Modern C++ Programming

14. C++ Ecosystem

Cmake and Other Tools

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Feature Complete

AAAAND...
DONE!
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CMake

CMake Overview

`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.`

CMake - References

- `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/`

```
# 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 for isolating temporary files
$ cd build
$ cmake ..     # search for CMakeLists.txt directory
$ make         # makefile automatically generated

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

```cmake
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

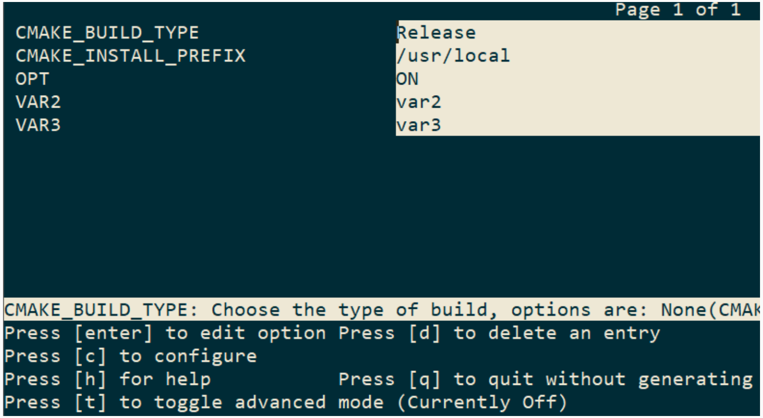
Cached variables can be reused across multiple runs, while *local variables* are only visible in a single run. Cached `FORCE` variables can be modified only after the initialization

```
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(CMAK
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(Boost 1.36.0 REQUIRED)  # compile only if Boost library
                                     # is found
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 1/2

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")
```

ctest 2/2

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)
```

CMake Alternatives - `xmake`

`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

doxygen

Doxygen is the de facto standard tool for generating documentation from annotated C++ sources

Doxygen usage

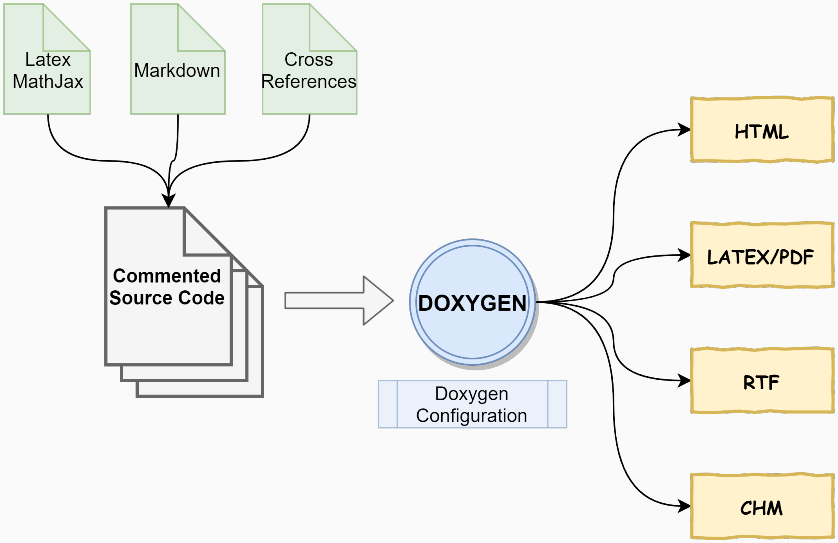
- comment the code with `///` or `/** comment */`
- generate doxygen base configuration file

```
$ doxygen -g
```

- modify the configuration file `Doxyfile`
- generate the documentation

