

Cmake

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Chapter 1

Cmake

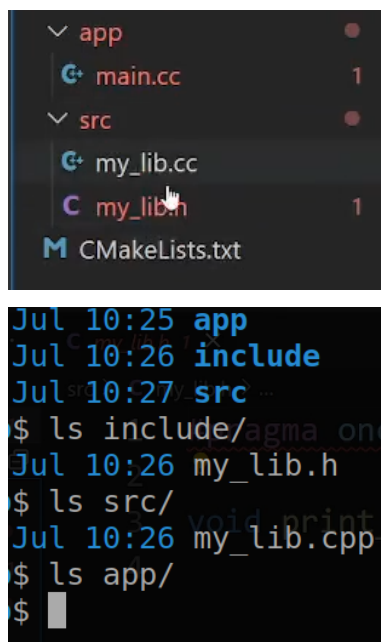
1.1 Overview

Cmake is super old. It has more than 300 functions to use, but 250 should not be used in modern cmake projects. This makes it particularly difficult to learn. Many older tutorials are confusing, out-of-date.

Moreover, modern cmake makes it as readable as possible with modern functions. Thus, way easier to read than older functions.

1.2 Project Structure

See basic project and intermediate project examples, in cmake udemy.

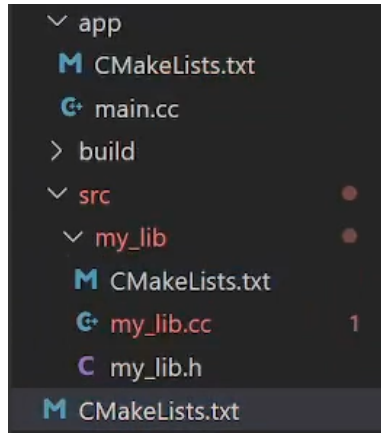


1.2.1 App Directory

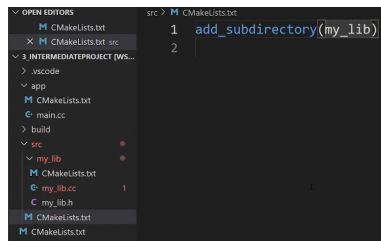
Define everything important for the executable target, including its own CMakeLists.txt.

1.2.2 Source Directory - src

Define everything important for our library. When you have multiple libraries, create multiple directories in src. As a naming convention, the subdirectory should have the same name as the library.



Don't forget to add a CMakeList in the src directory.



1.2.3 CMake Default Paths

Cmake has built-in paths to use. We use many in these notes.

```
# CMAKE_SOURCE_DIR is always the directory of the  
# root CMakeLists.txt file  
# our root directory
```

```
# CMAKE_BINARY_DIR is always our build directory
```

1.2.4 Template for Projects is Intermediate project

Create a project builder based on the architecture of the intermediate project.

1.3 Variables

You can create variables for your executable or your libraries in the root CMakeLists.txt. The variables will be usable in all add_subdirectory chain at the end of the same document.

```
# set a variable for the library you want to use
# common syntax is capital letters.

# we reference Library in other CMakeLists files
# we change the Library name for LIBA

set(LIBA Library)

# where we used Library, write ${LIBA}

# we have used Hello for our executable name so far.
# we can change it as well.
set(HE Hello)

# where we used Hello, write ${HE}

add_subdirectory(src)
add_subdirectory(app)
```

1.3.1 Standard for cpp

This is essential to have in your program. Otherwise, the compiler's default config will take the lead, with huge variability between compiler versions! In your root CMakeLists.txt file as well. This defines a variable and sets the standard to 17.

```
set(CMAKE_CXX_STANDARD 17)
set(CMAKE_C_STANDARD 98)
```

1.3.2 Standard Required

Indicate that the compiler 100 percent implemented the language's standard.

```
set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)
```

1.3.3 Compiler Extensions

Some compilers have features that are not implemented in the Cpp standard. These features are extensions. Some compilers allow you to use non-standard c code into a cpp program, even if they are not in the cpp standard.

```
set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)
set(CMAKE_CXX_EXTENSIONS OFF)
```

1.3.4 If Statement

Cmake has if statement. It even has string comparison functions, to compare variable and create conditions.

```
option(COMPILE_EXECUTABLE "Whether to compile the executable" OFF)

add_subdirectory(src)

if (COMPILE_EXECUTABLE)
    add_subdirectory(app)
else()
    message("Without executable compiling")
endif()
```

1.3.5 Options

You can set an option, the second argument is a simple comment for the reader (with no impact).

```
set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)
set(CMAKE_CXX_EXTENSIONS OFF)

set(LIBA Library)
set(HE Hello)

option(COMPILE_EXECUTABLE "Whether to compile the executable" OFF)

add_subdirectory(src)

if (COMPILE_EXECUTABLE)
    add_subdirectory(app)
endif()

# to call the option from the command line

#$ cmake .. -DCOMPILE_EXECUTABLE=ON

# then you can switch it back OFF later

#$ cmake .. -DCOMPILE_EXECUTABLE=OFF
```

1.4 Makefile Shell Scripting

Make is Cmake's ancestor. You can automate folder creation and files, just like any shell script would do.

