Modern C++ Programming

12. C++ Ecosystem

Federico Busato

University of Verona, Dept. of Computer Science

2020, v3.06

Table of Context

1 Execution Debugging

- Assertion
- Execution Debugging (`gdb`)

2 Memory Debugging

- `valgrind`

3 Sanitizers

- Address Sanitizer
- Leak Sanitizer
- Memory Sanitizers
- Undefined Behavior Sanitizer

4 Debugging Summary

Table of Context

5 Code Checking and Analysis

- Compiler Warnings
- Static Analyzers

6 Code Testing

- Unit Test
- Code Coverage
- Fuzz Testing

7 Code Quality

- clang-tidy

Table of Context

8 CMake

- `ctest`

9 Code Documentation

- `doxygen`

10 Code Statistics

- Count Lines of Code
- Cyclomatic Complexity Analyzer

Table of Context

11 Other Tools

- Code Formatting - `clang-format`
- `Compiler Explorer`
- Code Transformation - `CppInsights`
- Code Autocompletion - `TabNine`, `Kite`
- Local Code Search - `ripgrep`
- Code Search Engine - `searchcode`, `grep.app`
- Code Exploration - `SourceTrail`
- Code Benchmarking - `Quick-Bench`

Execution Debugging

Is this a bug?

```
for (int i = 0; i <= (2^32) - 1; i++) {
```

from: John Regehr (on Twitter)

Error Handing

Error/Exception indicates *"exceptional"* conditions (invalid user input, missing files, etc.)

- **Exceptions** are more robust but slower and requires more resources. They also involve code bloat
- **Error** are fast but difficult to handle in complex programs
- It is a *run-time* event that can happen in the public program ("release" mode)

An **assertion** is a statement to detect a violated assumption. An assertion represents an *invariant* in the code
It can happen both a *run-time* and *compile-time* event that should never happen in the public program

Assertion

```cpp
#include <cassert>   // <-- needed

int sqrt(int value) {
    int ret = sqrt_internal(value);
    assert(ret >= 0 && (ret == 0 || ret == 1 || ret < value));
    return ret;
}
```

Assertions may slow down the execution. They can be disable by define the `NDEBUG` macro

```cpp
#define NDEBUG // or with the flag "-DNDEBUG"
```

Execution Debugging (gdb)

How to compile and run for debugging:

```
g++ -g [-ggdb3] <program.cpp> -o program
gdb [--args] ./program <args...>
```

`-g` Enable debugging

- stores the *symbol table information* in the executable (mapping between assembly and source code lines)
- for some compilers, it may disable certain optimizations
- slow down the compilation phase

`-ggdb3` Produces debugging information specifically intended for gdb

- the last number produces extra debugging information, for example: including macro definitions
- in general, it is not portable across different compiler (supported by `gcc`, `clang`)

`gdb` - Breakpoints/Watchpoints

Command	Abbr.	Description
`breakpoint` <*file*>:<*line*>	**`b`**	insert a breakpoint in a specific line
`breakpoint` <*function_name*>	**`b`**	insert a breakpoint in a specific function
`breakpoint` <*ref*> **`if`** <*condition*>	**`b`**	insert a breakpoint with a conditional statement
`delete`	**`d`**	delete all breakpoints or watchpoints
`delete` <*breakpoint_number*>		delete a specific breakpoint
`clear` [*function_name*/*line_number*]		delete a specific breakpoint
`enable/disable` <*breakpoint_number*>		enable/disable a specific breakpoint
`watch` <*expression*>		stop execution when the value of `expression` changes (variable, comparison, etc.)

gdb - Control Flow

Command	Abbr.	Description
run [args]	**r**	run the program
continue	**c**	continue the execution
finish	**f**	continue until the end of the current function
step	**s**	execute next line of code (follow function calls)
next	**n**	execute next line of code
until <*program_point*>		continue until reach line number, function name, address, etc.
CTRL+C		stop the execution (not quit)
quit	**q**	exit

`gdb` - Stack and Info

Command	Abbr.	Description
`list`	**`l`**	print code
`list` <*function or #start,#end*>	**`l`**	print function/range code
`up`	**`u`**	move up in the call stack
`down`	**`d`**	move down in the call stack
`backtrace`	**`bt`**	prints stack backtrace (call stack)
`backtrace` <*full*>	**`bt`**	print values of local variables
`help` [<*command*>]	**`h`**	show help about command
`info` <*args/breakpoints/ watchpoints/registers/local*>		show information about program arguments/breakpoints/watchpoints/ registers/local variables

gdb - Print

Command	Abbr.	Description
`print` *<variable>*	`p`	print variable
`print/h` *<variable>*	`p/h`	print variable in hex
`print/nb` *<variable>*	`p/nb`	print variable in binary (n bytes)
`print/w` *<address>*	`p/w`	print address in binary
`p /s` *<char array/address>*		print `char` array
`p *array_var@n`		print n array elements
`p (int[4])`*<address>*		print four elements of type `int`
`p *(char**)&`*<std::string>*		print `std::string`

gdb - Disassemble

Command	Description
`disasseble` <*function_name*>	disassemble a specified function
`disasseble` <`0xStart,0xEnd` addr>	disassemble function range
`nexti` <*variable*>	execute next line of code (follow function calls)
`stepi` <*variable*>	execute next line of code
`x`/nfu <*address*>	examine address n number of elements, f format (**d**: int, **f**: float, etc.), u data size (**b**: byte, **w**: word, etc.)

