Modern C++ Programming

13. Debugging and Tools

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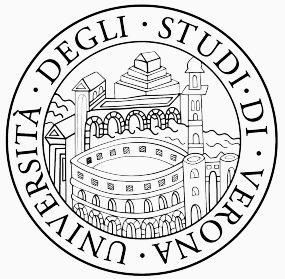

Agenda

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Execution Debugging

Assertions

An **Assertion** is a statement to detect a violated assumption. An assertions represents an *invariant* in the code

Error/Exception 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 disable by define the NDEBUG macro

```
#define NDEBUG // or at compile-time with "-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.)

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

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

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***

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www.zdnet.com

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

Website: valgrind.org

How to install the last version:

```
$ wget ftp://sourceware.org/pub/valgrind/valgrind-3.14.0.tar.bz2
$ tar xf valgrind-3.14.0.tar.bz2
$ cd valgrind-3.14.0
$ ./configure
$ make -j 12
$ sudo make install
$ sudo apt install libc6-dbg
```

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 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

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`

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`

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` $\rightarrow$ `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`
  ```

CMake

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

Website: `https://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

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

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

# 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_otpions("-g")
    add_compile_otpions("-O1")
    if (CMAKE_COMPILER_IS_GNUCXX)                   # if compiler is gcc
        add_compile_otpions("-ggdb3")
    elseif (CMAKE_CXX_COMPILER_ID EQUAL "Clang") # if compiler is clang
        add_compile_otpions("-fsanitize=address")
        add_compile_otpions("-fno-omit-frame-pointer")
    endif()
elseif (CMAKE_BUILD_TYPE STREQUAL "Release") # "Release" mode
    add_compile_otpions("-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 the compiler:

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

Useful variables:

`gitlab.kitware.com/cmake`

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`

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
```

GCC Warnings

Additional GCC warning flags ($\geq$ 8.0):

```
-Wcatch-value=2
-Wextra-semi
-Wstringop-truncation
-Wsuggest-attribute=cold
-Wsuggest-attribute=malloc
-Walloca
-Wduplicated-branches
-Wformat-overflow=2
-Wformat-truncation=2
-Wstringop-overflow=3
-Wduplicated-cond
-Wnull-dereference
-Wplacement-new=2
-Wshift-overflow=2
```

Full story:

gcc.gnu.org/onlinedocs/gcc/Warning-Options.html

github.com/barro/compiler-warnings

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]; // warning: 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 construct. The goal is to detect only real errors in the code (i.e. have very few false positives)

Website: cppcheck.sourceforge.net

```
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

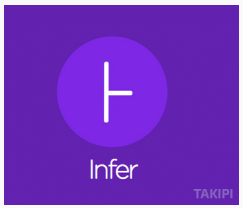
```
cmake -DCMAKE_EXPORT_COMPILE_COMMANDS=ON .
oclint-json-compilation-database -enable-global-analysis
                  -i <includes_dirs>
```

Static Analyzer (`PVS-Studio/FBInfer`)

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

Website: `www.viva64.com/en/pvs-studio`

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.

Website: `fbinfer.com`

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

Code Quality

Linter (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

Linter (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-*'
```

Linter (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)

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-lib`
- `Google Test`
- `CppUnit`
- `Boost.Test`

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

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