Make do not support space, use tabs.

```
prepare:
    rm -rf build
    mkdir build
    cd build

# to execute it

# $ make prepare
```

1.5 Starter Pack - Jason Turner's Template

lefticus/cmake_template // Jason Turner 2023 cmake starter pack

rename "myproject" in the cmake files to use it.

1.5.1 Lefticus Defaults - ProjectOptions.cmake

```
Address sanitizer
Undefined behavior sanitizer
Fuzzing example built
Procedural optimization IPO (link time optimization)
Warnings as errors
Clang-tidy enabled
CPPcheck enabled
Options for precompiled headers
```

1.5.2 Hardening - Hardening.cmake

Hardened compilation // make code safer
More compilation options / securities.

```
-fstack-protector
-fcf-protection
-fsanitize=undefined // undefined behavior sanitizer
-fno-sanitize-recover=undefined
-fsanitize-minimal-runtime

+ debug information
```

1.6 Simple Cmake (Modern)

1.6.1 Context

Cmake is "a generator of make files", it abstracts away makefile complexity.

First, cmake // generate make files
Second, make // run make files
Last, ./hello // run the created executable

To create an executable of hello.cpp. We usually:

```
:wq // quit vim
g++ main.cpp -o hello // compile
./hello // run the executable
```

1.6.2 CMakeLists.txt

With Cmake, we can have:

```
// have cmake installed
```

```
cmake_minimum_required(VERSION 3.10)
set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)
```

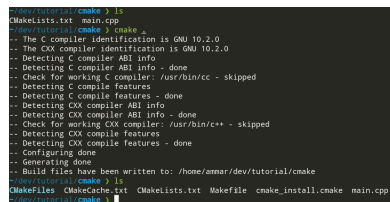
```
project(hello VERSION 1.0)
add_executable(hello main.cpp)
```

Run CMake from the command line, specify a directory.

```
cmake . && make && ./hello
```

1.6.3 Cmake .

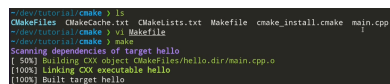
Generates all needed make files (Artifacts).



```
~/dev/tutorial/cmake $ ls
CMakeLists.txt main.cpp
~/dev/tutorial/cmake $ cmake .
-- The C compiler identification is GNU 10.2.0
-- The CXX compiler identification is GNU 10.2.0
-- Detecting C compiler ABI info
-- Detecting C compiler ABI info - done
-- Check for working C compiler: /usr/bin/cc - skipped
-- Detecting C compile features
-- Detecting C compile features - done
-- Detecting CXX compiler ABI info
-- Detecting CXX compiler ABI info - done
-- Check for working CXX compiler: /usr/bin/c++ - skipped
-- Detecting CXX compile features
-- Detecting CXX compile features - done
-- Configuring done
-- Generating done
-- Build files have been written to: /home/amar/dev/tutorial/cmake
~/dev/tutorial/cmake $ ls
CMakeFiles CMakeCache.txt CMakeLists.txt Makefile cmake_install.cmake main.cpp
~/dev/tutorial/cmake $
```

1.6.4 Make

With the MakeFile generated by cmake. Build your binary (the executable) with:



```
~/dev/tutorial/cmake $ ls
CMakeFiles CMakeCache.txt CMakeLists.txt Makefile cmake_install.cmake main.cpp
~/dev/tutorial/cmake $ cat Makefile
~/dev/tutorial/cmake $ make
Scanning dependencies of target hello
[ 50%] Building CXX object CMakeFiles/hello.dir/main.cpp.o
[100%] Linking CXX executable hello
[100%] Built target hello
```

1.6.5 Build folder

```
~/dev/tutorial/cmake $ ls
build CMakeLists.txt main.cpp
~/dev/tutorial/cmake $ cd build
~/dev/tutorial/cmake/build $ ls
~/dev/tutorial/cmake/build $ cmake ..
-- The C compiler identification is GNU 10.2.0
-- The CXX compiler identification is GNU 10.2.0
-- Detecting C compiler ABI info
-- Detecting C compiler ABI info - done
-- Check for working C compiler: /usr/bin/cc - skipped
-- Detecting C compile features
-- Detecting C compile features - done
-- Detecting CXX compiler ABI info
-- Detecting CXX compiler ABI info - done
-- Check for working CXX compiler: /usr/bin/c++ - skipped
-- Detecting CXX compile features
-- Detecting CXX compile features - done
-- Configuring done
-- Generating done
-- Build files have been written to: /home/amar/dev/tutorial/cmake/build
~/dev/tutorial/cmake/build $ ls
CMakeFiles CMakeCache.txt Makefile cmake_install.cmake
~/dev/tutorial/cmake/build $
```

1.6.6 Sick CMake Vim plugins combos

See [codevion/cpp2.md](#)

