

# Modern C++ Programming

## 17. C++ ECOSYSTEM

### CMAKE AND OTHER TOOLS

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*Federico Busato*

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# CMake

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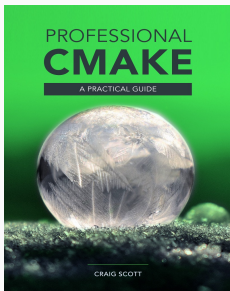


CMake [↗](#) is an *open-source*, cross-platform family of tools designed to build, test and package software

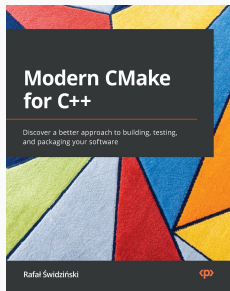
CMake is used to control the software compilation process using simple platform and compiler independent configuration files, and *generate* native Makefile/Ninja and workspaces that can be used in the compiler environment of your choice

CMake features:

- Turing complete language (if/else, loops, functions, etc.)
- Multi-platform (Windows, Linux, etc.)
- Open-Source
- Generate: makefile, ninja, etc.
- Supported by many IDEs: Visual Studio, Clion, Eclipse, etc.



**Professional CMake: A Practical Guide**  
(14th)  
*C. Scott*, 2023



**Modern CMake for C++ (2nd)**  
*R. Świdziński*, 2024

- 19 reasons why CMake is actually awesome
- An Introduction to Modern CMake
- Effective Modern CMake
- Awesome CMake
- Useful Variables

# Install CMake

## Using PPA repository

```
$ wget -O - https://apt.kitware.com/keys/kitware-archive-latest.asc 2>/dev/null |  
  gpg --dearmor - | sudo tee /etc/apt/trusted.gpg.d/kitware.gpg >/dev/null  
$ sudo apt-add-repository 'deb https://apt.kitware.com/ubuntu/ focal main' # bionic, xenial  
$ sudo apt update  
$ sudo apt install cmake cmake-curses-gui
```

## Using the installer or the pre-compiled binaries: [cmake.org/download/](https://cmake.org/download/)

```
# download the last cmake package, e.g. cmake-x.y.z-linux-x86_64.sh  
$ sudo sh cmake-x.y.z-linux-x86_64.sh
```



# A Minimal Example

CMakeLists.txt:

```
project(my_project)           # project name

add_executable(program program.cpp) # compile command
```

```
# we are in the project root dir
$ mkdir build      # 'build' dir is needed to isolate temporary files
$ cd build
$ cmake ..         # search for CMakeLists.txt directory
$ cmake --build . # makefile automatically generated, -j to parallelize the build
```

Scanning dependencies of target program

[100%] Building CXX object CMakeFiles/out\_program.dir/program.cpp.o

Linking CXX executable program

[100%] Built target program

# Parameters and Message

CMakeLists.txt:

```
project(my_project)
add_executable(program program.cpp)

if (VAR)
    message("VAR is set, NUM is ${NUM}")
else()
    message(FATAL_ERROR "VAR is not set")
endif()
```

```
$ cmake ..
VAR is not set
$ cmake -DVAR=ON -DNUM=4 ..
VAR is set, NUM is 4
...
[100%] Built target program
```

# Language Properties

```
project(my_project
        DESCRIPTION "Hello World"
        HOMEPAGE_URL "github.com/"
        LANGUAGES    CXX)

cmake_minimum_required(VERSION 3.15)

set(CMAKE_CXX_STANDARD          14) # force C++14
set(CMAKE_CXX_STANDARD_REQUIRED ON)
set(CMAKE_CXX_EXTENSIONS        OFF) # no compiler extensions

add_executable(program ${PROJECT_SOURCE_DIR}/program.cpp) #$
# PROJECT_SOURCE_DIR is the root directory of the project
```

# Target Commands

```
add_executable(program) # also add_library(program)

target_include_directories(program
    PUBLIC include/
    PRIVATE src/)
# target_include_directories(program SYSTEM ...) for system headers

target_sources(program # best way for specifying
    PRIVATE src/program1.cpp # program sources and headers
    PRIVATE src/program2.cpp
    PUBLIC include/header.hpp)

target_compile_definitions(program PRIVATE MY_MACRO=ABCEF)

target_compile_options(program PRIVATE -g)

target_link_libraries(program PRIVATE boost_lib)

target_link_options(program PRIVATE -s)
```