```
$ doxygen <config_file>
```

doxygen


Latex MathJax
Markdown
Cross References
Commented Source Code
DOXYGEN
Doxygen Configuration
HTML
LATEX/PDF
RTF
CHM

`doxygen` 3/6

`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

`doxygen` - Features

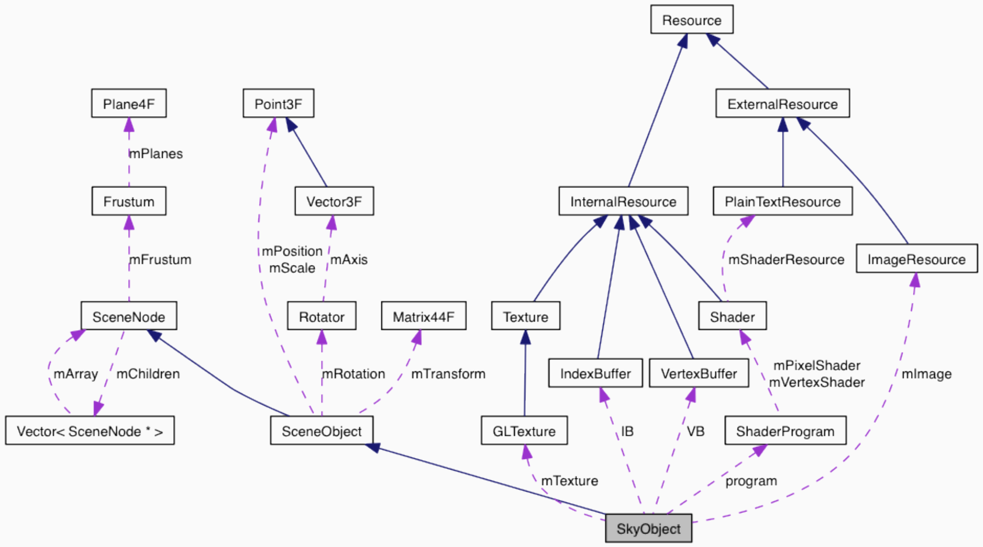
- *Automatic cross references* between functions, variables, etc.
- *Specific highlight*. Code `` `<code>` ``, input/output parameters `@param[in] <param>`
- *Latex/MathJax* `$<code>$`
- *Markdown* (Markdown Cheatsheet link), Italic text `*<code>*`, bold text `**<code>**`, table, list, etc.
- Call/Hierarchy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

doxygen - Example

```cpp
/**
 * @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 {
```

```cpp
/**
 * @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 - Call Graph



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

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.

Cyclomatic Complexity Analyzer - lyzard

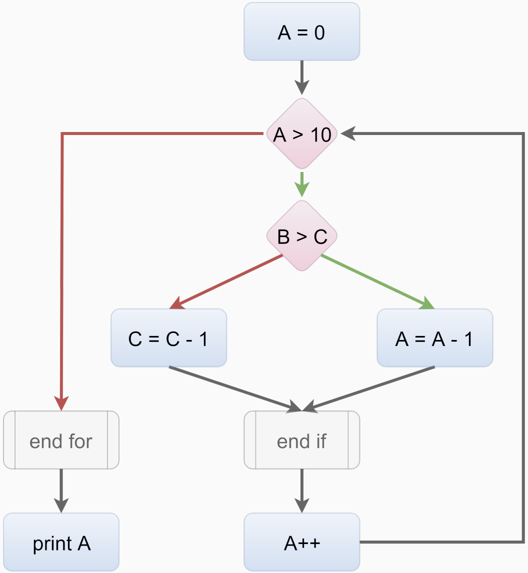
Lizard is an extensible Cyclomatic Complexity Analyzer for many programming languages including C/C++

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

Cyclomatic Complexity Analyzer - `lyzard`



`CCN = 3`

Cyclomatic Complexity Analyzer - `lyzard`

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

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`
- `blog.feabhas.com/2018/07/code-quality-cyclomatic-complexity`

Other Tools

Code Formatting - `clang-format`

`clang-format` is a tool to automatically format C/C++ code (and other languages)