1.6.7 COC - for code completion in nvim

<https://github.com/neoclide/coc.nvim>
Jason Turner has this too

1.6.8 Include Header File - CMake Continued

```
target_include_directories(hello PUBLIC ${CMAKE_CURRENT_SOURCE_DIR}/include)
```

```
    // Standard is having header files in /include directory!
```

```
hello // our target, where to add the stuff from headers
```

```
PUBLIC // gives the scope of added stuff from headers.
```

```
    // Public, Private or Interface
```

```
    // Usage: when you have cmake library, make sure it is seen by #include in files
```

```
cmake_minimum_required(VERSION 3.10)
```

```
set(CMAKE_CXX_STANDARD 17)
```

```
set(CMAKE_CXX_STANDARD_REQUIRED ON)
```

```
project(hello VERSION 1.0)
```

```
add_executable(hello main.cpp)
```

```
target_include_directories(hello PUBLIC ${CMAKE_CURRENT_SOURCE_DIR}/include)
```

In header file

```
#pragma once
```

```
#include <iostream>
```

```
class Blah {
```

```
    public:
```

```
        inline void boo() {
```

```
            std::cout << "Boo!\n";
```

```
        }
```

```
};
```

1.6.9 Pragma Once

`#pragma once` is a non-standard directive that serves as an include guard. It ensures that a header file is included only once during the compilation process, regardless of how many times it is referenced.

Placed at the beginning of a header file, it acts as a compiler directive to prevent multiple inclusions. Supported by most compilers, including GCC, Clang, and MSVC.

1.6.10 Glob - Include Many files with CMake

You have at least two options. First, include every files one-by-one in the `CMakeList.txt`.

```
cmake_minimum_required(VERSION 3.10)
set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)

project(hello VERSION 1.0) // traditional way to include files
add_executable(hello main.cpp Blah.cpp) // added here
target_include_directories(hello PUBLIC ${CMAKE_CURRENT_SOURCE_DIR}/include)
```

Cmake discourages this glob method, but it is a more sane options for large projects.

```
file(GLOB_RECURSE SRC_FILES src/*.cpp) // glob everything in src/
add_executable(hello ${SRC_FILES})
```

1.6.11 /src Directory - source files

Declaration in the header file **blah.h**.

```
#pragma once

class Blah {
public:
    void boo(); // declaring function boo in header
}
```

Definition (implementation) of class Blah in the source files **blah.cpp**.

```
#include "blah.h"
#include <iostream>

void Blah::boo() {
    std::cout << "Boo!\n"; // defining function boo in src file
}
```

In CMake - Traditionally Added

```
add_executable(hello main.cpp src/Blah.cpp) // added here
```

In CMake - Globing

```
file(GLOB_RECURSE SRC_FILES src/*.cpp)
add_executable(hello main.cpp ${SRC_FILES})
```

1.6.12 CMake Custom Libraries

Create a lib from some source files:

Replace `add_executable` with `add_library`

```
add_library(mylib STATIC lib/blah.cpp) // create a library
                                         // Staticly linked or dynamicly linked
```

Then, include it in your main executable

```
target_link_libraries(hello PUBLIC mylib)
```

1.6.13 Custom Library Implementation - Blah example

```
~/dev/tutorial/cmake y is
Debug blah src CMakeLists.txt compile_commands.json main.cpp
```

```
cmake_minimum_required(VERSION 3.10)
set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)

project(hello VERSION 1.0)

add_library(blah STATIC blah/Blah.cpp)
target_include_directories(blah PUBLIC ${CMAKE_CURRENT_SOURCE_DIR}/blah/include)

// file(GLOB_RECURSE SRC_FILES src/*.cpp)
// now useless, since main.cpp has #include added library

// We are linking our library with our executable directly, with
// target_include_libraries

add_executable(hello main.cpp)
target_link_libraries(hello PUBLIC blah)
```

The target link generates a `libblah.a`

```
cmake --build Debug
Scanning dependencies of target blah
[ 25%] Building CXX object CMakeFiles/blah.dir/blah/Blah.cpp.o
[ 50%] Linking CXX static library libblah.a
[ 50%] Built target blah
Scanning dependencies of target hello
[ 75%] Building CXX object CMakeFiles/hello.dir/main.cpp.o
[100%] Linking CXX executable hello
[100%] Built target hello
```