# Build Types

```
project(my_project)                # project name
cmake_minimum_required(VERSION 3.15) # minimum version

add_executable(program program.cpp)

if (CMAKE_BUILD_TYPE STREQUAL "Debug") # "Debug" mode
                                        # cmake already adds "-g -O0"

    message("DEBUG mode")
    if (CMAKE_COMPILER_IS_GNUCXX)      # if compiler is gcc
        target_compile_options(program "-g3")
    endif()
elseif (CMAKE_BUILD_TYPE STREQUAL "Release") # "Release" mode
    message("RELEASE mode")                # cmake already adds "-O3 -DNDEBUG"
endif()
```

```
$ cmake -DCMAKE_BUILD_TYPE=Debug ..
```

# Custom Targets and File Managing

```
project(my_project)
add_executable(program)

add_custom_target(echo_target          # makefile target name
                  COMMAND echo "Hello" # real command
                  COMMENT "Echo target")

# find all .cpp file in src/ directory
file(GLOB_RECURSE SRCS ${PROJECT_SOURCE_DIR}/src/*.cpp)
# compile all *.cpp file
target_sources(program PRIVATE ${SRCS}) # prefer the explicit file list instead
```

```
$ cmake ..
$ make echo_target
```

## Local and Cached Variables

*Cached variables* can be reused across multiple runs, while *local variables* are only visible in a single run. Cached `FORCE` variables can be modified only after the initialization

```
project(my_project)

set(VAR1 "var1")                # local variable
set(VAR2 "var2" CACHE STRING "Description1") # cached variable
set(VAR3 "var3" CACHE STRING "Description2" FORCE) # cached variable
option(OPT "This is an option" ON) # boolean cached variable
                                   # same of var2

message(STATUS "${VAR1}, ${VAR2}, ${VAR3}, ${OPT}")
```

```
$ cmake .. # var1, var2, var3, ON
$ cmake -DVAR1=a -DVAR2=b -DVAR3=c -DOPT=d .. # var1, b, var3, d
```

# Manage Cached Variables

```
$ ccmake . # or 'cmake-gui'
```

```
Page 1 of 1
CMAKE_BUILD_TYPE      Release
CMAKE_INSTALL_PREFIX  /usr/local
OPT                    ON
VAR2                   var2
VAR3                   var3

CMAKE_BUILD_TYPE: Choose the type of build, options are: None(CMAKE
Press [enter] to edit option Press [d] to delete an entry
Press [c] to configure
Press [h] for help          Press [q] to quit without generating
Press [t] to toggle advanced mode (Currently Off)
```



# Find Packages

```
project(my_project)           # project name
cmake_minimum_required(VERSION 3.15) # minimum version

add_executable(program program.cpp)

find_package(Doxyxygen REQUIRED) # compile only if Doxygen is found
find_package(Boost 1.87.0)      # search for a specific version

if (Boost_FOUND)
    target_include_directories("${PROJECT_SOURCE_DIR}/include" PUBLIC ${Boost_INCLUDE_DIRS})
else()
    message(FATAL_ERROR "Boost Lib not found")
endif()
```

# Compile Commands

Generate JSON compilation database (`compile_commands.json`)

It contains the exact compiler calls for each file that are used by other tools

```
project(my_project)
cmake_minimum_required(VERSION 3.15)

set(CMAKE_EXPORT_COMPILE_COMMANDS ON) # <--

add_executable(program program.cpp)
```

Change the C/C++ compiler:

```
CC=clang CXX=clang++ cmake ..
```

CTest is a testing tool (integrated in CMake) that can be used to automate updating, configuring, building, testing, performing memory checking, performing coverage

```
project(my_project)
cmake_minimum_required(VERSION 3.5)
add_executable(program program.cpp)

enable_testing()

add_test(NAME Test1          # check if "program" returns 0
         WORKING_DIRECTORY ${PROJECT_SOURCE_DIR}/build
         COMMAND ./program <args>) # command can be anything

add_test(NAME Test2          # check if "program" print "Correct"
         WORKING_DIRECTORY ${PROJECT_SOURCE_DIR}/build
         COMMAND ./program <args>)

set_tests_properties(Test2
                     PROPERTIES PASS_REGULAR_EXPRESSION "Correct")
```