gdb - Notes

The debugger automatically stops when:

- breakpoint (by using the debugger)
- assertion fail
- segmentation fault
- trigger software breakpoint (e.g. SIGTRAP on Linux)
  `github.com/scottt/debugbreak`

Full story: `www.yolinux.com/TUTORIALS/GDB-Commands.html`
(it also contains a script to *de-referencing* STL Containers)

`gdb reference card V5 link`

Memory Debugging

Memory Vulnerabilities 1/2

> *"70% of all the vulnerabilities in Microsoft products are memory safety issues"*
>
> ***Matt Miller***, *Microsoft Security Engineer*

> *"Chrome: 70% of all security bugs are memory safety issues"*
>
> ***Chromium Security Report***

Microsoft: 70% of all security bugs are memory safety issues

Chrome: 70% of all security bugs are memory safety issues

Memory Vulnerabilities 2/2

Terms like *buffer overflow*, *race condition*, *page fault*, *null pointer*, *stack exhaustion*, *heap exhaustion/corruption*, *use-after-free*, or *double free* – all describe ***memory safety vulnerabilities***

Solutions:

- Run-time check
- Static analysis
- Avoid unsafe language constructs

valgrind 1/4

valgrind is a tool suite to automatically detect many memory management and threading bugs

How to install the last version:

```
$ wget ftp://sourceware.org/pub/valgrind/valgrind-3.15.0.tar.bz2
$ tar xf valgrind-3.15.0.tar.bz2
$ cd valgrind-3.15.0
$ ./configure --enable-lto
$ make -j 12
$ sudo make install
$ sudo apt install libc6-dbg
```

valgrind 2/4

Basic usage:

- compile with `-g`

-
  ```
  $ valgrind ./program <args...>
  ```

Output example 1:

```
==60127== Invalid read of size 4             !!out-of-bound access
==60127==    at 0x100000D9E: f(int) (test01.C:86)
==60127==    by 0x100000C22: main (test01.C:40)
==60127==  Address 0x10042c148 is 0 bytes after a block of size 40 alloc'd
==60127==    at 0x1000161EF: malloc (vg_replace_malloc.c:236)
==60127==    by 0x100000C88: f(int) (test01.C:75)
==60127==    by 0x100000C22: main (test01.C:40)
```

valgrind 3/4

Output example 2:

```
!!memory leak
==19182== 40 bytes in 1 blocks are definitely lost in loss record 1 of 1
==19182==    at 0x1B8FF5CD: malloc (vg_replace_malloc.c:130)
==19182==    by 0x8048385: f (a.c:5)
==19182==    by 0x80483AB: main (a.c:11)

==60127== HEAP SUMMARY:
==60127==     in use at exit: 4,184 bytes in 2 blocks
==60127==   total heap usage: 3 allocs, 1 frees, 4,224 bytes allocated
==60127==
==60127== LEAK SUMMARY:
==60127==    definitely lost: 128 bytes in 1 blocks    !!memory leak
==60127==    indirectly lost: 0 bytes in 0 blocks
==60127==      possibly lost: 0 bytes in 0 blocks
==60127==    still reachable: 4,184 bytes in 2 blocks  !!not deallocated
==60127==         suppressed: 0 bytes in 0 blocks
```

valgrind 4/4

Advanced flags:

- `--leak-check=full` print details for each "`definitely lost`" or "`possibly lost`" block, including where it was allocated
- `--show-leak-kinds=all` to combine with `--leak-check=full`. Print all leak kinds
- `--track-fds=yes` list open file descriptors on exit (not closed)
- `--track-origins=yes` tracks the origin of uninitialized values (very slow execution)

```
valgrind --leak-check=full --show-leak-kinds=all
         --track-fds=yes --track-origins=yes ./program <args...>
```

Track stack usage:

```
valgrind --tool=drd --show-stack-usage=yes ./program <args...>
```

Sanitizers

Address Sanitizer

Sanitizers are compiler-based instrumentation components to perform *dynamic* analysis

Sanitizer are used during development and testing to discover and diagnose memory misuse bugs and potentially dangerous undefined behavior

Sanitizer are implemented in **`Clang`** (from 3.1), **`gcc`** (from 4.8) and **`Xcode`**

Project using Sanitizers:

- Chromium
- Firefox
- Linux kernel
- Android

Address Sanitizer

`Address Sanitizer` is a memory error detector

- heap/*stack*/*global* out-of-bounds
- memory leaks
- use-after-free, use-after-return, use-after-scope
- double-free, invalid free
- initialization order bugs
- etc.