```
#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:

```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

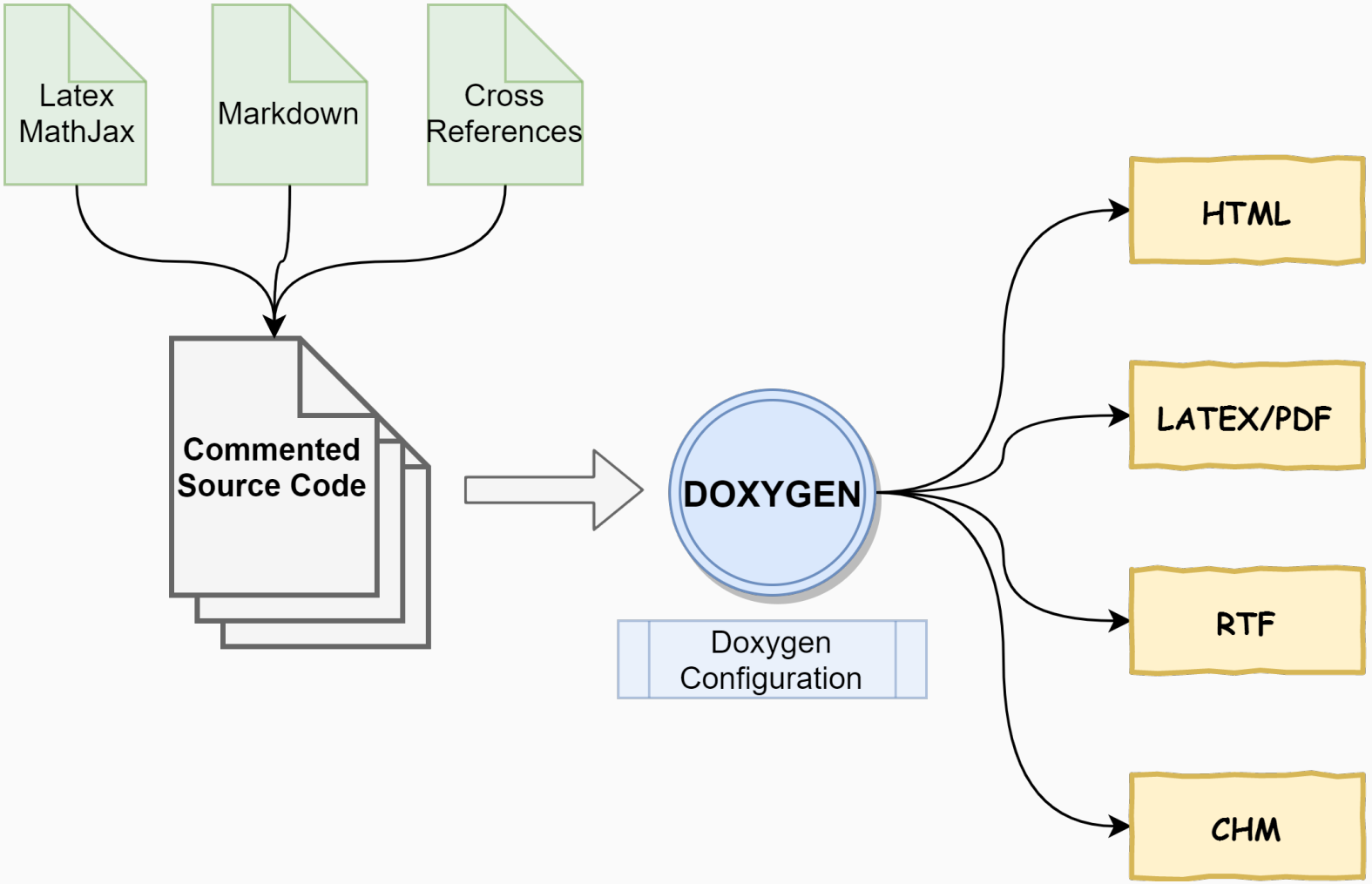
- comment the code with `///` or `/** comment */`
- generate doxygen base configuration file