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

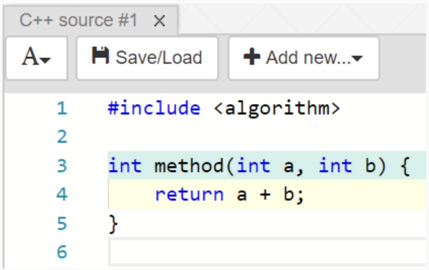
`clang-format` searches the configuration file `.clang-format` file located in the closest parent directory of the input file

`clang-format` example:

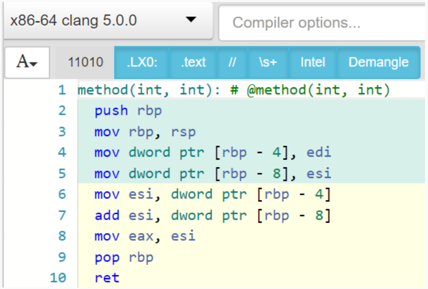
```
IndentWidth: 4
UseTab: Never
BreakBeforeBraces: Linux
ColumnLimit: 80
SortIncludes: true
```

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.



```cpp
#include <algorithm>

int method(int a, int b) {
    return a + b;
}

```

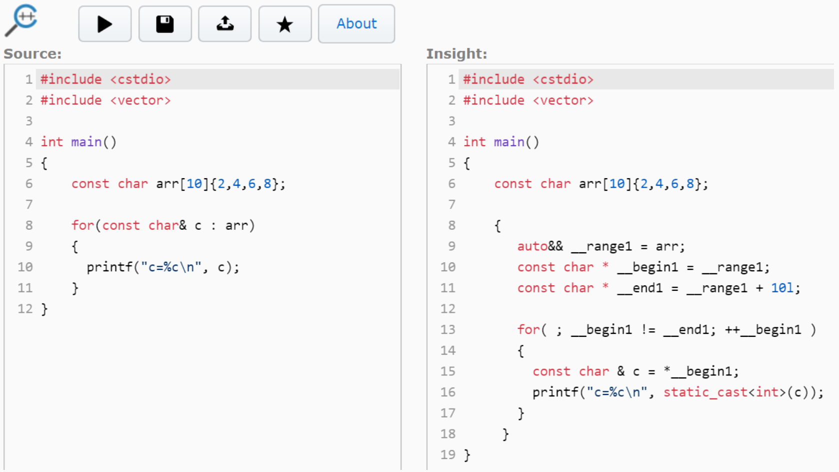


```
method(int, int): # @method(int, int)
  push rbp
  mov rbp, rsp
  mov dword ptr [rbp - 4], edi
  mov dword ptr [rbp - 8], esi
  mov esi, dword ptr [rbp - 4]
  add esi, dword ptr [rbp - 8]
  mov eax, esi
  pop rbp
  ret
```

Key features: support multiple architectures and compilers

Code Transformation - CppInsights

CppInsights See what your compiler does behind the scenes

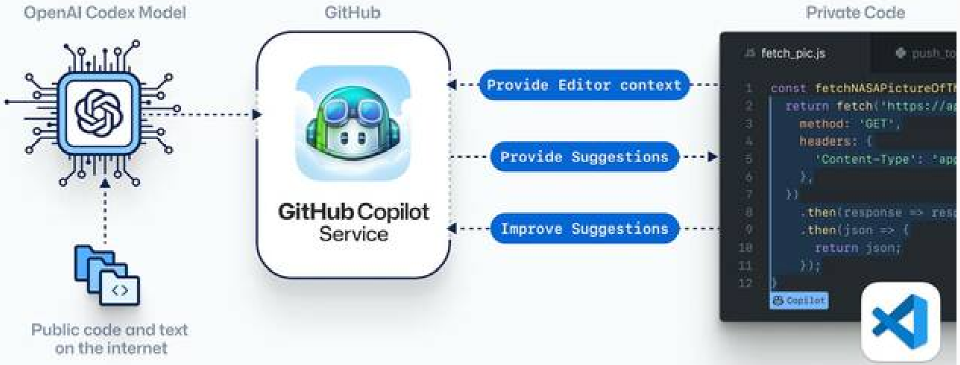


```cpp
#include <cstdio>
#include <vector>

int main()
{
    const char arr[10]{2,4,6,8};

    for(const char& c : arr)
    {
      printf("c=%c\n", c);
    }
}
```

```cpp
#include <cstdio>
#include <vector>

int main()
{
    const char arr[10]{2,4,6,8};

    {
      auto&& __range1 = arr;
      const char * __begin1 = __range1;
      const char * __end1 = __range1 + 10l;

      for( ; __begin1 != __end1; ++__begin1 )
      {
        const char & c = *__begin1;
        printf("c=%c\n", static_cast<int>(c));
      }
    }
}
```