* Similar to `valgrind` but faster (2X slowdown)

```
clang++ -O1 -g -fsanitize=address -fno-omit-frame-pointer <program>
```

`-O1` disable inlining

`-g` generate symbol table

Website:

clang.llvm.org/docs/AddressSanitizer.html
github.com/google/sanitizers/wiki/AddressSanitizer
gcc.gnu.org/onlinedocs/gcc/Instrumentation-Options.html

Leak Sanitizer

`LeakSanitizer` is a run-time *memory leak* detector

- integrated into `AddressSanitizer`, can be used as standalone tool
* almost no performance overhead until the very end of the process

```
g++     -O1 -g -fsanitize=address -fno-omit-frame-pointer <program>
clang++ -O1 -g -fsanitize=leak -fno-omit-frame-pointer <program>
```

Website:

`clang.llvm.org/docs/LeakSanitizer.html`
`github.com/google/sanitizers/wiki/AddressSanitizerLeakSanitizer`
`gcc.gnu.org/onlinedocs/gcc/Instrumentation-Options.html`

Memory Sanitizers

Memory Sanitizer is detector of *uninitialized* reads

- stack/heap-allocated memory read before it is written

* Similar to valgrind but faster (3X slowdown)

```
clang++ -O1 -g -fsanitize=memory -fno-omit-frame-pointer <program>
```

`-fsanitize-memory-track-origins=2`
track origins of uninitialized values

Note: not compatible with Address Sanitizer

Website:

clang.llvm.org/docs/MemorySanitizer.html
github.com/google/sanitizers/wiki/MemorySanitizer
gcc.gnu.org/onlinedocs/gcc/Instrumentation-Options.html

Undefined Behavior Sanitizer

`UndefinedBehaviorSanitizer` is a *undefined behavior* detector

- signed integer overflow, floating-point types overflow, enumerated not in range
- out-of-bounds array indexing, misaligned address
- divide by zero
- etc.

* Not included in `valgrind`

```
clang++ -O1 -g -fsanitize=undefined -fno-omit-frame-pointer <program>
```

`-fsanitize=integer` Checks for undefined or suspicious integer behavior (e.g. unsigned integer overflow)

`-fsanitize=nullability` Checks passing `null` as a function parameter, assigning `null` to an lvalue, and returning `null` from a function

Website:

`clang.llvm.org/docs/UndefinedBehaviorSanitizer.html`

`gcc.gnu.org/onlinedocs/gcc/Instrumentation-Options.html`

Debugging Summary

How to Debug Common Errors

Segmentation fault

- gdb
- valgrind
- Segmentation fault when just entered in a function → stack overflow

Double free or corruption

- gdb
- valgrind

Infinite execution

- gdb + (CTRL + C)

Incorrect results

- valgrind + assertion + gdb + UndefinedBehaviorSanitizer

Demangling

Name mangling is a technique used to solve various problems caused by the need to resolve unique names

Transforming C++ ABI (Application binary interface) identifiers into the original source identifiers is called **demangling**

Example (linking error):

```
_ZNSt13basic_filebufIcSt11char_traitsIcEED1Ev
```

After demangling:

```
std::basic_filebuf<char, std::char_traits<char> >::~basic_filebuf()
```

How to demangle:

-
  ```
  make |& c++filt | grep -P '`.*(?=))'
  ```
- Online Demangler: `https://demangler.com`

Code Checking and Analysis

Compiler Warnings

Enable specific warnings:

```
g++ -W<warning> <args...>
```

Disable specific warnings:

```
g++ -Wno-<warning> <args...>
```

Common warning flags to minimize accidental mismatches:

`-Wall` Enables many standard warnings (∼50 warnings)

`-Wextra` Enables some extra warning flags that are not enabled by `-Wall` (∼15 warnings)

`-Wpedantic` Issue all the warnings demanded by strict ISO C/C++

Enable <u>ALL</u> warnings (only `clang`) `-Weverything`

GCC Warnings

Additional GCC warning flags ($\geq$ 5.0):

```
-Wcast-align
-Wcast-qual
-Wconversion
# -Wfloat-conversion
# -Wsign-conversion
-Wdate-time
-Wdouble-promotion
-Weffc++
# -Wdelete-non-virtual-dtor
# -Wnon-virtual-dtor
-Wformat-signedness
-Winvalid-pch
-Wlogical-op
-Wmissing-declarations
-Wmissing-include-dirs
-Wodr
```

```
-Wold-style-cast
-Wpragmas
-Wredundant-decls
-Wshadow
-Wsign-promo*
-Wstrict-aliasing
-Wstrict-overflow=1  # 5
-Wswitch-bool
# -Wswitch-default
# -Wswitch-enum
-Wtrampolines
-Wunused-macros
-Wuseless-cast
-Wvla
-Wformat=2
-Wno-long-long
```

Static Analyzers - `clang static analyzer`

The **`Clang Static Analyzer`** is a source code analysis tool that finds bugs in C/C++ programs at compile-time

It find bugs by reasoning about the semantics of code (may produce false positives)

Example:

```
void test() {
    int i, a[10];
    int x = a[i]; // warning: array subscript is undefined
}
```

How to use:

```
scan-build make
```

`scan-build` is included in the LLVM suite

Static Analyzers - cppcheck

cppcheck provides code analysis to detect bugs, undefined behavior and dangerous coding construct. The goal is to detect only real errors in the code (i.e. have very few false positives)

```
cppcheck --enable=warning,performance,style,portability,information,error
          <src_file/directory>
```

```
cmake -DCMAKE_EXPORT_COMPILE_COMMANDS=ON .
cppcheck --enable=<enable_flags> --project=compile_commands.json
```

Static Analyzers - PVS-Studio, FBInfer

PVS-Studio is a high-quality *proprietary* (free for open source projects) static code analyzer supporting C, C++

Customers: IBM, Intel, Adobe, Microsoft, Nvidia, Bosh, IdGames, EpicGames, etc.