```
$doxygen -g
```

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

```
$doxygen <config_file>
```

Code Commenting (doxygen)



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

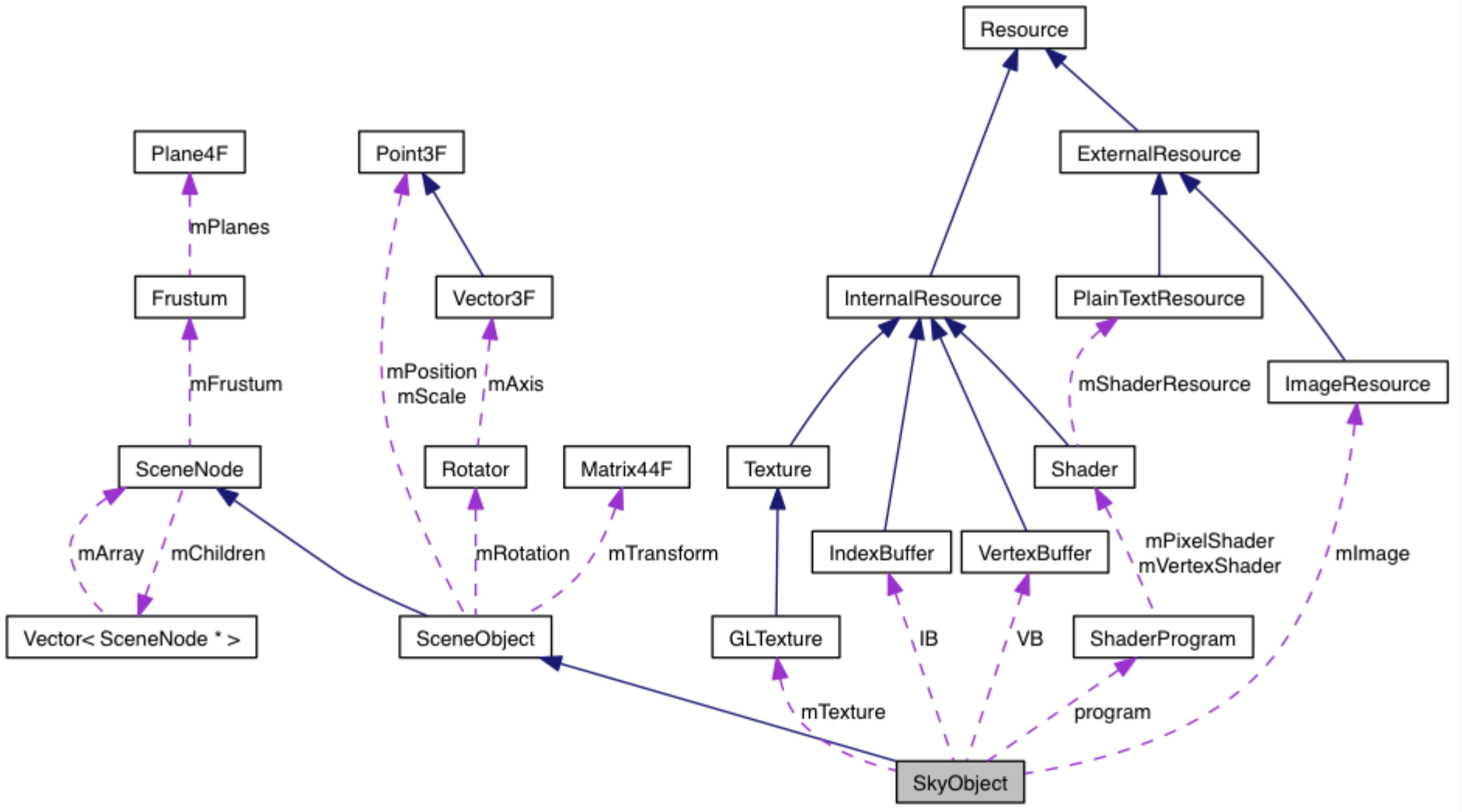
```
/**
 * @copyright MyProject
 * license BSD3, Apache, MIT, etc.
 * @author MySelf
 * @version v3.14159265359
 * @date March, 2018
 * @file
 */

