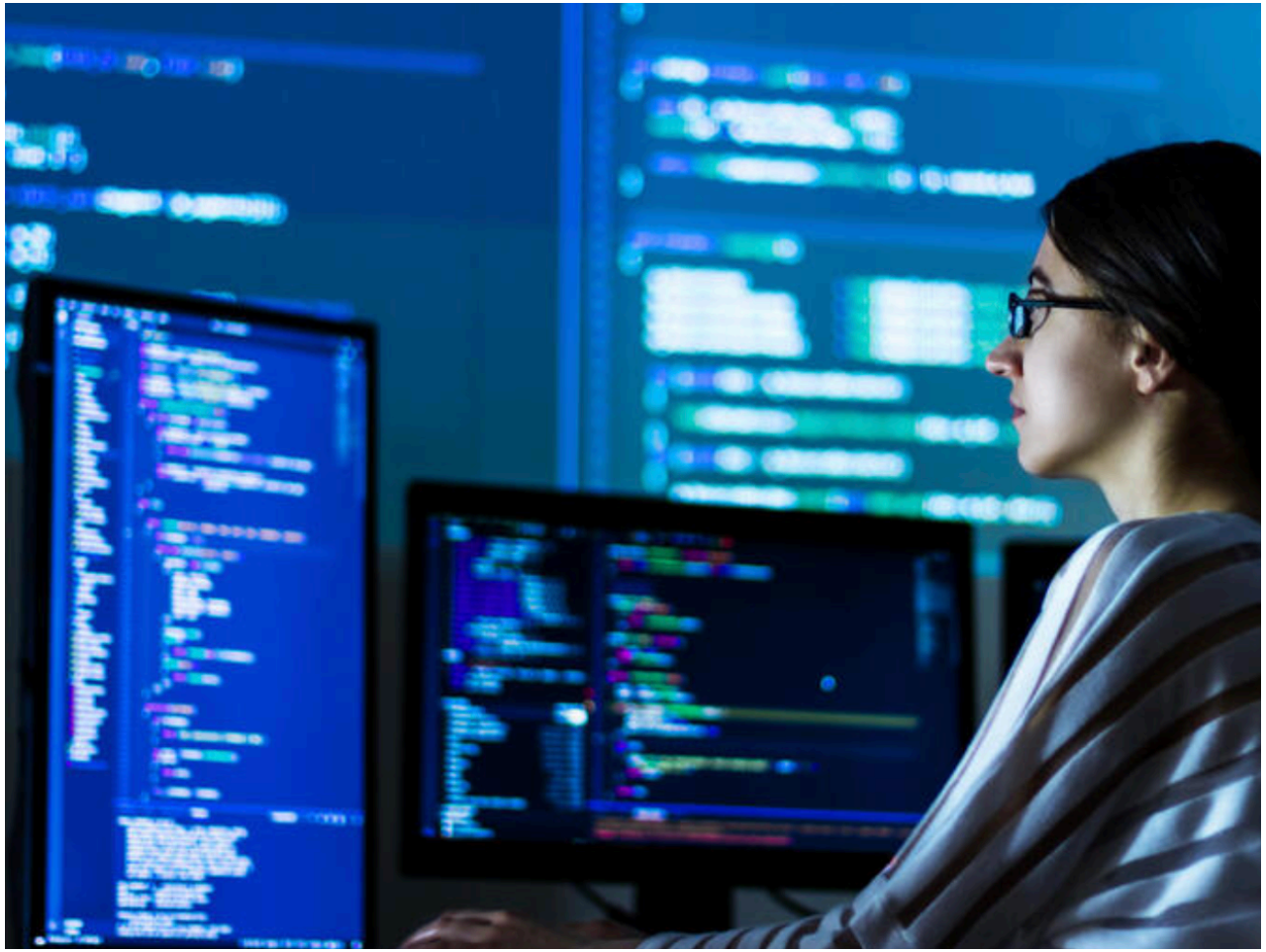
  Or any of the teaching or GTA team

- Your feedback will be most appreciated
  - On style, contents, detail, examples, clarity, conceptual problems, exercises, missing information, depth, etc.