FBInfer is a static analysis tool (also available online) to checks for null pointer deferencing, memory leak, coding conventions, unavailable APIs, etc.

Customers: Amazon AWS, Facebook/Ocolus, Instagram, Whatapp, Mozilla, Spotify, Uber, Sky, etc.

Static Analyzers - `DeepCode, SonarSource`

DEEPCODE

`deepCode` is an AI-powered code review system, with machine learning systems trained on billions of lines of code from open-source projects

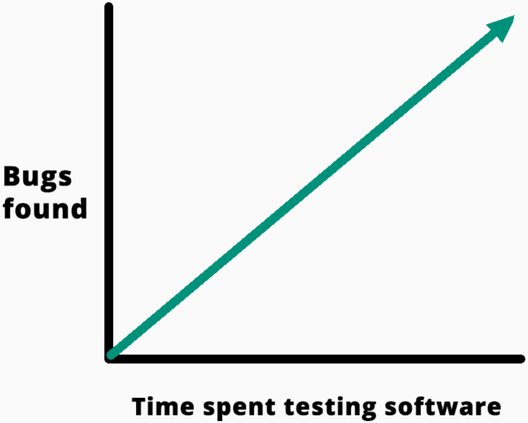
Available for Visual Studio Code, Sublime, IntelliJ IDEA, and Atom

`SonarSource` is a static analyzer which inspects source code for bugs, code smells, and security vulnerabilities for multiple languages (C++, Java, etc.)

`SonarLint` plugin is available for Visual Code, Visual Studio Code, Eclipse, and IntelliJ IDEA

Code Testing

Code Testing



from: Kat Maddox (on Twitter)

Unit Test

Unit testing involves breaking your program into pieces, and subjecting each piece to a series of tests

Unit Testing Benefits:

- Increases confidence in changing/ maintaining code
- The cost of fixing a defect detected during unit testing is lesser in comparison to that of defects detected at higher levels
- Debugging is easy. When a test fails, only the latest changes need to be debugged

C++ Unit testing frameworks:

- `catch`
- `doctest`
- `Google Test`
- `CppUnit`
- `Boost.Test`

catch 1/2

Catch2 is a multi-paradigm test framework for C++

Catch2 features

- Header only and no external dependencies
- Assertion macro
- Floating point tolerance comparisons

Basic usage:

- Create the test program
- Run the test

```
$./test_program [<TestName>]
```

Other commands:
github.com/catchorg/Catch2

catch 2/2

```
#define CATCH_CONFIG_MAIN  // This tells Catch to provide a main()
#include "catch.hpp"       // only do this in one cpp file

unsigned int Factorial(unsigned int number) {
    return number <= 1 ? number : Factorial(number - 1) * number;
}

float floatComputation() { ... }

"Test description and tag name"
TEST_CASE( "Factorials are computed", "[Factorial]" ) {
    REQUIRE( Factorial(1) == 1 );
    REQUIRE( Factorial(2) == 2 );
    REQUIRE( Factorial(3) == 6 );
    REQUIRE( Factorial(10) == 3628800 );
}

TEST_CASE( "floatCmp computed", "[floatComputation]" ) {
    REQUIRE( floatComputation() == Approx( 2.1 ) );
}
```

Code Coverage

Code coverage is a measure used to describe the degree to which the source code of a program is executed when a particular test suite runs

gcov is a tool you can use in conjunction with GCC to test code coverage in programs

lcov is a graphical front-end for gcov. It collects gcov data for multiple source files and creates HTML pages containing the source code annotated with coverage information

Step for code coverage:

- compile with `--coverage` flag (objects + linking)
- run the test
- visualize the results with gcov or lcov

Code Coverage 2/3

program.cpp:

```cpp
#include <iostream>
#include <string>

int main(int argc, char* argv[]) {
    int value = std::stoi(argv[1]);
    if (value % 3 == 0)
        std::cout << "first\n";
    if (value % 2 == 0)
        std::cout << "second\n";
}
```

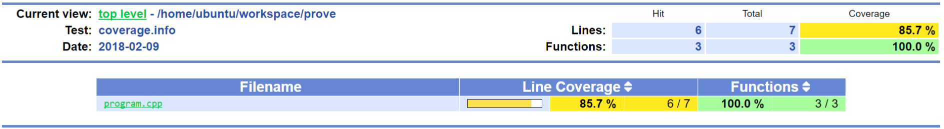
```
$gcc --std=c++11 --coverage program.cpp -o program
$./program 9
first
$gcov program.cpp
File 'program.cpp'
Lines executed:85.71% of 7
Creating 'program.cpp.gcov'
$lcov --capture --directory . --output-file coverage.info
$genhtml coverage.info --output-directory out
```

Code Coverage 3/3

program.cpp.gcov:

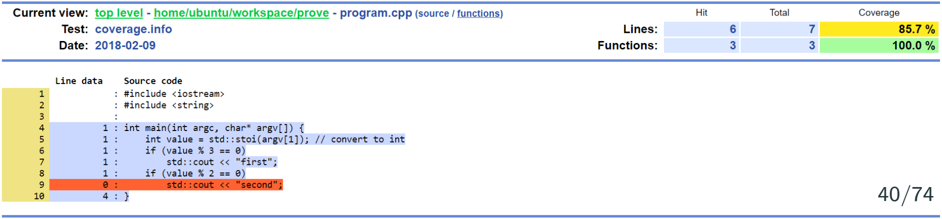
```
    1:    4:int main(int argc, char* argv[]) {
    1:    5:    int value = std::stoi(argv[1]);
    1:    6:    if (value % 3 == 0)
    1:    7:        std::cout << "first\n";
    1:    8:    if (value % 2 == 0)
#####:    9:        std::cout << "second\n";
    4:   10:}
```

lcov output:



			Hit	Total	Coverage
Current view:	top level - /home/ubuntu/workspace/prove				
Test:	coverage.info	Lines:	6	7	85.7 %
Date:	2018-02-09	Functions:	3	3	100.0 %

Filename	Line Coverage ⬍			Functions ⬍	
program.cpp		85.7 %	6 / 7	100.0 %	3 / 3



			Hit	Total	Coverage
Current view:	top level - home/ubuntu/workspace/prove - program.cpp (source / functions)				
Test:	coverage.info	Lines:	6	7	85.7 %
Date:	2018-02-09	Functions:	3	3	100.0 %

```
           Line data    Source code
   1                  : #include <iostream>
   2                  : #include <string>
   3                  :
   4                1 : int main(int argc, char* argv[]) {
   5                1 :     int value = std::stoi(argv[1]); // convert to int
   6                1 :     if (value % 3 == 0)
   7                1 :         std::cout << "first";
   8                1 :     if (value % 2 == 0)
   9                0 :         std::cout << "second";
  10                4 : }
```

Coverage-Guided Fuzz Testing

A **fuzzer** is a specialized tool that tracks which areas of the code are reached, and generates *mutations* on the corpus of input data in order to *maximize* the code coverage

`LibFuzzer` is the library provided by LLVM and feeds fuzzed inputs to the library via a specific fuzzing entrypoint

The *fuzz target function* accepts an array of bytes and does something interesting with these bytes using the API under test:

```
extern "C" int LLVMFuzzerTestOneInput(const uint8_t* Data,
                                      size_t         Size) {
  DoSomethingInterestingWithMyAPI(Data, Size);
  return 0;
}
```

Code Quality

Linters - `clang-tidy` 1/2

lint: The term was derived from the name of the undesirable bits of fiber

`clang-tidy` provides an extensible framework for diagnosing and fixing typical *programming errors*, like *style violations*, *interface misuse*, or *bugs* that can be deduced via static analysis

```
$cmake -DCMAKE_EXPORT_COMPILE_COMMANDS=ON .
$clang-tidy -p .
```

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

`clang-tidy` is included in the LLVM suite

Linters - clang-tidy 2/2

Coding Guidelines:

- CERT Secure Coding Guidelines
- C++ Core Guidelines
- High Integrity C++ Coding Standard

Supported Code Conventions:

- Fuchsia
- Google
- LLVM

Bug Related:

- Android related
- Boost library related
- Misc
- Modernize
- Performance
- Readability
- clang-analyzer checks
- bugprone code constructors

.clang-tidy

```
Checks: 'android-*,boost-*,bugprone-*,cert-*,cppcoreguidelines-*,
clang-analyzer-*,fuchsia-*,google-*,hicpp-*,llvm-*,misc-*,modernize-*,
performance-*,readability-*'
```

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/Ninjia and workspaces that can be used in the compiler environment of your choice

CMake features:

- Turing complete language
- Multi-platform (Windows, Linux, etc.)
- Open-Source
- Generate: makefiles, ninja, etc.
- Supported by many IDE: Visual Studio, Eclipse, etc.

CMake - References

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

CMake - Example 1 1/5

CMakeLists.txt minimal example:

```
project(my_project)                 # project name

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

```
$ cmake .     # 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
```

CMake - Example 2 2/5

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

set(CMAKE_CXX_STANDARD           14) # force C++14
set(CMAKE_CXX_STANDARD_REQUIRED  ON)
set(CMAKE_CXX_EXTENSIONS         OFF)

add_executable(program)

# indicate include directory
target_include_directories(program
    PUBLIC "${PROJECT_SOURCE_DIR}/include")

# 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})
```

CMake - Example 3

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

add_executable(program)

if (CMAKE_BUILD_TYPE STREQUAL "Debug")      # "Debug" mode
    target_compile_options(program "-g")
    target_compile_options(program "-O1")
    if (CMAKE_COMPILER_IS_GNUCXX)           # if compiler is gcc
        target_compile_options(program "-ggdb3")
    endif()
elseif (CMAKE_BUILD_TYPE STREQUAL "Release") # "Release" mode
    target_compile_options(program "-O2")
endif()

target_sources(program PRIVATE program.cpp)
```

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

CMake - Example 4 4/5

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

add_custom_target(rm                   # makefile target name
                  COMMAND rm -rf *.o   # real command
                  COMMENT "Clear build directory")

add_executable(program)
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()
target_sources(program PRIVATE program.cpp)
```

```
$ cmake .
$ make rm
```