Code Autocompletion - `GitHub CoPilot`

`CoPilot` is an AI pair programmer that helps you write code faster and with less work. It draws context from comments and code to suggest individual lines and whole functions instantly



```
const fetchNASAPictureOfTh
  return fetch('https://ap
    method: 'GET',
    headers: {
      'Content-Type': 'app
    },
  })
    .then(response => resp
    .then(json => {
      return json;
    });
}
```

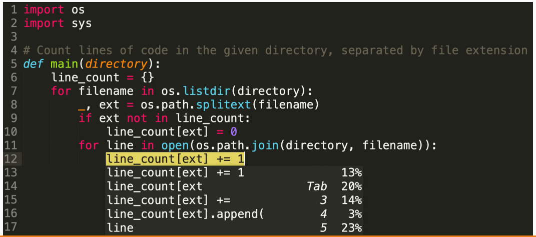
Code Autocompletion - TabNine

TabNine uses deep learning to provide code completion

Features:

- Support all languages
- C++ semantic completion is available through clangd
- Project indexing
- Recognize common language patterns
- Use even the documentation to infer this function name, return type, and arguments

Available for Visual Studio Code, IntelliJ, Sublime, Atom, and Vim



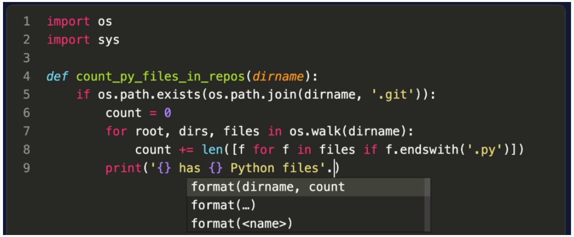
```
import os
import sys

# Count lines of code in the given directory, separated by file extension
def main(directory):
    line_count = {}
    for filename in os.listdir(directory):
        _, ext = os.path.splitext(filename)
        if ext not in line_count:
            line_count[ext] = 0
        for line in open(os.path.join(directory, filename)):
            line_count[ext] += 1
            line_count[ext] += 1              13%
            line_count[ext               Tab  20%
            line_count[ext] +=             3  14%
            line_count[ext].append(        4   3%
            line                           5  23%
```

Code Autocompletion - `Kite`

`Kite` adds AI powered code completions to your code editor

Support 13 languages

Available for Visual Studio Code, IntelliJ, Sublime, Atom, Vim, + others



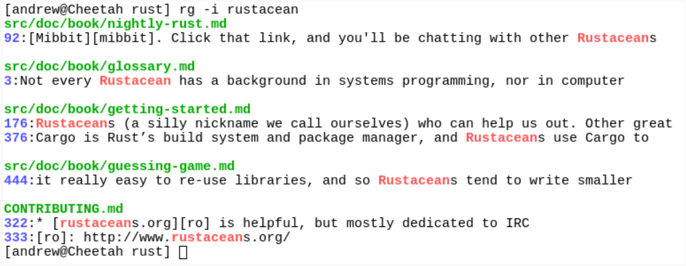
```python
import os
import sys

def count_py_files_in_repos(dirname):
    if os.path.exists(os.path.join(dirname, '.git')):
        count = 0
        for root, dirs, files in os.walk(dirname):
            count += len([f for f in files if f.endswith('.py')])
        print('{} has {} Python files'.)
```