1.7 Jason Turner's CMake Template - Options

```
include(cmake/SystemLink.cmake)
include(cmake/LibFuzzer.cmake)
include(CMakeDependentOption)
include(CheckCXXCompilerFlag)
```

```

macro(myproject_supports_sanitizers)
    if((CMAKE_CXX_COMPILER_ID MATCHES ".*Clang.*" OR CMAKE_CXX_COMPILER_ID MATCHES ".*GNU.*") AND NOT WIN32)
        set(SUPPORTS_UBSAN ON)
    else()
        set(SUPPORTS_UBSAN OFF)
    endif()

    if((CMAKE_CXX_COMPILER_ID MATCHES ".*Clang.*" OR CMAKE_CXX_COMPILER_ID MATCHES ".*GNU.*") AND WIN32)
        set(SUPPORTS_ASAN OFF)
    else()
        set(SUPPORTS_ASAN ON)
    endif()
endmacro()

macro(myproject_setup_options)
    option(myproject_ENABLE_HARDENING "Enable hardening" ON)
    option(myproject_ENABLE_COVERAGE "Enable coverage reporting" OFF)
    cmake_dependent_option(
        myproject_ENABLE_GLOBAL_HARDENING
        "Attempt to push hardening options to built dependencies"
        ON
        myproject_ENABLE_HARDENING
        OFF)

    myproject_supports_sanitizers()

    if(NOT PROJECT_IS_TOP_LEVEL OR myproject_PACKAGING_MAINTAINER_MODE)
        option(myproject_ENABLE_IPO "Enable IPO/LTO" OFF)
        option(myproject_WARNINGS_AS_ERRORS "Treat Warnings As Errors" OFF)
        option(myproject_ENABLE_USER_LINKER "Enable user-selected linker" OFF)
        option(myproject_ENABLE_SANITIZER_ADDRESS "Enable address sanitizer" OFF)
        option(myproject_ENABLE_SANITIZER_LEAK "Enable leak sanitizer" OFF)
        option(myproject_ENABLE_SANITIZER_UNDEFINED "Enable undefined sanitizer" OFF)
        option(myproject_ENABLE_SANITIZER_THREAD "Enable thread sanitizer" OFF)
        option(myproject_ENABLE_SANITIZER_MEMORY "Enable memory sanitizer" OFF)
        option(myproject_ENABLE_UNITY_BUILD "Enable unity builds" OFF)
        option(myproject_ENABLE_CLANG_TIDY "Enable clang-tidy" OFF)
        option(myproject_ENABLE_CPPCHECK "Enable cpp-check analysis" OFF)
        option(myproject_ENABLE_PCH "Enable precompiled headers" OFF)
        option(myproject_ENABLE_CACHE "Enable ccache" OFF)
    else()
        option(myproject_ENABLE_IPO "Enable IPO/LTO" ON)
        option(myproject_WARNINGS_AS_ERRORS "Treat Warnings As Errors" ON)
        option(myproject_ENABLE_USER_LINKER "Enable user-selected linker" OFF)
        option(myproject_ENABLE_SANITIZER_ADDRESS "Enable address sanitizer" ${SUPPORTS_ASAN})
        option(myproject_ENABLE_SANITIZER_LEAK "Enable leak sanitizer" OFF)
        option(myproject_ENABLE_SANITIZER_UNDEFINED "Enable undefined sanitizer" ${SUPPORTS_UBSAN})
        option(myproject_ENABLE_SANITIZER_THREAD "Enable thread sanitizer" OFF)
        option(myproject_ENABLE_SANITIZER_MEMORY "Enable memory sanitizer" OFF)
        option(myproject_ENABLE_UNITY_BUILD "Enable unity builds" OFF)
    endif()
endmacro()

```

```

    option(myproject_ENABLE_CLANG_TIDY "Enable clang-tidy" ON)
    option(myproject_ENABLE_CPPCHECK "Enable cpp-check analysis" ON)
    option(myproject_ENABLE_PCH "Enable precompiled headers" OFF)
    option(myproject_ENABLE_CACHE "Enable ccache" ON)
endif()

if(NOT PROJECT_IS_TOP_LEVEL)
    mark_as_advanced(
        myproject_ENABLE_IPO
        myproject_WARNINGS_AS_ERRORS
        myproject_ENABLE_USER_LINKER
        myproject_ENABLE_SANITIZER_ADDRESS
        myproject_ENABLE_SANITIZER_LEAK
        myproject_ENABLE_SANITIZER_UNDEFINED
        myproject_ENABLE_SANITIZER_THREAD
        myproject_ENABLE_SANITIZER_MEMORY
        myproject_ENABLE_UNITY_BUILD
        myproject_ENABLE_CLANG_TIDY
        myproject_ENABLE_CPPCHECK
        myproject_ENABLE_COVERAGE
        myproject_ENABLE_PCH
        myproject_ENABLE_CACHE)
endif()

myproject_check_libfuzzer_support(LIBFUZZER_SUPPORTED)
if(LIBFUZZER_SUPPORTED AND (myproject_ENABLE_SANITIZER_ADDRESS OR myproject_ENABLE_SANITIZER_THREAD))
    set(DEFAULT_FUZZER ON)
else()
    set(DEFAULT_FUZZER OFF)
endif()

option(myproject_BUILD_FUZZ_TESTS "Enable fuzz testing executable" ${DEFAULT_FUZZER})

endmacro()

macro(myproject_global_options)
    if(myproject_ENABLE_IPO)
        include(cmake/InterproceduralOptimization.cmake)
        myproject_enable_ipo()
    endif()

    myproject_supports_sanitizers()

    if(myproject_ENABLE_HARDENING AND myproject_ENABLE_GLOBAL_HARDENING)
        include(cmake/Hardening.cmake)
        if(NOT SUPPORTS_UBSAN
            OR myproject_ENABLE_SANITIZER_UNDEFINED
            OR myproject_ENABLE_SANITIZER_ADDRESS
            OR myproject_ENABLE_SANITIZER_THREAD
            OR myproject_ENABLE_SANITIZER_LEAK)
            set(ENABLE_UBSAN_MINIMAL_RUNTIME FALSE)
        endif()
    endif()
endmacro()