Basic usage (call ctest):

```
$ make test      # run all tests
```

ctest usage:

```
$ ctest -R Python      # run all tests that contains 'Python' string
$ ctest -E Iron        # run all tests that not contain 'Iron' string
$ ctest -I 3,5         # run tests from 3 to 5
```

Each ctest command can be combined with other tools (e.g. valgrind)

## ctest with Different Compile Options

It is possible to combine a custom target with ctest to compile the same code with different compile options

```
add_custom_target(program-compile
    COMMAND mkdir -p test-release test-ubsan test-asan # create dirs
    COMMAND cmake .. -B test-release # -B change working dir
    COMMAND cmake .. -B test-ubsan -DUBSAN=ON
    COMMAND cmake .. -B test-asan -DASAN=ON
    COMMAND make -C test-release -j20 program # -C run make in a
    COMMAND make -C test-ubsan -j20 program # different dir
    COMMAND make -C test-asan -j20 program)

enable_testing()

add_test(NAME Program-Compile
    COMMAND make program-compile)
```



xmake [↗](#) is a cross-platform build utility based on Lua.

Compared with `makefile/CMakeLists.txt`, the configuration syntax is more concise and intuitive. It is very friendly to novices and can quickly get started in a short time. Let users focus more on actual project development

Comparison: xmake vs cmake

# Code

# Documentation

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Doxygen [↗](#) is the de facto standard tool for generating documentation from annotated C++ sources

## Doxygen usage

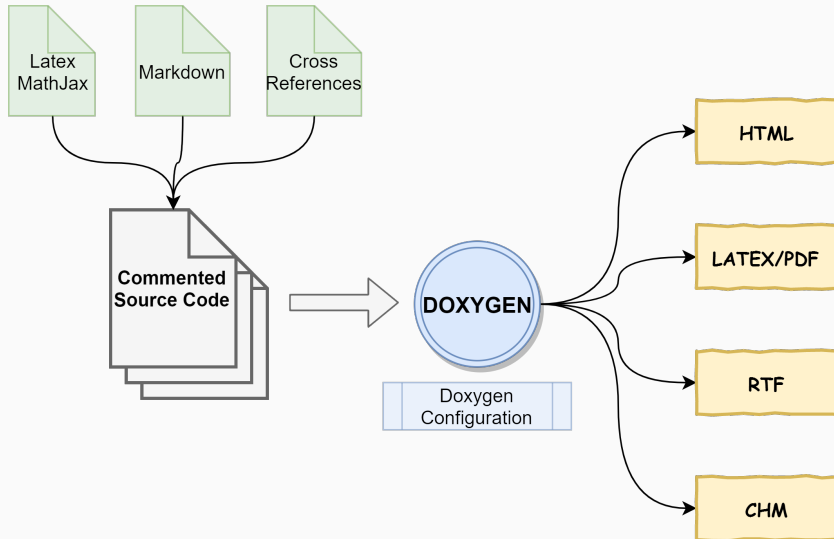
- comment the code with `///` or `/** comment */`
- generate doxygen base configuration file

```
$ doxygen -g
```

- modify the configuration file Doxyfile, e.g. `PROJECT_NAME`, `OUTPUT_DIRECTORY`, `INPUT`.
- generate the documentation

```
$ doxygen <config_file>
```





Doxygen requires the following tags for generating the documentation:

- `@file` Document a file
- `@brief` Brief description for an entity
- `@param` Run-time parameter description
- `@tparam` Template parameter description
- `@return` Return value description

- *Automatic cross references* between functions, variables, etc.
- *Specific highlight*. Code `<code>`, input/output parameters  
`@param[in] <param>`
- *Latex/MathJax* `$<code>$`
- *Markdown* ([Markdown Cheatsheet link](#)), Italic text `*<code>*`, bold text `**<code>**`, table, list, etc.
- Call/Hierarchy graph can be useful in large projects (requires graphviz)  
`HAVE_DOT = YES`  
`GRAPHICAL_HIERARCHY = YES`  
`CALL_GRAPH = YES`  
`CALLER_GRAPH = YES`