Local Code Search - ripgrep, hypergrep

Ripgrep and 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`



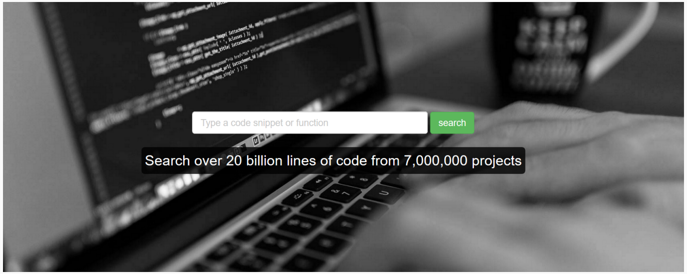
```
[andrew@Cheetah rust] rg -i rustacean
src/doc/book/nightly-rust.md
92:[Mibbit][mibbit]. Click that link, and you'll be chatting with other Rustaceans

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:

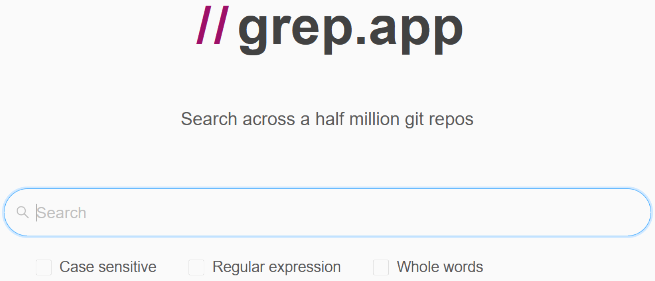
- Search over 20 billion lines of code from 7,000,000 projects
- Search sources: `github`, `bitbucket`, `gitlab`, `google code`, `sourceforge`, etc.



Search over 20 billion lines of code from 7,000,000 projects

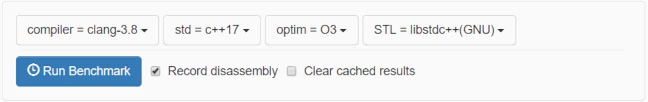
Code Search Engine - `grep.app`

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

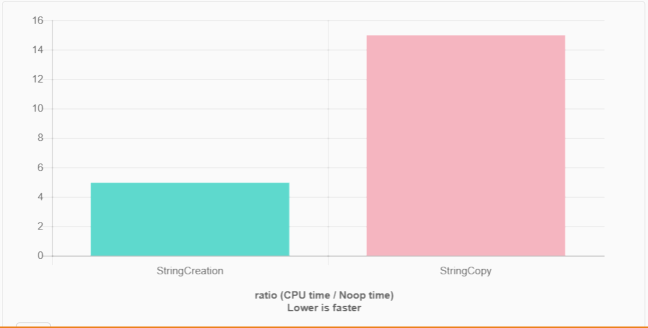


Code Benchmarking - Quick-Bench

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

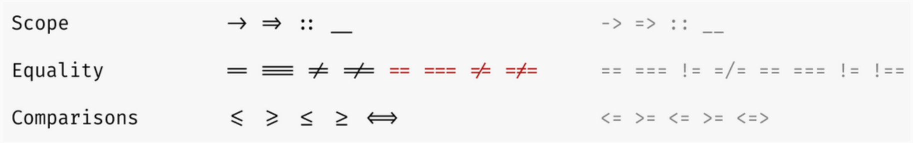


compiler = clang-3.8 · std = c++17 · optim = O3 · STL = libstdc++(GNU)



Font for Coding

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



Scope	→ ⇒ :: __	`-> => :: __`
Equality	═ ≡ ≠ ≠ == === ≠ =≠=	`== === != =/= == === != !==`
Comparisons	⩽ ⩾ ≤ ≥ ⟺	`<= >= <= >= <=>`

Some examples:

- `JetBrain Mono`
- `Fira Code`
- `Microsoft Cascadia`
- `Consolas Ligaturized`