```

```

    else()
        set(ENABLE_UBSAN_MINIMAL_RUNTIME TRUE)
    endif()
    message("${myproject_ENABLE_HARDENING} ${ENABLE_UBSAN_MINIMAL_RUNTIME} ${myproject_ENABLE_SANITIZERS}")
    myproject_enable_hardening(myproject_options ON ${ENABLE_UBSAN_MINIMAL_RUNTIME})
endif()
endmacro()

macro(myproject_local_options)
    if(PROJECT_IS_TOP_LEVEL)
        include(cmake/StandardProjectSettings.cmake)
    endif()

    add_library(myproject_warnings INTERFACE)
    add_library(myproject_options INTERFACE)

    include(cmake/CompilerWarnings.cmake)
    myproject_set_project_warnings(
        myproject_warnings
        ${myproject_WARNINGS_AS_ERRORS}
        ""
        ""
        ""
        "")

    if(myproject_ENABLE_USER_LINKER)
        include(cmake/Linker.cmake)
        configure_linker(myproject_options)
    endif()

    include(cmake/Sanitizers.cmake)
    myproject_enable_sanitizers(
        myproject_options
        ${myproject_ENABLE_SANITIZER_ADDRESS}
        ${myproject_ENABLE_SANITIZER_LEAK}
        ${myproject_ENABLE_SANITIZER_UNDEFINED}
        ${myproject_ENABLE_SANITIZER_THREAD}
        ${myproject_ENABLE_SANITIZER_MEMORY})

    set_target_properties(myproject_options PROPERTIES UNITY_BUILD ${myproject_ENABLE_UNITY_BUILD})

    if(myproject_ENABLE_PCH)
        target_precompile_headers(
            myproject_options
            INTERFACE
            <vector>
            <string>
            <utility>)
    endif()

    if(myproject_ENABLE_CACHE)

```



```

    include(cmake/Cache.cmake)
    myproject_enable_cache()
endif()

include(cmake/StaticAnalyzers.cmake)
if(myproject_ENABLE_CLANG_TIDY)
    myproject_enable_clang_tidy(myproject_options ${myproject_WARNINGS_AS_ERRORS})
endif()

if(myproject_ENABLE_CPPCHECK)
    myproject_enable_cppcheck(${myproject_WARNINGS_AS_ERRORS} "" # override cppcheck options
    )
endif()

if(myproject_ENABLE_COVERAGE)
    include(cmake/Tests.cmake)
    myproject_enable_coverage(myproject_options)
endif()

if(myproject_WARNINGS_AS_ERRORS)
    check_cxx_compiler_flag("-Wl,--fatal-warnings" LINKER_FATAL_WARNINGS)
    if(LINKER_FATAL_WARNINGS)
        # This is not working consistently, so disabling for now
        # target_link_options(myproject_options INTERFACE -Wl,--fatal-warnings)
    endif()
endif()

if(myproject_ENABLE_HARDENING AND NOT myproject_ENABLE_GLOBAL_HARDENING)
    include(cmake/Hardening.cmake)
    if(NOT SUPPORTS_UBSAN
        OR myproject_ENABLE_SANITIZER_UNDEFINED
        OR myproject_ENABLE_SANITIZER_ADDRESS
        OR myproject_ENABLE_SANITIZER_THREAD
        OR myproject_ENABLE_SANITIZER_LEAK)
        set(ENABLE_UBSAN_MINIMAL_RUNTIME FALSE)
    else()
        set(ENABLE_UBSAN_MINIMAL_RUNTIME TRUE)
    endif()
    myproject_enable_hardenig(myproject_options OFF ${ENABLE_UBSAN_MINIMAL_RUNTIME})
endif()

endmacro()

```

1.7.1 CPM (C++ package manager)

A nice section to expand on later.

1.8 Project Software Toolkit

Doxygen - create html documentation based on your codebase
Conan/VCPKG Packaging - How to install and use external libraries
Unit Testing
Code Coverage
CI Testing -- use all these tools in continuous integration, Github actions

We'll see how to create an html documentation based on your codebase

1.9 Installation Commands

```
sudo apt-get update
sudo apt-get upgrade
```

Mandatory

```
sudo apt-get install gcc g++ gdb
sudo apt-get install make cmake
sudo apt-get install git
sudo apt-get install doxygen
sudo apt-get install python3 python3-pip
```

Optional

```
sudo apt-get install lcov gcovr
sudo apt-get install ccache
sudo apt-get install cppcheck
sudo apt-get install llvm clang-format clang-tidy
sudo apt-get install curl zip unzip tar
```

for VSCODE

in extension, download franneck94 c/c++ extension pack

And the coding tools extension pack

Then, with command palette (in view), Config: generate C config file. It configures all tools the same as the teacher's

1.10 Command Line Options

1.10.1 Generating a Project

```
cmake [<options>] -S <path-to-source> -B <path-to-build>
```

Assuming that a CMakeLists.txt is in the root directory, you can generate a project like the following.

```
mkdir build
cd build
cmake -S .. -B . # Option 1
cmake .. # Option 2
```

Assuming that you have already built the CMake project, you can update the generated project.

```
cd build
cmake .
```

1.10.2 Generator for GCC and Clang

```
cd build
cmake -S .. -B . -G "Unix Makefiles" # Option 1
cmake .. -G "Unix Makefiles" # Option 2
```

1.10.3 Generator for MSVC

```
cd build
cmake -S .. -B . -G "Visual Studio 16 2019" # Option 1
cmake .. -G "Visual Studio 16 2019" # Option 2
```

1.10.4 Specify the Build Type

Per default, the standard type is in most cases the debug type. If you want to generate the project, for example, in release mode you have to set the build type.

```
cd build
cmake -DCMAKE_BUILD_TYPE=Release ..
```

1.10.5 Passing Options

If you have set some options in the CMakeLists, you can pass values in the command line.

```
cd build
cmake -DMY_OPTION=[ON|OFF] ..
```

1.10.6 Specify the Build Target (Option 1)

The standard build command would build all created targets within the CMakeLists. If you want to build a specific target, you can do so.

```
cd build
cmake --build . --target ExternalLibraries_Executable
```

The target `ExternalLibraries.Executable` is just an example of a possible target name. Note: All dependent targets will be built beforehand.