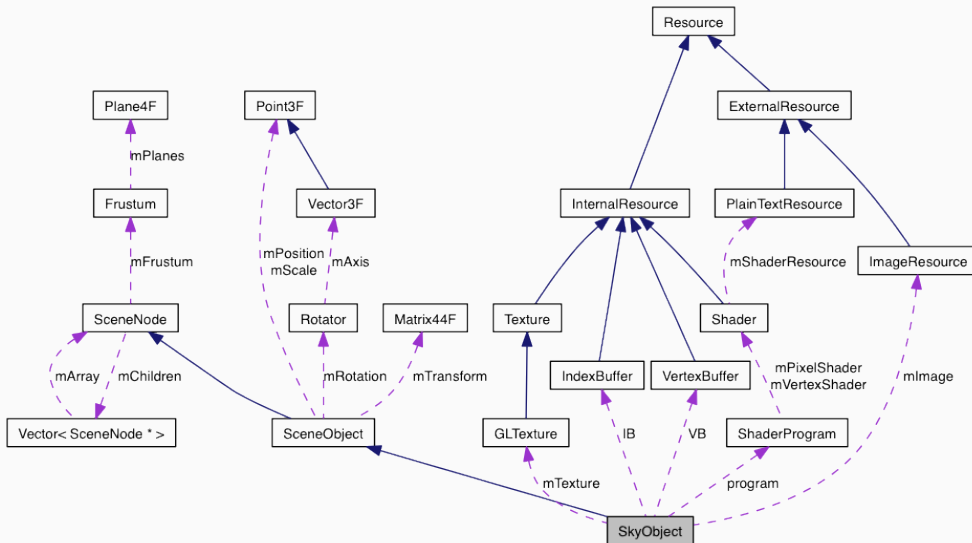
```
/**
 * @file
 * @copyright MyProject
 * license BSD3, Apache, MIT, etc.
 * @author MySelf
 * @version v3.14159265359
 * @date March, 2018
 */

/// @brief Namespace brief description
namespace my_namespace {

/// @brief "Class brief description"
/// @tparam R "Class template for"
template<typename R>
class A {
```

```
/**
 * @brief "What the function does?"
 * @details "Some additional details",
 *          Latex/MathJax:  $\sqrt{a}$ 
 * @tparam T Type of input and output
 * @param[in] input Input array
 * @param[out] output Output array
 * @return `true` if correct,
 *         `false` otherwise
 * @remark it is *useful* if ...
 * @warning the behavior is **undefined** if
 *          @p input is `nullptr`
 * @see related_function
 */
template<typename T>
bool my_function(const T* input, T* output);

/// @brief
void related_function();
```



# Doxygen Alternatives

`M.CSS` Doxygen C++ theme

`Doxypress` Doxygen fork

`clang-doc` LLVM tool

`Sphinx` Clear, Functional C++ Documentation with Sphinx + Breathe  
+ Doxygen + CMake

`standardese` The nextgen Doxygen for C++ (experimental)

`HDoc` The modern documentation tool for C++ (alpha)

`Adobe Hyde` Utility to facilitate documenting C++

# Code Statistics

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# Count Lines of Code - cloc

cloc [↗](#) counts blank lines, comment lines, and physical lines of source code in many programming languages

```
$cloc my_project/
```

```
4076 text files.
```

```
3883 unique files.
```

```
1521 files ignored.
```

```
http://cloc.sourceforge.net v 1.50 T=12.0 s (209.2 files/s, 70472.1 lines/s)
```

Language	files	blank	comment	code
C	135	18718	22862	140483
C/C++ Header	147	7650	12093	44042
Bourne Shell	116	3402	5789	36882

**Features:** filter by-file/language, SQL database, archive support, line count diff, etc.

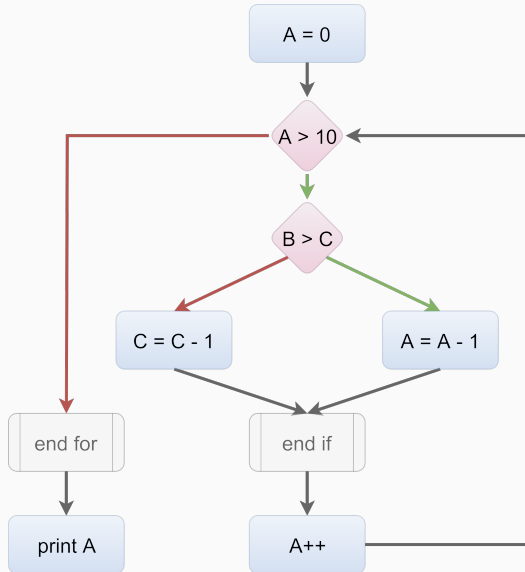


Lizard [↗](#) is an extensible Cyclomatic Complexity Analyzer for many programming languages including C/C++

