

Modern C++ Programming

10. DEBUGGING AND TOOLS

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Agenda

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 - Execution debuggging
 - Memory debuggging
 - Clang sanitizer
 - Demangling
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Debugging

Assertions

Assertions are intended to be used as a means of detecting programming bugs. Assertions represent an *invariant* in the code

Error/Exceptions can indicate “exceptional” conditions (invalid user input, missing files, etc.)

- **Exceptions** are more robust but slower
- **Error** are fast but difficult to handle in complex programs

```
#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 disabled by defining the `NDEBUG` macro

```
#define NDEBUG
```

How to compile for debugging:

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

-g Enable debugging

- stores the *symbol table information* in the executable
- 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)

How to run the debugger:

```
gdb --args ./program <args...>
```

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

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

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

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

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

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](#)



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

Website: valgrind.org

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)
```

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
```

Advanced use 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...>
```

Address Sanitizer is a memory error detector (out-of-bounds, use-after-free, etc.). It relies on code instrumentation at compile-time. Similar to valgrind but faster (2X slowdown)

Website: clang.llvm.org/docs/AddressSanitizer.html

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

-O1 disable inlining

-g generate symbol table

Memory Sanitizer is detector of uninitialized reads. It relies on code instrumentation at compile-time. Similar to valgrind but faster (3X slowdown)

Website: clang.llvm.org/docs/MemorySanitizer.html

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

LeakSanitizer is a run-time memory leak detector. It relies on code instrumentation at compile-time. Similar to valgrind but faster

Website: clang.llvm.org/docs/LeakSanitizer.html

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

UndefinedBehaviorSanitizer is a undefined behavior detector (signed integer overflow, enumerated not in range, etc.). It relies on code instrumentation at compile-time. Not included in valgrind

Website: clang.llvm.org/docs/UndefinedBehaviorSanitizer.html

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


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: demangler.com

How to Debug Common Errors

Segmentation fault/assertion fail

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

Double free or corruption

- valgrind

Infinite execution

- gdb + (CTRL + C)

Incorrect results

- valgrind + assertion + gdb + UndefinedBehaviorSanitizer

CMake



CMake is an *open-source*, *cross-platform* family of tools designed to build, test and package software

Website: cmake.org

CMake is used to control the software compilation process using simple platform and compiler independent configuration files, and *generate* native makefiles 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.

CMakeLists.txt minimal example:

```
PROJECT(my_project)           # project name
CMAKE_MINIMUM_REQUIRED(VERSION 3.5) # minimum version

ADD_EXECUTABLE(out_program program.cpp) # compile command
```

```
$cmake .      # CMakeLists.txt directory
$make        # makefile automatically generated
Scanning dependencies of target out_program
[100%] Building CXX object CMakeFiles/out_program.dir/program.cpp.o
Linking CXX executable out_program
[100%] Built target out_program
```

```
PROJECT(my_project)                # project name
CMAKE_MINIMUM_REQUIRED(VERSION 3.5) # minimum version

# verify if a compiler flag is supported
CHECK_CXX_COMPILER_FLAG("-std=c++14" COMPILER_SUPPORTS_CXX14)
IF (COMPILER_SUPPORTS_CXX14)      # if statement
    ADD_COMPILE_OPTIONS("-std=c++14") # if supported add the flag
ELSE()                             # else statement
    # if not supported exit and print message
    MESSAGE(FATAL_ERROR "Compiler ${CMAKE_CXX_COMPILER} has no C++14"
            "support.")
ENDIF()                             # end if statement

# indicate include directory
INCLUDE_DIRECTORIES("${PROJECT_SOURCE_DIR}/include")
# find all .cpp file in src/ directory
FILE(GLOB_RECURSE SRCS "${PROJECT_SOURCE_DIR}/src/*.cpp")

ADD_EXECUTABLE(out_program ${SRCS}) # compile all *.cpp file
```

```
PROJECT(my_project)                # project name
CMAKE_MINIMUM_REQUIRED(VERSION 3.5) # minimum version

IF (CMAKE_BUILD_TYPE STREQUAL "Debug") # "Debug" mode
  ADD_COMPILE_OPTIONS("-g")
  ADD_COMPILE_OPTIONS("-O1")
  IF (CMAKE_COMPILER_IS_GNUCXX)        # if compiler is gcc
    ADD_COMPILE_OPTIONS("-ggdb3")
  ELSEIF (CMAKE_CXX_COMPILER_ID EQUAL "Clang") # if compiler is clang
    ADD_COMPILE_OPTIONS("-fsanitize=address")
    ADD_COMPILE_OPTIONS("-fno-omit-frame-pointer")
  ENDIF()
ELSEIF (CMAKE_BUILD_TYPE STREQUAL "Release") # "Release" mode
  ADD_COMPILE_OPTIONS("-O2")
ENDIF()

ADD_EXECUTABLE(out_program program.cpp)
```