- Do complete surveys when sent to make your voice count

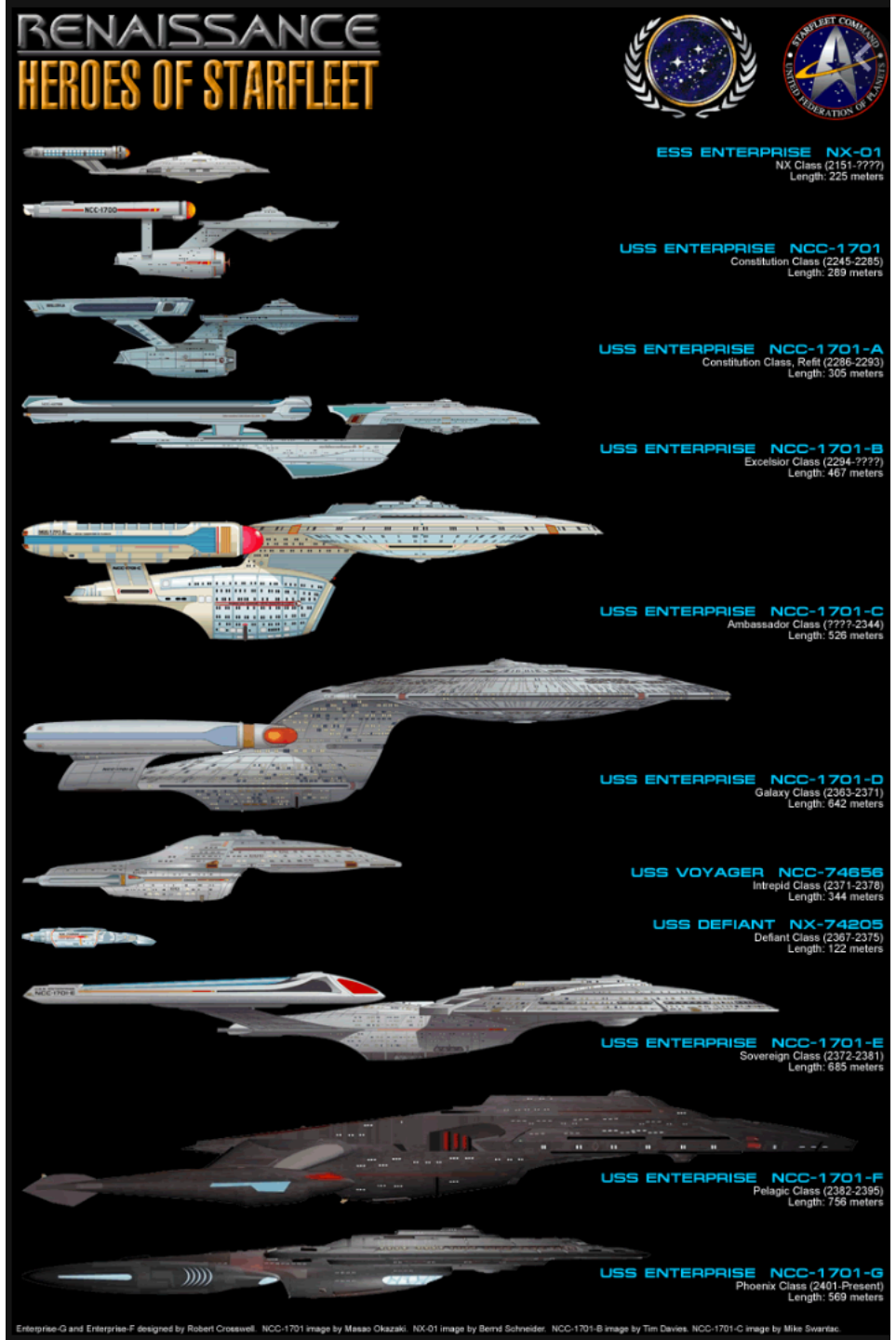
Advanced Programming

- What does it mean to be an “advanced programmer”?
- “Competitive programming”



The goals

- Modularity
- Abstraction
- Speed
- Security
- Sustainability
- Efficiency (Hw)
- Longevity
- Growth/Scale



Why C++ ?

- The purpose of a programming language is to allow you to express your ideas in code
- C++ is the language that most directly allows you to express ideas from the largest number of application areas
- Abstraction + Hardware control
- C++ is the most widely used language in engineering areas
  - Amazon, Google, Facebook, YouTube, Twitter, Bing
  - Finance, Ships, Aviation, Aircrafts, Phones, Energy (Oil, Gas, ..), Visualization, Manufacturing, Comms, Games, Mars Rover
  - Adobe, Google file system, Bloomberg, Microsoft OS, MS Office, MS Explorer, Visual Studio, Mozilla Firefox, mySQL

Who created it?

Bjarne Stroustrup

From Wikipedia, the free encyclopedia

"Stroustrup" redirects here. It is not to be confused with Jakob Stoustrup.

Bjarne Stroustrup (/ˈbjɑːrnə ˈstraʊstrʊp/; Danish: [ˈpjaːnə ˈstʁʌwˀstʁɔp];[2][3] born 30 December 1950) is a Danish computer scientist, most notable for the creation and development of the C++ programming language.[4] He is a visiting professor at Columbia University, and works at Morgan Stanley as a Managing Director in New York.[5][6][7][8][9]

Contents [hide]

Early life and education [edit]

Stroustrup was born in Aarhus, Denmark. His family was working class, and he went to the local schools.[10]

He attended Aarhus University 1969–1975 and graduated with a master's degree in mathematics and computer science. His interests focused on microprogramming and machine architecture. He learned the fundamentals of object-oriented programming from its inventor, Kristen Nygaard, who frequently visited Aarhus.