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

/// @brief
void related_function;
```


Resource
Plane4F
Point3F
ExternalResource
mPlanes
Frustum
Vector3F
InternalResource
PlainTextResource
mFrustum
mPosition
mScale
mAxis
mShaderResource
ImageResource
SceneNode
Rotator
Matrix44F
Texture
Shader
mArray
mChildren
mRotation
mTransform
IndexBuffer
VertexBuffer
mPixelShader
mVertexShader
mImage
Vector< SceneNode * >
SceneObject
GLTexture
IB
VB
ShaderProgram
mTexture
program
SkyObject

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

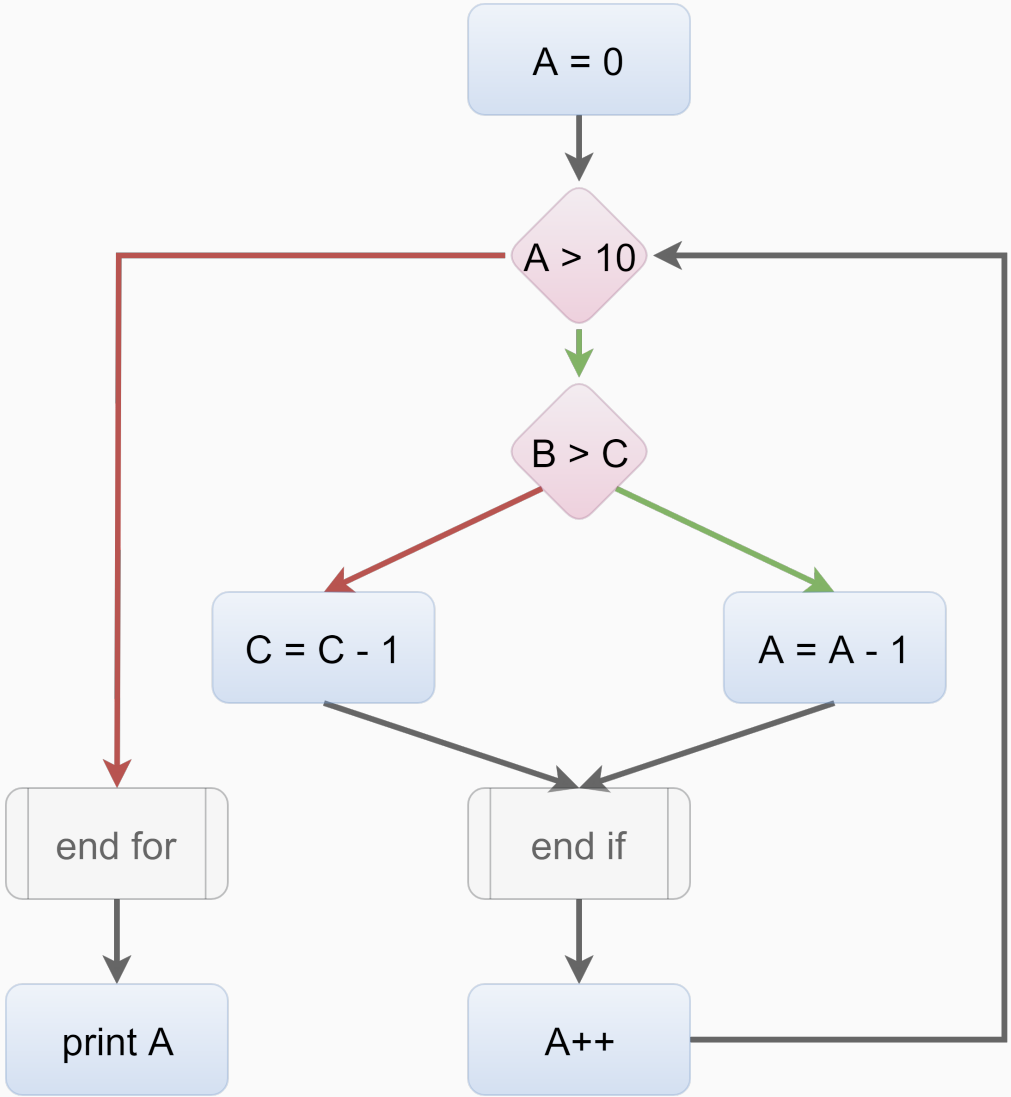
Cyclomatic Complexity: is a software metric used to indicate the complexity of a program. It is a quantitative measure of the number of linearly independent paths through a program source code

```
$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`)

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)

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

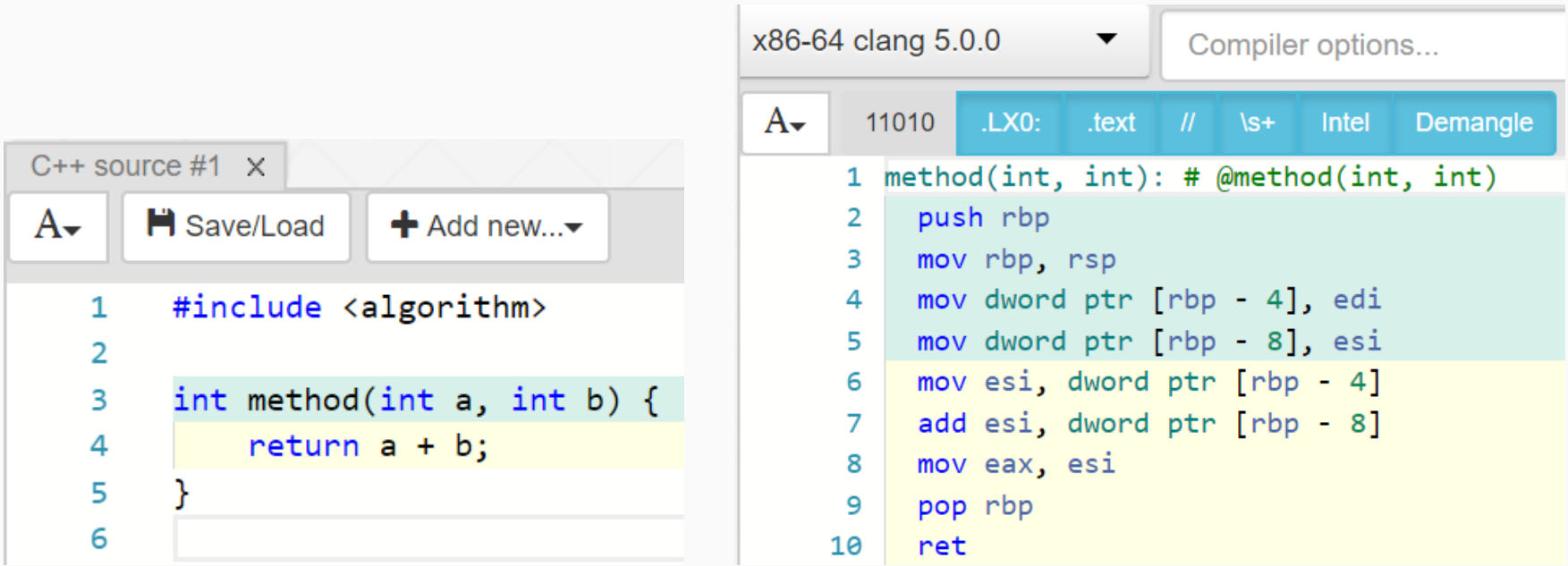
clang-format example:

```
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, control flow graph, optimization hint, etc.

Website: `godbolt.org`



Key feature: support multiple architectures and compilers

CppInsights

CppInsights See what your compiler does behind the scenes

Website: `cppinsights.io`

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 }
```