CMake - Notes 5/5

Generate JSON compilation database (`compile_commands.json`)

It contains the exact compiler calls for each file (used by other tools)

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

set(CMAKE_EXPORT_COMPILE_COMMANDS ON)  # <--

add_executable(program)
target_sources(program PRIVATE program.cpp)
```

Change the compiler:

```
CC=gcc CXX=g++ 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

```cmake
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)

Code Documentation

doxygen 1/6

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

Doxygen usage

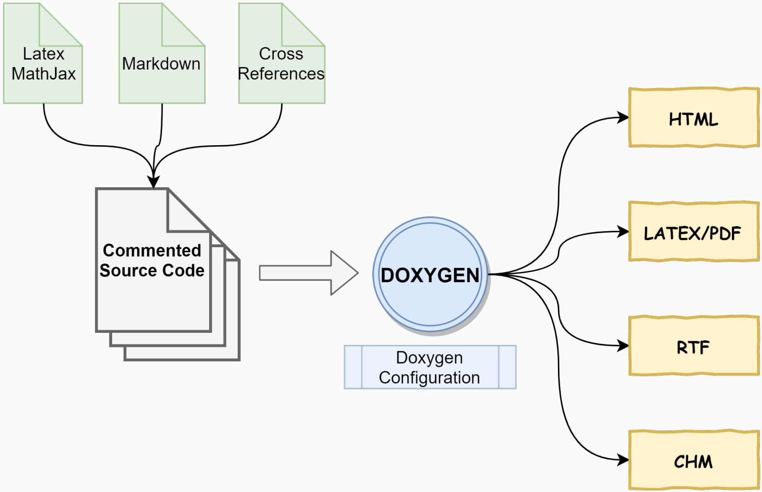
- comment the code with `///` or `/** comment */`
- generate `doxygen` base configuration file

```
$doxygen -g
```

- modify the configuration file `doxygen.cfg`
- generate the documentation

```
$doxygen <config_file>
```

An alternative in early development stage is `clang-doc`


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

Doxygen provides support for:

- **Latex/MathJax** Insert latex math `$<code>$`
- **Markdown** (Markdown Cheatsheet link) Italic text `*<code>*`, bold text `**<code>**`, table, list, etc.
- **Automatic cross references** Between functions, variables, etc.
- **Specific highlight** Code ``` `<code>` ```, parameter `@param <param>`

doxygen - Guidelines 4/6

Doxygen guidelines:

- Include in every file **copyright**, **author**, **date**, **version**
- Comment `namespaces` and `classes`
- Comment `template` parameters
- Distinguish `input` and `output` parameters
- Call/Hierarchy graph can be useful in large projects (should include `graphviz`)

  ```
  HAVE_DOT = YES
  GRAPHICAL_HIERARCHY = YES
  CALL_GRAPH = YES
  CALLER_GRAPH = YES
  ```

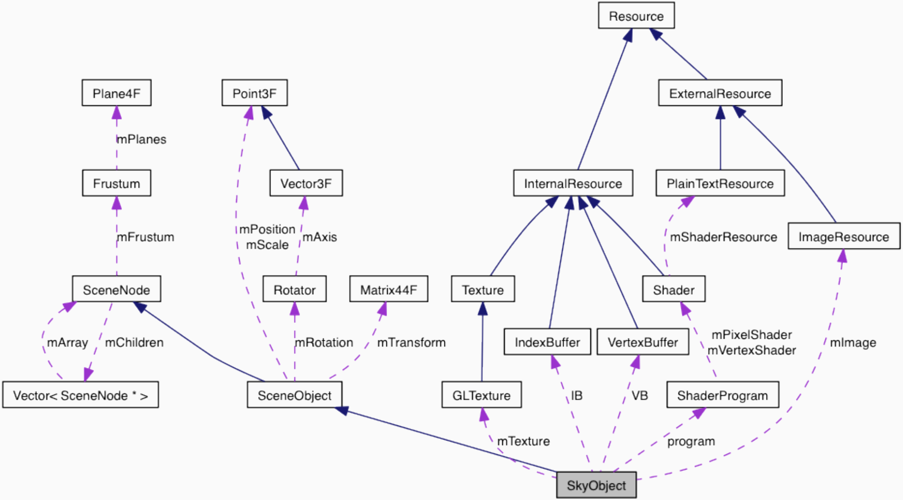
μOS++ Doxygen style guide link

doxygen - Example 5/6

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

/// @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 - 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++

Writing Good Documentation

`Teaching the art of great documentation`, by Google

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 1/3

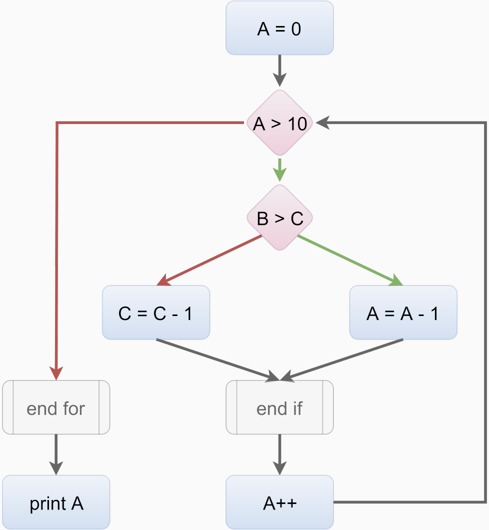
Lizard is an extensible Cyclomatic Complexity Analyzer for many programming languages including C/C++

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
- param: Parameter count of functions

Cyclomatic Complexity Analyzer - `lyzard`



`CCN = 3`

Cyclomatic Complexity Analyzer - `lyzard` 3/3

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

References:

`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>
```