In 1979, he received a PhD in computer science from the University of Cambridge,[11] where he was supervised by David Wheeler.[1][12] His thesis concerned communication in distributed computer systems.[13]

Bjarne Stroustrup

Stroustrup in 2010

Born	30 December 1950 (age 70) Aarhus, Denmark
Nationality	Danish
Education	Aarhus University (MSc) University of Cambridge (PhD)
Known for	C++
Awards	Grace Murray Hopper Award (1993) ACM Fellow (1994) IEEE Fellow (1994)

Why C++? (As a programmer)

- C++ is precisely and comprehensively defined by an ISO standard
  - And that standard is almost universally accepted
  - The most recent standard is ISO C++ 2017
- C++ is available on almost all kinds of computers/environments
- Programming concepts that you learn using C++ can be used fairly directly in other languages
  - Including C, Java, C#, and (less directly) Fortran
- C++ is changing and evolving all the time, and it is very fast!

Committee

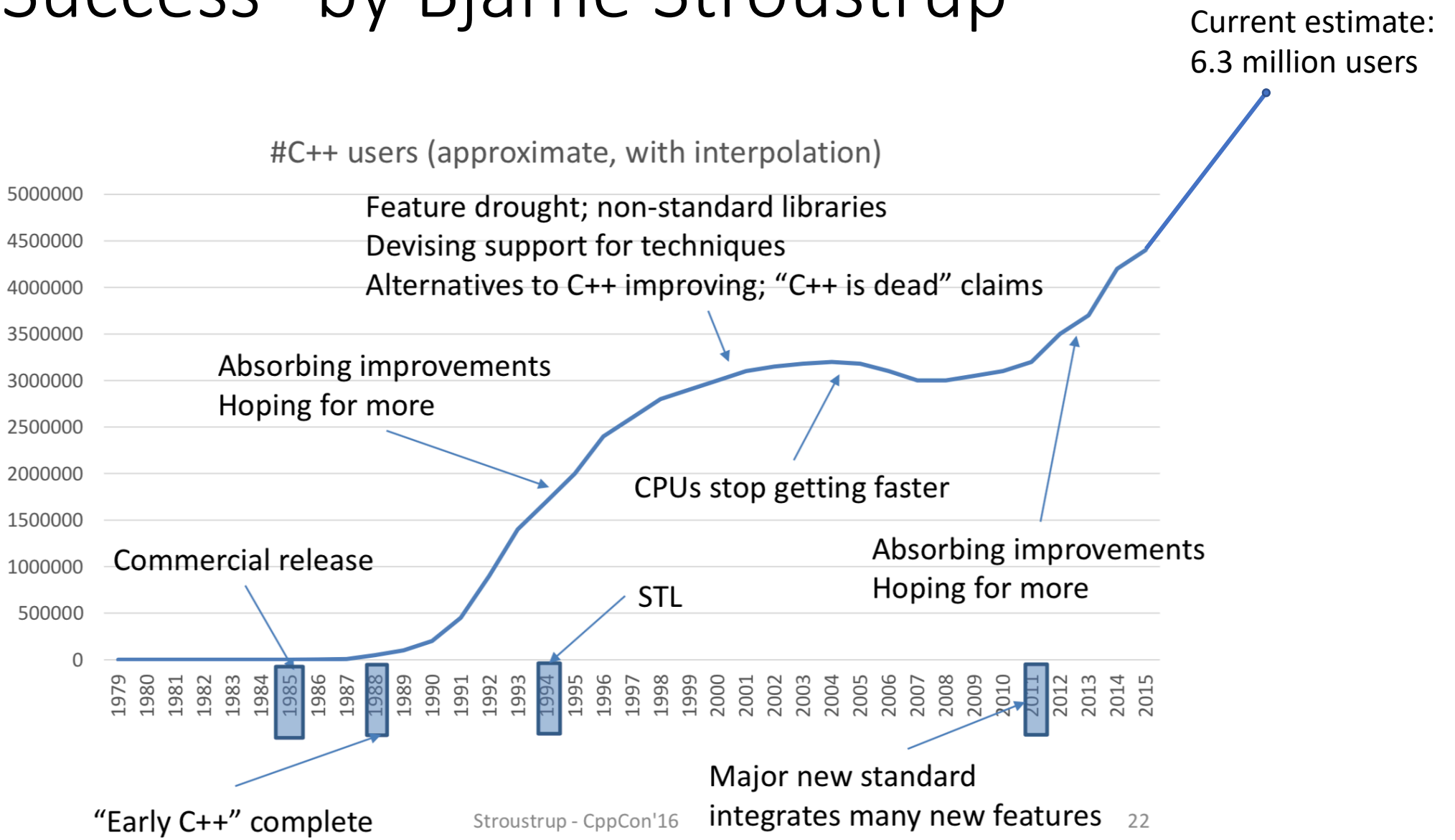
International Organization for Standardization