**Cyclomatic Complexity:** is a software metric used to indicate the complexity of a program. It is a quantitative measure of the number of linearly independent paths through a program source code

```
$lizard my_project/
=====
NLOC      CCN   token  param   function@line@file
-----
10         2     29     2     start_new_player@26@./html_game.c
6          1     3      0     set_shutdown_flag@449@./httpd.c
24         3     61     1     server_main@454@./httpd.c
-----
```

- CCN: cyclomatic complexity (should not exceed a threshold)
- NLOC: lines of code without comments
- token: Number of conditional statements



CCN = 3

CC	Risk Evaluation
1-10	a simple program, <i>without much risk</i>
11-20	more complex, <i>moderate risk</i>
21-50	complex, <i>high risk</i>
> 50	untestable program, <i>very high risk</i>

CC	Guidelines
1-5	The routine is probably fine
6-10	Start to think about ways to simplify the routine
> 10	Break part of the routine

Risk: Lizard: 15, OCLint: 10

- [www.microsoftpressstore.com/store/code-complete-9780735619678](http://www.microsoftpressstore.com/store/code-complete-9780735619678)
- [blog.feabhas.com/2018/07/code-quality-cyclomatic-complexity](http://blog.feabhas.com/2018/07/code-quality-cyclomatic-complexity)

# Other Tools

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## Code Formatting - clang-format

clang-format [↗](#) is a tool to automatically format C/C++ code (and other languages)

```
$ clang-format <file/directory>
```

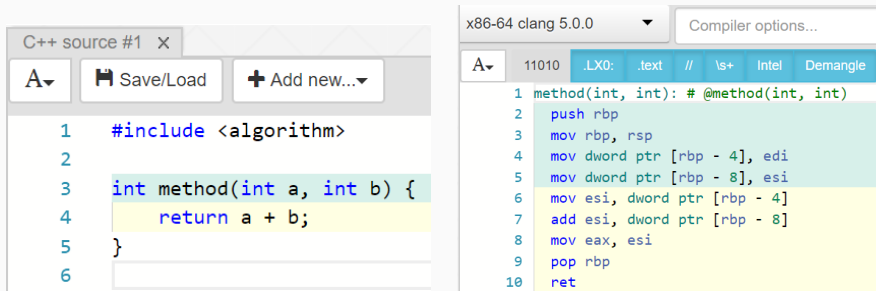
clang-format searches the configuration file .clang-format file located in the closest parent directory of the input file

clang-format example:

```
IndentWidth: 4
UseTab: Never
BreakBeforeBraces: Linux
ColumnLimit: 80
SortIncludes: true
```

# Compiler Explorer (assembly and execution)

Compiler Explorer [↗](#) is an interactive tool that lets you type source code and see assembly output, control flow graph, optimization hint, etc.



The screenshot displays the Compiler Explorer web application. On the left, a text editor window titled 'C++ source #1' contains the following C++ code:

```
1  #include <algorithm>
2
3  int method(int a, int b) {
4      return a + b;
5  }
6
```

On the right, the assembly output for 'x86-64 clang 5.0.0' is shown. The assembly code is as follows:

```
1  method(int, int): # @method(int, int)
2      push rbp
3      mov rbp, rsp
4      mov dword ptr [rbp - 4], edi
5      mov dword ptr [rbp - 8], esi
6      mov esi, dword ptr [rbp - 4]
7      add esi, dword ptr [rbp - 8]
8      mov eax, esi
9      pop rbp
10     ret
```

**Key features:** support multiple architectures and compilers

# Code Transformation - CppInsights

CppInsights  See what your compiler does behind the scenes



About

Source:

```
1 #include <cstdio>
2 #include <vector>
3
4 int main()
5 {
6     const char arr[10]{2,4,6,8};
7
8     for(const char& c : arr)
9     {
10         printf("c=%c\n", c);
11     }
12 }
```

Insight:

```
1 #include <cstdio>
2 #include <vector>
3
4 int main()
5 {
6     const char arr[10]{2,4,6,8};
7
8     {
9         auto&& __range1 = arr;
10         const char * __begin1 = __range1;
11         const char * __end1 = __range1 + 10;
12
13         for( ; __begin1 != __end1; ++__begin1 )
14         {
15             const char & c = *__begin1;
16             printf("c=%c\n", static_cast<int>(c));
17         }
18     }
19 }
```