1.10.7 Specify the Build Target (Option 2)

Besides setting the target within the `cmake build` command, you could also run the previously generated Makefile (from the generating step). If you want to build the `ExternalLibraries_Executable`, you could do the following.

```
cd build
make ExternalLibraries_Executable
```

1.11 Run the Executable

After generating the project and building a specific target you might want to run the executable. In the default case, the executable is stored in `build/5_ExternalLibraries/app/ExternalLibraries_Executable`, assuming that you are building the project `5_ExternalLibraries` and the main file of the executable is in the `app` dir.

```
cd build
./bin/ExternalLibraries_Executable
```

1.11.1 Different Linking Types

```
add_library(A ...)
add_library(B ...)
add_library(C ...)
```

1.11.2 Public

```
target_link_libraries(A PUBLIC B)
target_link_libraries(C PUBLIC A)
```

When A links in B as PUBLIC, it says that A uses B in its implementation, and B is also used in A's public API. Hence, C can use B since it is part of the public API of A.

1.11.3 Private

```
target_link_libraries(A PRIVATE B)
target_link_libraries(C PRIVATE A)
```

When A links in B as PRIVATE, it is saying that A uses B in its implementation, but B is not used in any part of A's public API. Any code that makes calls into A would not need to refer directly to anything from B.

1.11.4 Interface

```
add_library(D INTERFACE)
target_include_directories(D INTERFACE {CMAKE_CURRENT_SOURCE_DIR}/include)
```

In general, used for header-only libraries.

1.12 Different Library Types

1.12.1 Library

A binary file that contains information about code. A library cannot be executed on its own. An application utilizes a library.

A library must be build too, if it is used by an executable.

```
cmake --build . --target Library
```

```
cmake --build . --target Executable // it is dependent to the Library build!
```

1.12.2 Shared

Linux: *.so

MacOS: *.dylib

Windows: *.dll

Shared libraries reduce the amount of code that is duplicated in each program that makes use of the library, keeping the binaries small. Shared libraries will however have a small additional cost for the execution. In general the shared library is in the same directory as the executable.

1.12.3 Static

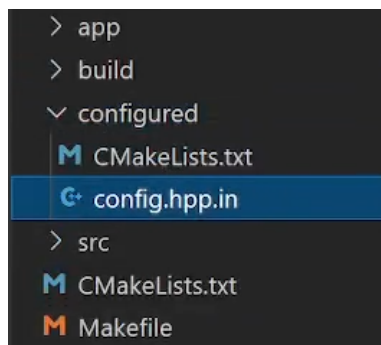
Linux/MacOS: *.a

Windows: *.lib

Static libraries increase the overall size of the binary, but it means that you don't need to carry along a copy of the library that is being used. As the code is connected at compile time there are not any additional run-time loading costs.

1.13 Configuration - Precompiling Information

Create a configuration directory. With a config.hpp.in file.



In the CMakeLists.txt of this new configured directory.

```
configure_file(  
    "config.hpp.in"
```

```
# "${CMAKE_BINARY_DIR}" this is our build directory
# it is one of prebuilt directories in CMAKE
# thus, we reference it with CMAKE_BINARY_DIR
# we create an output for a config file,
# in our build directory.

# "${PROJECT_SOURCE_DIR}" # stores absolute path to project's root directory

"${CMAKE_BINARY_DIR}/configured_files/include/config.hpp" ESCAPE_QUOTES
```

1.13.1 Project Version Number

In config.hpp.in

```
# @ cmake looks for and replaces text between @@ this text @

#include <cstdint>
#include <string_view>
static constexpr std::string_view project_name = "@PROJECT_NAME@";
static constexpr std::string_view project_version = "@PROJECT_VERSION@";
```

1.13.2 Semantic Versioning

In version names: 1.0.0 . This is the first Major version (1). Incrementing the major version means that the previous and the new codebase are not compatible at all. 2.0.0 have breaking changes with the 1.0.0 version.

The minor version 1.6.0, number 6 here, indicate that new features are available. Yet, nothing breaks between minor versions.