- ISO C++ WG21
- Standards Committee
- Design C++
- Other companies implement the compilers: Intel, Microsoft, gnu (OA)
- The standard moves faster than the implementation
- https://isocpp.org/std/the-committee

Design Principles

- Evolutionary (Stability, Adaptation)
- Simple things simple
  - Don’t make complicated tasks impossible/unreasonably hard to complete
- Zero-overhead principle
  - Pay for what you use
- Aim high
  - Change the way we think

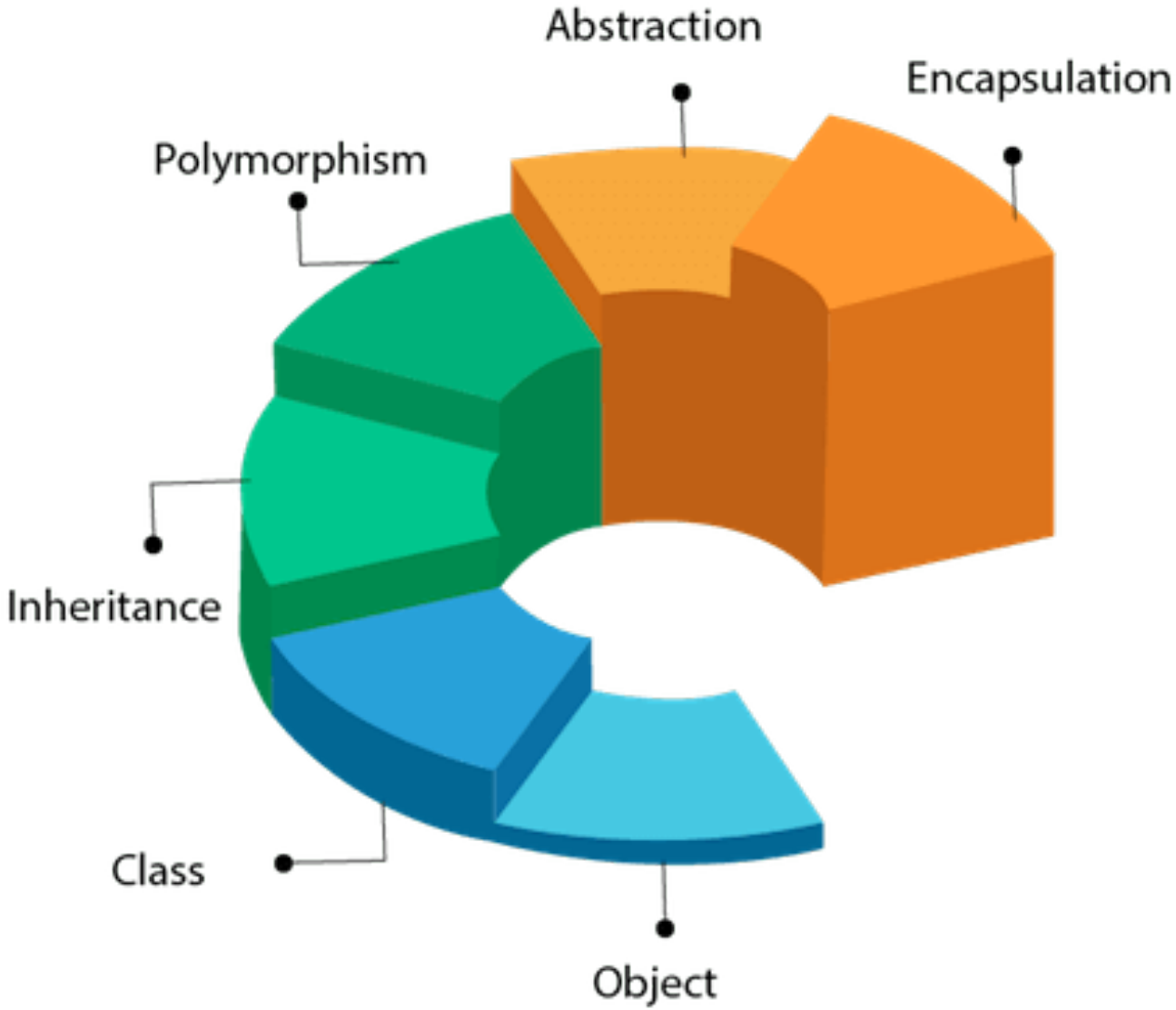
“C++ Success” by Bjarne Stroustrup



Main characteristics of C++

Three main concepts define C++

- Object oriented
- Inheritance
- Polymorphism



Python and C++

- C++ has a stricter syntax
- Learning also requires understanding of inner workings (Mid- to low-level language)
- More prone to human error
- Compiled: executable tailored to platform
- Allows for tailored code
- Allows for substantial optimization
- Allows control of computer resources
- Fast
- Access to specialized libraries
- Connection to other libraries requires care
- Large systems, Live Systems, Cloud, Gaming, Medical, Banking, …