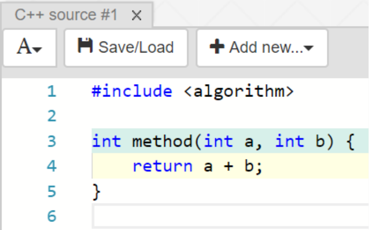
`clang-format` searches the configuration file `.clang-format` file located in the closest parent directory of the input file

`clang-format` example:

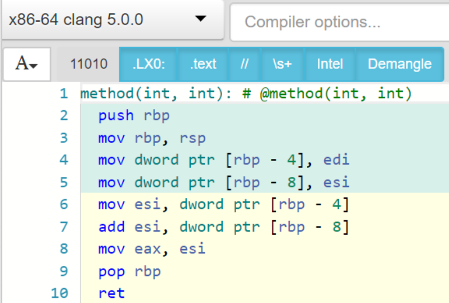
```
IndentWidth: 4
UseTab: Never
BreakBeforeBraces: Linux
ColumnLimit: 80
SortIncludes: true
```

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.



```
#include <algorithm>

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

```

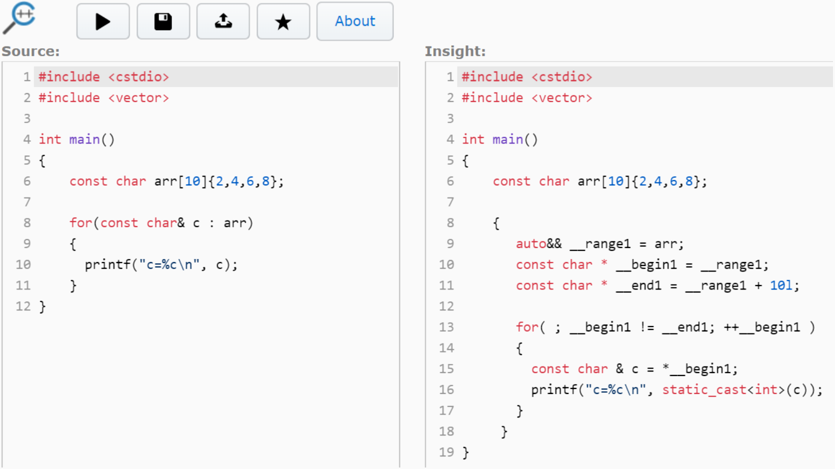


```
method(int, int): # @method(int, int)
  push rbp
  mov rbp, rsp
  mov dword ptr [rbp - 4], edi
  mov dword ptr [rbp - 8], esi
  mov esi, dword ptr [rbp - 4]
  add esi, dword ptr [rbp - 8]
  mov eax, esi
  pop rbp
  ret
```

Key feature: support multiple architectures and compilers

Code Transformation - CppInsights

CppInsights See what your compiler does behind the scenes



Source:

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

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

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

Insight:

```
#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));
      }
    }
}
```

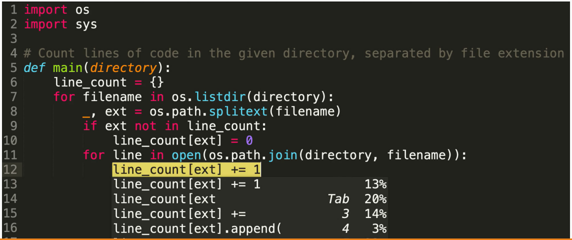
Code Autocompletion - `TabNine`

`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



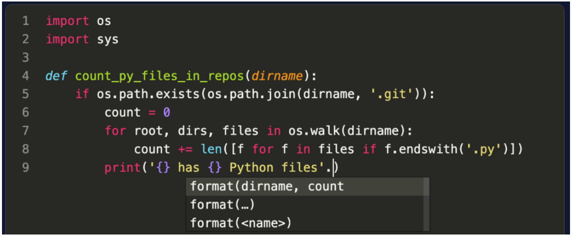
```
import os
import sys

# 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%
```