The patches are the last number, the last small fixes.

```
static constexpr std::int32_t project_version_major{@PROJECT_VERSION_MAJOR@};
static constexpr std::int32_t project_version_minor{@PROJECT_VERSION_MINOR@};
static constexpr std::int32_t project_version_patch{@PROJECT_VERSION_PATCH@};
```

Resulting file looks like.

```
#pragma once

#include <cstdint>
#include <string_view>

static constexpr std::string_view project_name = "CppProjectTemplate";
static constexpr std::string_view project_version = "1.0.0";

static constexpr std::int32_t project_version_major{1};
static constexpr std::int32_t project_version_minor{0};
static constexpr std::int32_t project_version_patch{0};
```

1.14 Sources and Headers

When you have many libraries and many headers, create a variable for all of your headers. Then, reference this variable to include everything. List all of your source files in my_lib directory.

```
set(LIBRARY_SOURCES
    "my_lib.cpp"
    "my_lib2.cpp"
    ) # quotes are not mandatory, just preference.
set(LIBRARY_HEADERS
    "my_lib.h")

add_library(${LIBRARY_NAME} STATIC
    "./"
    "${CMAKE_BINARY_DIR}/configured_files/include")
```

1.14.1 Executables

You can do the same thing if you generate many executables, I think. This would be in your app directory.

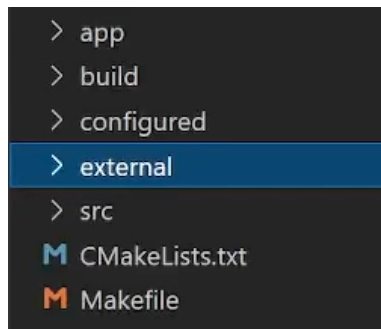
```
set(EXE_SOURCES
    "main.cpp")

add_executable(${EXECUTABLE_NAME} ${EXE_SOURCES})
target_link_libraries(${EXECUTABLE_NAME} PUBLIC ${LIBRARY_NAME})
```

1.15 Using External Libraries

1.15.1 Git Submodule - nlohman/json

Create an external directory. Our project looks like this:



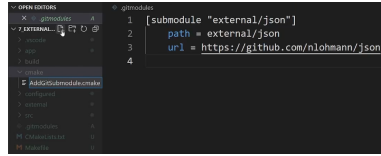
```
// make sure that your root folder is a git repo, git init

git submodule add https://github.com/nlohmann/json external/json

// it creates the json directory, when cloning the module in it.
```

1.15.2 Custom Cmake Functions

In a cpp project, when you create your own cmake functions, they are stored in a Cmake directory. We just cloned a git repo in our external directory.



Now we create a AddGitSubmodule.cmake file. Inside, we define our function.

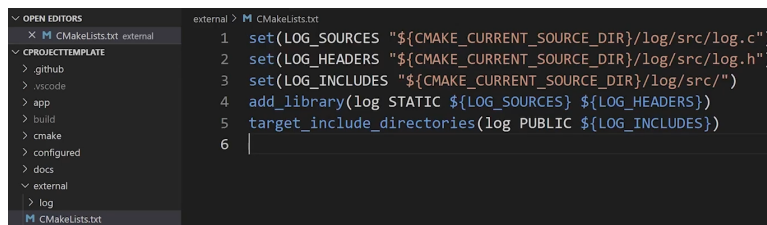
```
function(add_git_submodule dir) # our function takes one argument called dir
                                # this dir, is where the submodule is located
                                # making the add_ action possible.
    find_package(Git REQUIRED) # Git must be on your computer, or it
                                # Error's out.
    if (NOT EXISTS ${dir}/CMakeLists.txt)
        execute_process (COMMAND ${GIT_EXECUTABLE}
                        submodule update --init --recursive -- ${dir}
                                # recursive is essential here
                                # If someone clones your project,
                                # It automatically clones this submodules,
                                # It clones auto repos, inside your repo.

                                WORKING_DIRECTORY ${PROJECT_SOURCE_DIR}) # cmake saves some variable
                                # including the source dir
                                # of our project.
    endif()

    if (EXISTS ${dir}/CMakeLists.txt)
        message("Adding ${dir}/CMakeLists.txt")
        add_subdirectory(${dir})
    else
        message("Could not add ${dir}/CMakeLists.txt")
    endif()
endfunction(add_git_submodule)
```

1.15.3 Log example

Here we are using an external library called log, with only two files, log.c and log.h . We have the library in our external directory. Plus, we have a CMakeLists.txt at the root of the external folder, taking care of the log library.



1.15.4 Call Your Own Functions

In the source CMakeFiles.txt, knowing that we have a new git submodule. We add:

```
set(CMAKE_MODULE_PATH "${PROJECT_SOURCE_DIR}/cmake")
include(AddGitSubmodule) # includes indicates that it is a cmake module file.
                          # it will look where cmake modules are defined
                          # in our cmake dir

add_git_submodule(external/json) # this calls our custom function.

# In our app, we add this as well

set(EXE_SOURCES
    "main.cpp")

add_executable(${EXECUTABLE_NAME} ${EXE_SOURCES})
target_link_libraries(${EXECUTABLE_NAME} PUBLIC
    ${LIBRARY_NAME}
    nlohmann_json) # this links the submodule with the executable

# In main.cpp, we add

#include <nlohmann/json.hpp>
```