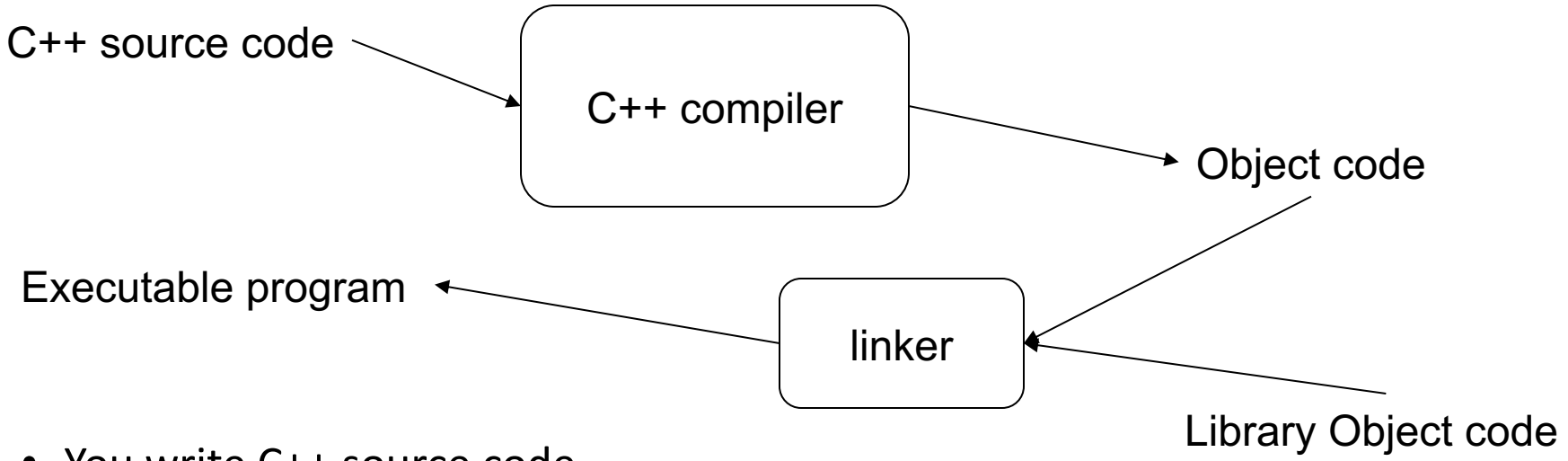
- Python has a syntax designed to make it easy to use
- Quick to learn (high level)
- Less prone to human error
- Interpreted: precompiled and virtual machine
- Code will be run in pre-established ways
- Complex ways to optimize
- Less control
- Slow
- Access to specialized libraries
- Easier to connect to other libraries
- Machine Learning, Testing new concepts, Data Analysis, Research, …

Both can be integrated, both powerful tools in the development stack

A first program – complete

```
// a first program:

#include <iostream>          // get the library facilities needed for now

int main()                                  // main() is where a C++ program starts
{
    std::cout << "Hello, world!\n";        // output the 13 characters  Hello, world!
                                            // followed by a new line
    return 0;                               // return a value indicating success
}

    // note the semicolons; they terminate statements
    // braces { … } group statements into a block – the block defines the "scope" of a variable
    // main( ) is a function that usually takes no arguments ( )
    //      and returns an int (integer value) to indicate success or failure
```

Compilation and linking



- You write C++ source code
  - Source code is (in principle) human readable
- The compiler translates what you wrote into object code (sometimes called machine code)
  - Object code is simple enough for a computer to "understand"
- The linker links your code to system code needed to execute
  - E.g., input/output libraries, operating system code, and windowing code
- The result is an executable program
  - E.g., a **.exe** file on windows or an **a.out** file on Unix

Source files

header.h:

Who am I?

Interfaces to libraries
(declarations)

source.cpp:

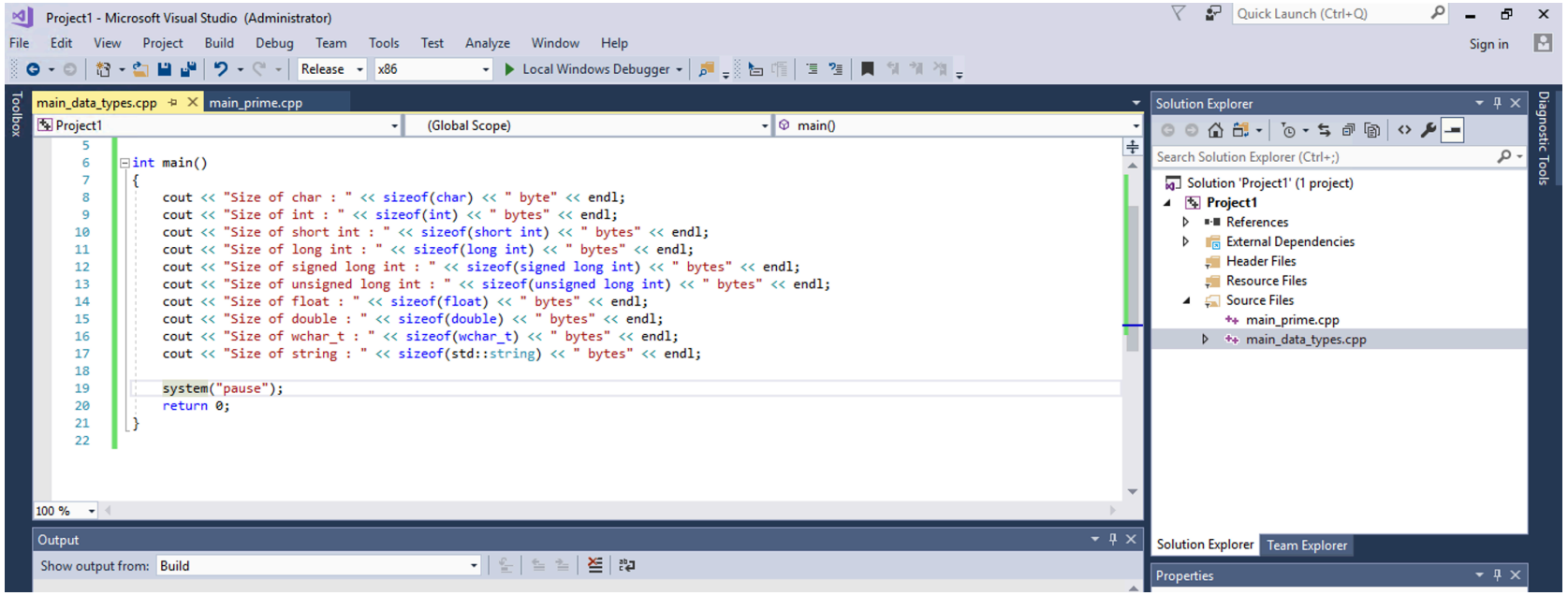
What am I?

```
#include <string>
#include “MyFile.h”

My code
My data
(definitions)
```

An IDE = MSVC Community 2017/2019

Integrated Development Environment (IDE)

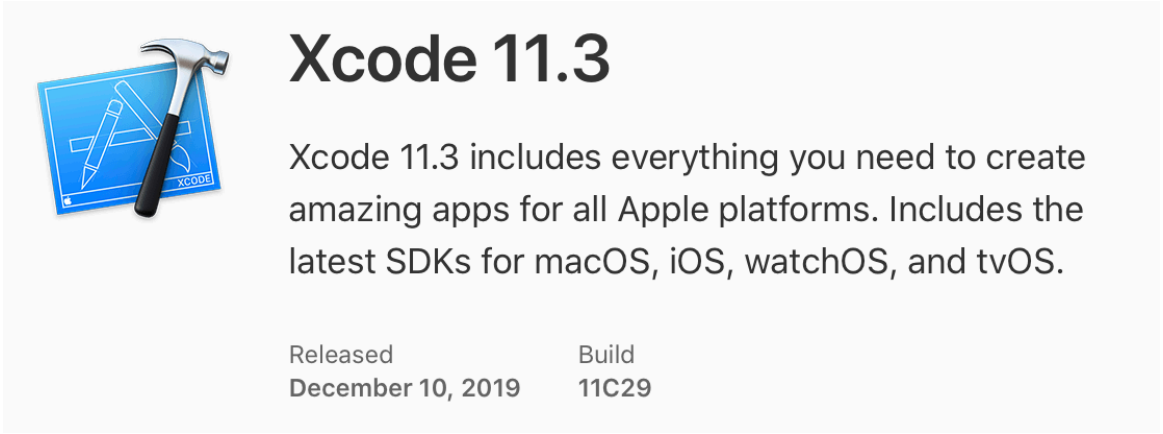
Beyond a file editor it provides support for the construction of the makefiles = Editor + Compiler + Linker + Debugger + Profiler



Many other IDEs and Editors

- Visual Studio Code, Eclipse, Code::Blocks, CodeLite, NetBeans, Qt Creator, Dev C++, Clion, Sublime, Xcode, and others

- And there are also partially integrated environments – basically enriched text editors – with compiling done via command line



Objects, types, and values aka. “Data types”

After Chapter 3 of Bjarne Stroustrup

www.stroustrup.com/Programming

Overview

- Strings and string I/O
- Integers and integer I/O
- Types and objects
- Type safety

Go to MSVC

Live coding …

[the following slides will be for reference]

Integers and Strings

- Strings
  - **cin >>** reads a word
  - **cout <<** writes
  - **+** concatenates
  - **+= s** adds the string **s** at end
  - **++** is an error
  - **-** is an error
  - …
- Integers and floating-point numbers
  - **cin >>** reads a number
  - **cout <<** writes
  - **+** adds
  - **+= n** increments by the int **n**
  - **++** increments by **1**
  - **-** subtracts
  - …