**AI-Powered Code Completion** tools help writing code faster by drawing context from comments and code to suggest individual lines and whole functions

*Common features:*

- Semantic completion
- Recognize common language patterns
- Use the documentation to infer this function name, return type, and arguments
- Suggest bug fixes
- Generate comments, documentation, and even Pull Request text



They are commonly provided as plug-in for the most popular editors and IDE

- CoPilot [↗](#)
- TabNine [↗](#)
- Codeium [↗](#)
- Replit Ghostwriter [↗](#)
- CodeWhisperer [↗](#)

# Local Code Search - ugrep, ripgrep, hypergrep

ugrep [↗](#), Ripgrep [↗](#), Hypergrep [↗](#) are code-searching-oriented tools for regex pattern

## Features:

- Default recursively searches
- Skip .gitignore patterns, binary and hidden files/directories
- Windows, Linux, Mac OS support
- Up to 100x faster than GNU grep

```
[andrew@Cheetah rust] rg -i rustacean
src/doc/book/nightly-rust.md
92:[Mibbit][mibbit]. Click that link, and you'll be chatting with other Rustaceans

src/doc/book/glossary.md
3:Not every Rustacean has a background in systems programming, nor in computer

src/doc/book/getting-started.md
176:Rustaceans (a silly nickname we call ourselves) who can help us out. Other great
376:Cargo is Rust's build system and package manager, and Rustaceans use Cargo to

src/doc/book/guessing-game.md
444:it really easy to re-use libraries, and so Rustaceans tend to write smaller

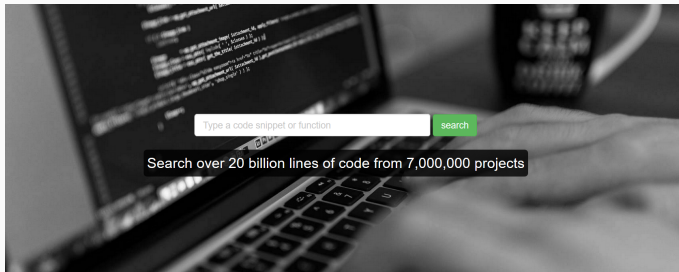
CONTRIBUTING.md
322:* [rustaceans.org][ro] is helpful, but mostly dedicated to IRC
333:[ro]: http://www.rustaceans.org/
[andrew@Cheetah rust] □
```

# Code Search Engine - searchcode

Searchcode [↗](#) is a free source code search engine

## Features:


- Search over 20 billion lines of code from 7,000,000 projects
- Search sources: github, bitbucket, gitlab, google code, sourceforge, etc.



`grep.app`  searches across a half million GitHub repos

## // `grep.app`

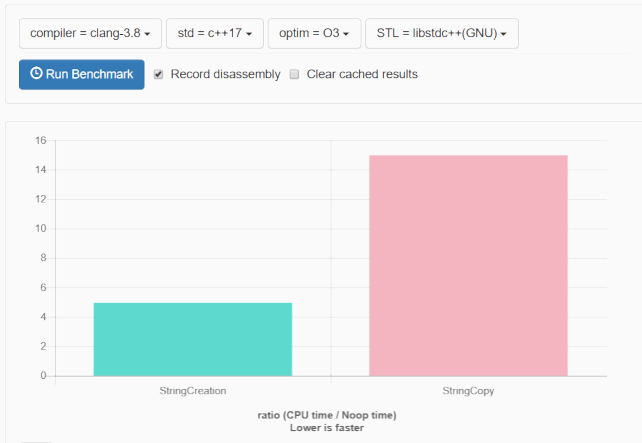
Search across a half million git repos

 Search

☐ Case sensitive    ☐ Regular expression    ☐ Whole words

# Code Benchmarking - Quick-Bench

Quick-benchmark [↗](#) is a micro benchmarking tool intended to quickly and simply compare the performances of two or more code snippets. The benchmark runs on a pool of AWS machines



# Font for Coding

Many editors allow adding optimized fonts for programming which improve legibility and provide extra symbols (ligatures)

Scope	→ ⇒ :: __	-> => :: __
Equality	= ≡ ≠ ≠ <del>=</del> <del>==</del> <del>≠</del> <del>≠</del>	== === != /= == === != !==
Comparisons	≤ ≥ ≤ ≥ ⇔	<= >= <= >= <=>

Some examples:

- JetBrains Mono
- Fira Code
- Microsoft Cascadia
- Consolas Ligaturized