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

```
PROJECT(my_project)           # project name
CMAKE_MINIMUM_REQUIRED(VERSION 3.5) # minimum version

FIND_PACKAGE(Boost 1.36.0 REQUIRED) # compile only if Boost library
                                     # is found

IF (Boost_FOUND)
    INCLUDE_DIRECTORIES("${PROJECT_SOURCE_DIR}/include"
                        Boost_INCLUDE_DIRS) # automatic variable
ELSE()
    MESSAGE(FATAL_ERROR "Boost Lib not found")
ENDIF()

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

ADD_EXECUTABLE(out_program program.cpp)
```

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


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 3.5) # minimum version

SET(CMAKE_EXPORT_COMPILE_COMMANDS ON) # <--

ADD_EXECUTABLE(out_program program.cpp)
```

Change compiler:

```
CC=gcc CXX=g++ cmake .
```

Useful variables:

cmake.org/Wiki/CMake_Useful_Variables

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 ALL warnings (only clang) **-Weverything**

Full list: gcc.gnu.org/onlinedocs/gcc/Warning-Options.html

Which Clang Warning Is Generating This Message?

fuckingclangwarnings.com

Static Analyzer (clang static analyzer)



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

Website: clang-analyzer.llvm.org

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]; // warn: array subscript is undefined  
}
```

How to use:

```
scan-build make
```

scan-build is included in the LLVM suite

Static Analyzer (cppcheck/oclint)

Cppcheck provides code analysis to detect bugs, undefined behavior and dangerous coding constructs

Website: cppcheck.sourceforge.net or

```
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
```

Oclint is a tool for improving quality and reducing defects by inspecting C/C++ code and looking for potential problems

Website: oclint.org

```
cmake -DCMAKE_EXPORT_COMPILE_COMMANDS=ON .  
oclint-json-compilation-database -enable-global-analysis  
         -i <includes_dirs>
```

Code Quality

Linters (clang-tidy)

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

Website: clang.llvm.org/extra/clang-tidy

```
$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)

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-*
```


Linters (vera++)

Vera++ is tool for verification and analysis of C++ source code. It is complementary to clang-tidy: It provides weaker checkers, more oriented to syntax, then semantic

- well-formed file names
- space rules
- variable names
- etc.

Website: bitbucket.org/verateam/vera/wiki/Home

```
vera++ --rule <rule_list> <src_file/include_file>
```

```
vera++ --profile <profile_name> <src_file/include_file>
```

Code Testing

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)

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

Alternatives: Google Test, Boost.Test, CppUnit, etc.

Website: catch-lib.net

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/blob/master/docs/command-line.md 31/46

```
#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 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`

program.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
```


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:

Current view: [top level](#) - /home/ubuntu/workspace/prove

Test: coverage.info

Date: 2018-02-09

	Hit	Total	Coverage
Lines:	6	7	85.7 %
Functions:	3	3	100.0 %

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

Current view: [top level](#) - [home/ubuntu/workspace/prove](#) - program.cpp (source / functions)

Test: coverage.info

Date: 2018-02-09

	Hit	Total	Coverage
Lines:	6	7	85.7 %
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: }