The type of a variable determines which operations are valid and what their meanings are for that type

(that's called “overloading” or “operator overloading”)

Names

- A name in a C++ program
  - Starts with a letter, contains letters, digits, and underscores (only)
    - **x, number_of_elements, Fourier_transform, z2**
    - Not names:
      - **12x**
      - **timetomarket**
      - **main line**
    - Do not start names with underscores: **_foo**
      - those are reserved for implementation and systems entities
  - Users can't define names that are taken as keywords
    - E.g.:
      - **int**
      - **if**
      - **while**
      - **double**

Names

- Choose meaningful names
  - Abbreviations and acronyms can confuse people
    - **mtbf, TLA, myw, nbv**
  - Short names can be meaningful
    - (only) when used conventionally:
      - **x** is a local variable
      - **i** is a loop index
  - Don't use overly long names
    - Ok:
      - **partial_sum**
        element_count
        staple_partition
    - Too long:
      - **the_number_of_elements**
        remaining_free_slots_in_the_symbol_table

Types and literals

- Built-in types
  - Boolean type
    - **bool**
  - Character types
    - **char**
  - Integer types
    - **int**
      - **and short** and **long**
  - Floating-point types
    - **double**
      - and **float**
- Standard-library types
  - **string**
  - **complex<Scalar>**

- Boolean literals
  - **true false**
- Character literals
  - **'a', 'x', '4', '\n', '$'**
- Integer literals
  - **0, 1, 123, -6, 034, 0xa3**
- Floating point literals
  - **1.2, 13.345, .3, -0.54, 1.2e3, .3F**
- String literals **"asdf"**,
  "Howdy, all y'all!"
- Complex literals
  - **complex<double>(12.3,99)**
  - **complex<float>(1.3F)**

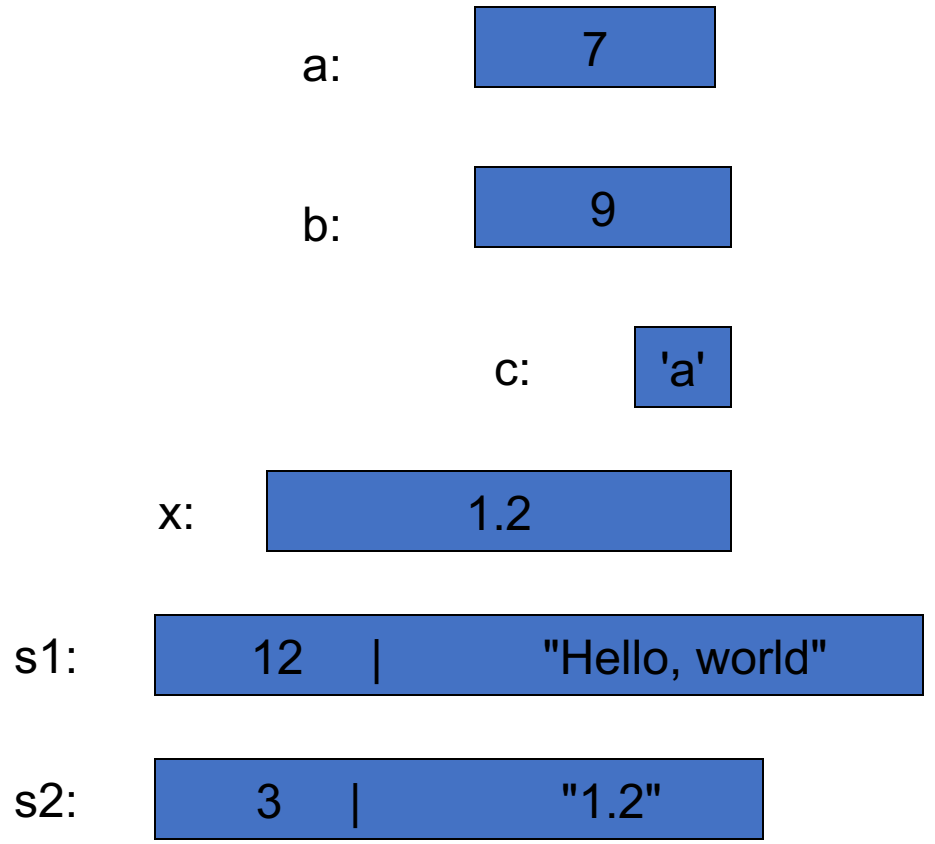
If (and only if) you need more details, see the book!