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



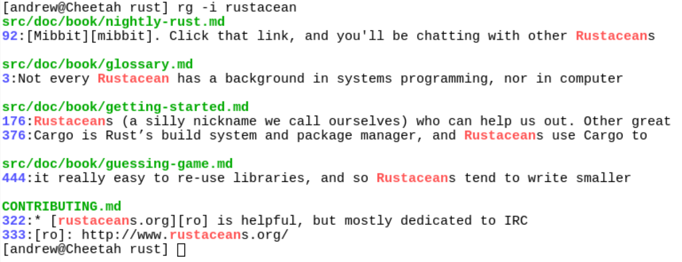
```python
import os
import sys

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`

`Ripgrep` is a code-searching-oriented tool 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`



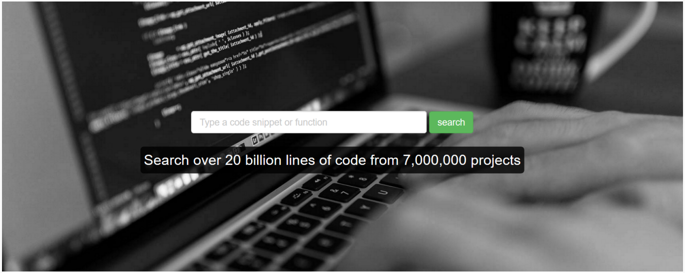
```
[andrew@Cheetah rust] rg -i rustacean
src/doc/book/nightly-rust.md
92:[Mibbit][mibbit]. Click that link, and you'll be chatting with other Rustaceans

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

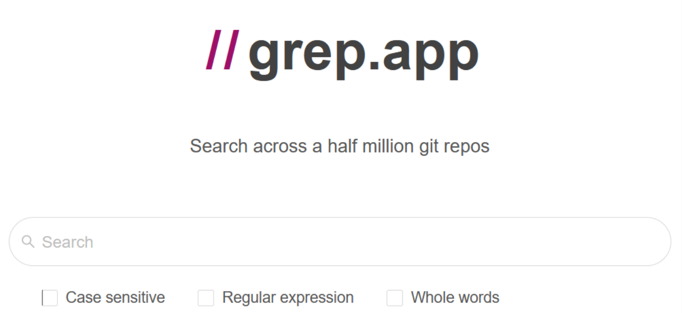
Features:

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


Type a code snippet or function
search
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



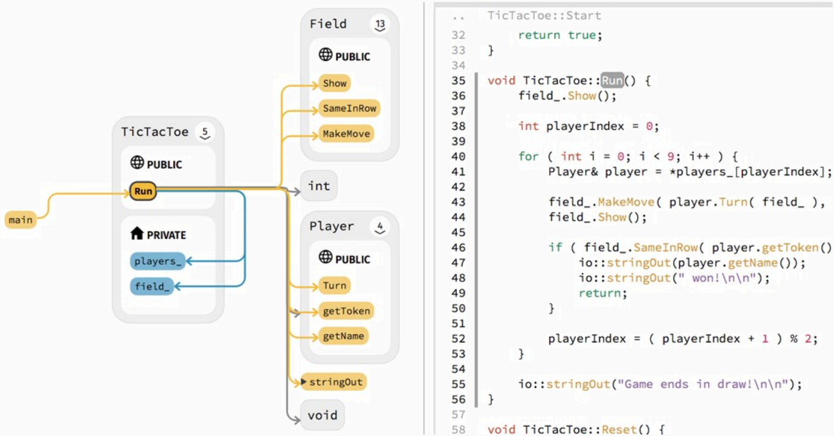
//grep.app

Search across a half million git repos

□ Case sensitive □ Regular expression □ Whole words

Code Exploration - SourceTrail

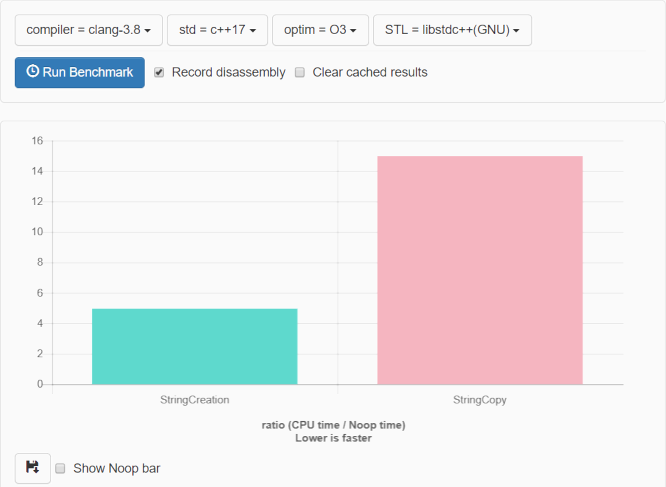
Sourcetrail is an interactive code explorer that simplifies navigation in complex source code



```
.. TicTacToe::Start
    return true;
}

void TicTacToe::Run() {
    field_.Show();

    int playerIndex = 0;

    for ( int i = 0; i < 9; i++ ) {
        Player& player = *players_[playerIndex];

        field_.MakeMove( player.Turn( field_ ),
        field_.Show();

        if ( field_.SameInRow( player.getToken()
            io::stringOut(player.getName());
            io::stringOut(" won!\n\n");
            return;
        }

        playerIndex = ( playerIndex + 1 ) % 2;
    }

    io::stringOut("Game ends in draw!\n\n");
}

void TicTacToe::Reset() {
```

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) ▾

☑ Record disassembly □ Clear cached results

□ Show Noop bar