Code Commenting

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

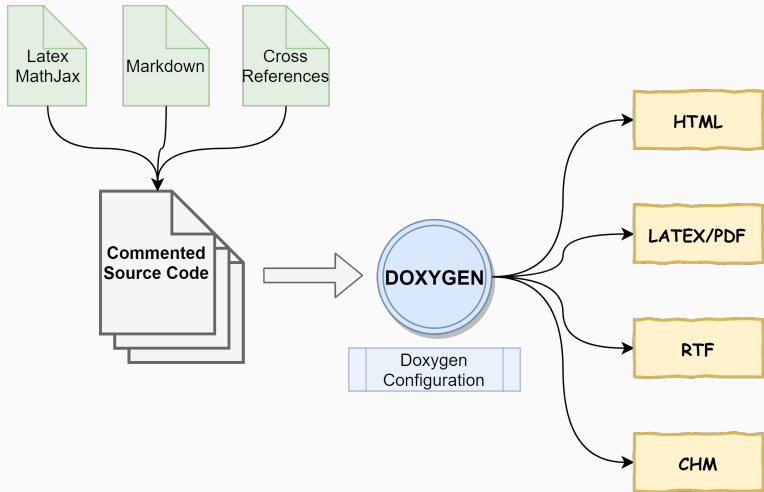
Doxygen usage

- 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>
```



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:

- 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](#)

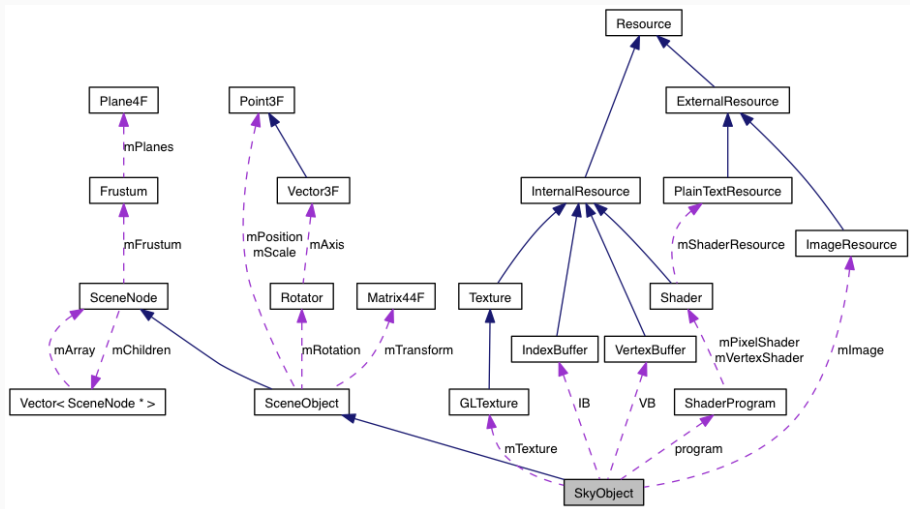
```
/**
 * @copyright MyProject
 * license BSD3, Apache, MIT, etc.
 * @author MySelf
 * @version v3.14159265359
 * @date March, 2018
 */

/// @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>
int my_function(const T* input, T* output);

/// @brief
void related_function;
```



Code Statistics

Count Lines of Code (cloc)

Website: cloc.sourceforge.net

```
$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)

Website: github.com/terryyin/lizard

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's 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

Other Tools

Code Formatting (clang-format)

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

Website: clang.llvm.org/docs/ClangFormat.html

```
$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
```

Assembly Explorer

Compiler Explorer is an interactive tool that lets you type source code and see assembly output

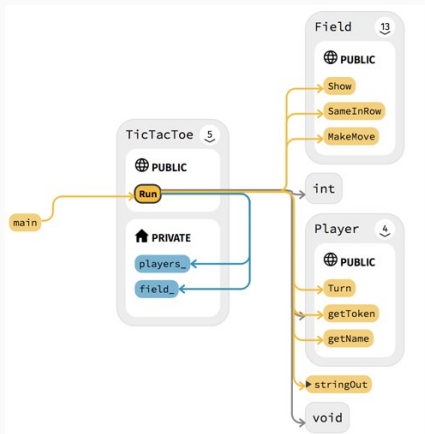
Website: godbolt.org

```
C++ source #1 X
A Save/Load + Add new...
1 #include <algorithm>
2
3 int method(int a, int b) {
4     return a + b;
5 }
6
```

```
x86-64 clang 5.0.0 Compiler options...
A 11010 .LX0: .text // \s+ Intel Demangle
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
```

SourceTrail is an interactive source explorer that simplifies navigation in existing source code

Website: www.sourcetrail.com/#intro



```
.. TicTacToe::Start
32     return true;
33 }
34
35 void TicTacToe::Run() {
36     field_.Show();
37
38     int playerIndex = 0;
39
40     for ( int i = 0; i < 9; i++ ) {
41         Player& player = *players_[playerIndex];
42
43         field_.MakeMove( player.Turn( field_ ),
44             field_.Show());
45
46         if ( field_.SameInRow( player.getToken()
47             io::stringOut(player.getName());
48             io::stringOut(" won!\n\n");
49             return;
50         )
51     )
52     playerIndex = ( playerIndex + 1 ) % 2;
53 }
54
55 io::stringOut("Game ends in draw!\n\n");
56 }
57
58 void TicTacToe::Reset() {
```