Types

- C++ provides a set of types
  - E.g. **bool**, **char, int, double**
  - **Called “built-in types”**
- C++ programmers can define new types
  - Called “user-defined types”
  - We'll get to that eventually
- The C++ standard library provides a set of types
  - E.g. **string**, **vector**, **complex**
  - Technically, these are user-defined types
    - they are built using only facilities available to every user

Declaration and initialization

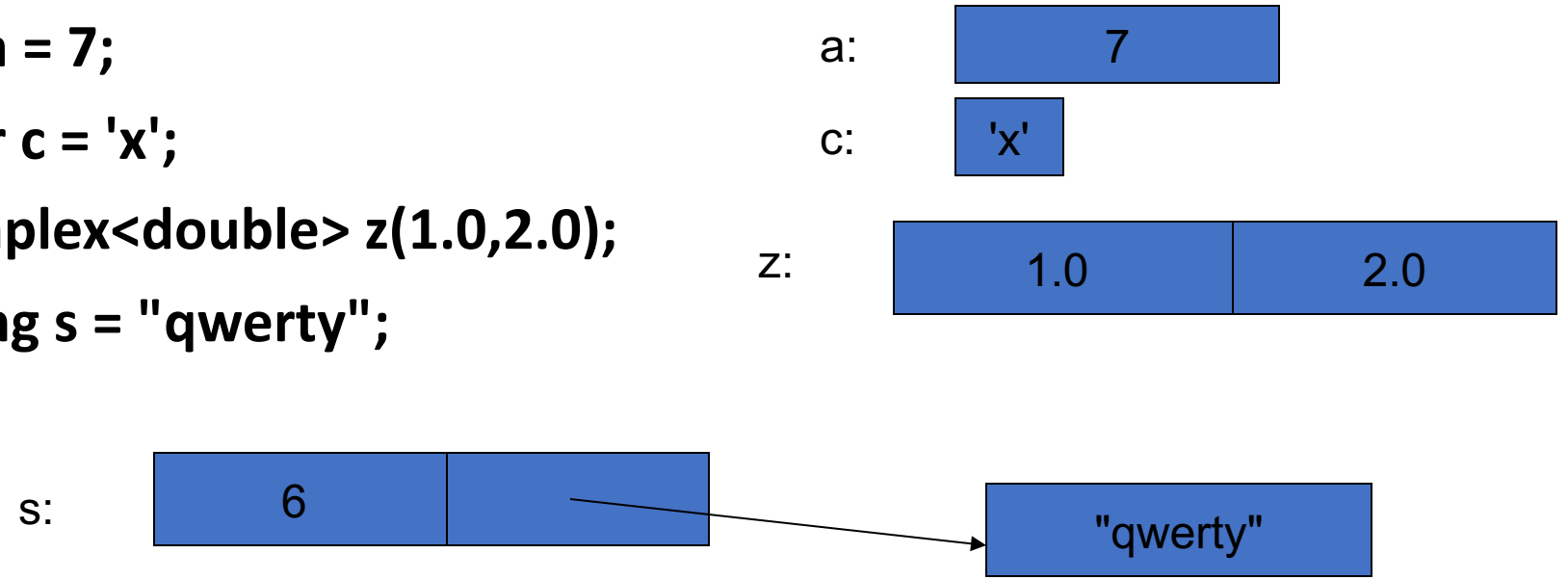
```
int a = 7;

int b = 9;

char c = 'a';

double x = 1.2;

string s1 = "Hello, world";

string s2 = "1.2";
```



Objects

- An object is some memory that can hold a value of a given type
- A variable is a named object
- A declaration names an object

```
int a = 7;
char c = 'x';
complex<double> z(1.0,2.0);
string s = "qwerty";
```



Type safety

- Language rule: type safety
  - Every object will be used only according to its type
    - A variable will be used only after it has been initialized
    - Only operations defined for the variable's declared type will be applied
    - Every operation defined for a variable leaves the variable with a valid value
- Ideal: static type safety
  - A program that violates type safety will not compile
    - The compiler reports every violation (in an ideal system)
- Ideal: dynamic type safety
  - If you write a program that violates type safety it will be detected at run time
    - Some code (typically "the run-time system") detects every violation not found by the compiler (in an ideal system)

Quick guide to safety

Safe conversions

bool to **char**
bool to **int**
bool to **double**
char to **int**
char to **double**
int to **double**

Unsafe conversions

double to **int**
double to **char**
double to **bool**
int to **char**
int to **bool**
char to **bool**

Go to MSVC

Live coding from now on…

A bit of philosophy

- One of the ways that programming resembles other kinds of engineering is that it involves tradeoffs.
- You must have ideals, but they often conflict, so you must decide what really matters for a given program.
  - Type safety
  - Run-time performance
  - Ability to run on a given platform
  - Ability to run on multiple platforms with same results
  - Compatibility with other code and systems
  - Ease of construction
  - Ease of maintenance
- Don’t skimp on correctness or testing
- By default, aim for type safety and portability

Homework

Read “An Overview of the C++ Programming Language” by Bjarne Stroustrup

Read “A Tour of C++” In: The C++ Programming Language, Special Edition by Bjarne Stroustrup

Afternoon: Start working on Homework 1:

Climate Change Focus: How can we predict temperature changes?