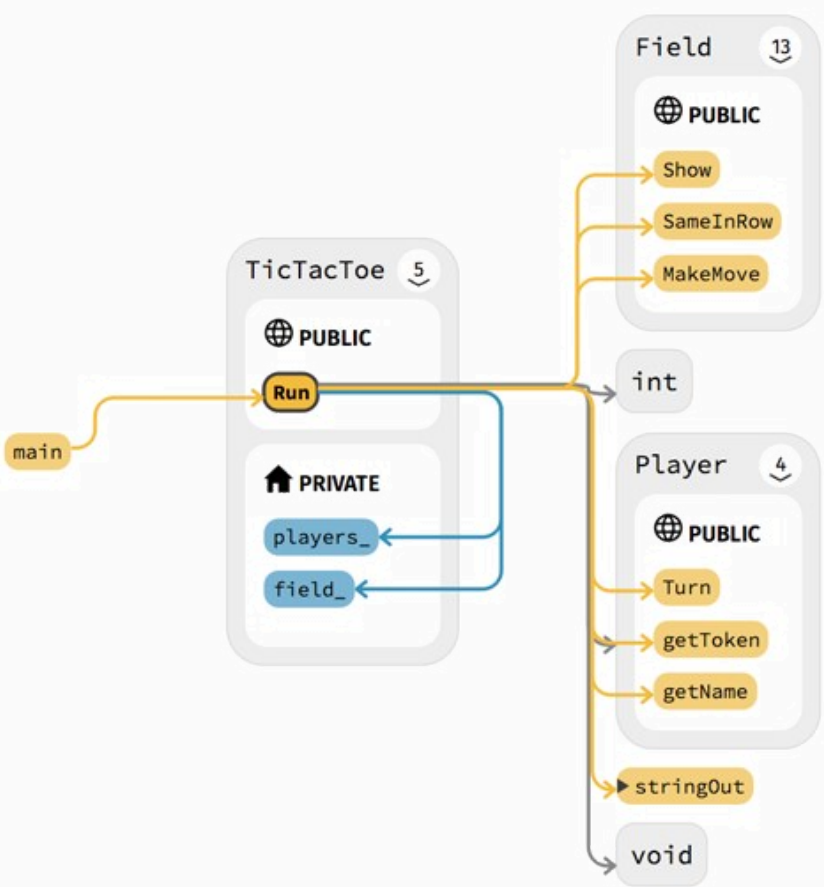
Insight:

```
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 + 10l;
12
13         for( ; __begin1 != __end1; ++__begin1 )
14         {
15           const char & c = *__begin1;
16           printf("c=%c\n", static_cast<int>(c));
17         }
18     }
19 }
```

SourceTrail

Sourcetrail is an interactive code explorer that simplifies navigation in complex 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() {
```

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

Website: `quick-bench.com`