1.15.5 Fetch Content - External Libraries

We have the gitmodule example, but modern CMake has a great fetching feature. Our root CMakeLists.txt will look like this,

```
...

set(CMAKE_MODULE_PATH "${PROJECT_SOURCE_DIR}/cmake/")
include(AddGitSubmodule)

include(FetchContent) # built-in library or file
                      # including it gives access to features

FetchContent_Declare() # Declare which github repository we would like to use
FetchContent_MakeAvailable() # will load this library in our cmake project.

                          # I want to use github.com/nlohmann/json
                          # any Gitlab is also possible
                          # I can do:
FetchContent_Declare(
```

```

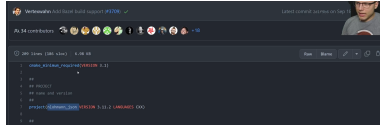
nlohmann_json      # since this repo is a cmake project,
                   # look at the project's root CMakeLists.txt file
                   # you will find the name of the project, to enter here
                   # see next image

GIT_REPOSITORY https://github.com/nlohmann/json
GIT_TAG v3.11.2    # the version I want to use
GIT_SHALLOW TRUE) # The function won't clone the repo recursively

# With this function, the git repository will be cloned in
# our cloned repository.
# And it needs to be a cmake project.

# if it is not a cmake project, use the AddGitSubmodule method shown.
FetchContent_MakeAvailable(nlohmann_json) # will load this library in our cmake project.

```



1.15.6 FMT

The best library to easily format strings in cpp.

```

FetchContent_Declare(
    fmt
    GIT_REPOSITORY https://github.com/fmtlib/fmt
    GIT_TAG 9.1.0
    GIT_SHALLOW TRUE)
FetchContent_MakeAvailable(fmt)

```

1.15.7 spdlog

The best fast logging library for cpp.

```

FetchContent_Declare(
    spdlog
    GIT_REPOSITORY https://github.com/gabime/spdlog
    GIT_TAG v1.11.0
    GIT_SHALLOW TRUE)
FetchContent_MakeAvailable(spdlog)

```

1.15.8 Cxxopts

The best library to work with command line arguments in cpp. From the received arguments, to any other type. The equivalent of the argument parser in python.

```

FetchContent_Declare(
    cxxopts
    GIT_REPOSITORY https://github.com/jaroo2783/cxxopts

```

```

GIT_TAG v3.0.0
GIT_SHALLOW TRUE)
FetchContent_MakeAvailable(cxxopts)

```

1.15.9 Catch2

The best Unit Testing library, seen further below.

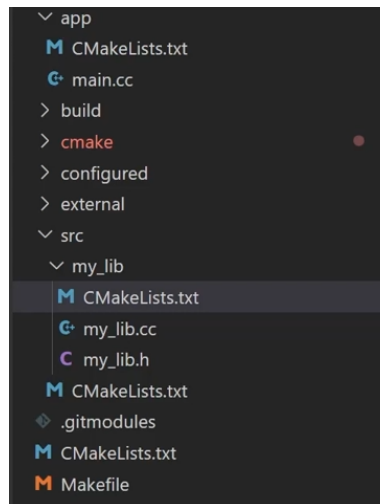
```

FetchContent_Declare(
    catch2
    GIT_REPOSITORY https://github.com/catchorg/Catch2
    GIT_TAG v2.13.9 # teacher recommended this version, not the latest.
    GIT_SHALLOW TRUE)
FetchContent_MakeAvailable(catch2)

```

1.15.10 Include All Libraries in root CMakeListstxt

Refer to Final project Template seen in the course. Modifying the CMakeLists.txt in our my-lib directory.



```

set(LIBRARY_SOURCES
    "my_lib.cpp")
set(LIBRARY_HEADERS
    "my_lib.h")
set(LIBRARY_INCLUDES
    "."
    "${CMAKE_BINARY_DIR}/configured_files/include")

add_library(${LIBA} STATIC
    ${LIBRARY_SOURCES}
    ${LIBRARY_HEADERS})
target_include_directories(${LIBA} PUBLIC
    ${LIBRARY_INCLUDES})
target_link_libraries(${LIBA} PUBLIC

```

```

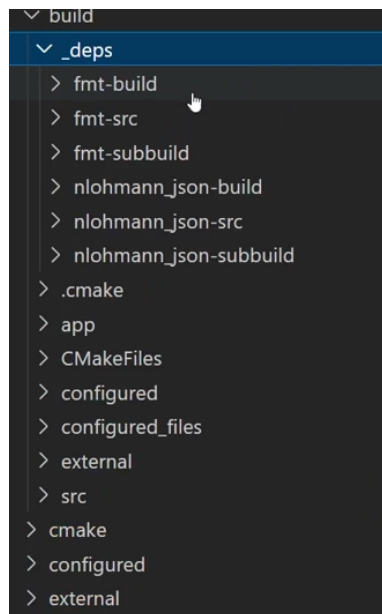
# Naming convention is project_name::library_name
# see next image, to find library_name in CMake project
# on github

nlohmann_json::nlohmann_json
fmt::fmt
spdlog::spdlog
catch2::catch2
cxxopts::cxxopts          # not always the same

)

```

When this is set-up, and we reconfigure our cmake project, the repository will be cloned in a `.deps` directory. This includes a build, subbuild and src directory for all dependencies. Don't worry about it for now.



1.15.11 Include all Libraries in App Main.cpp

It is tricky to include the libraries files in main. Some have directories, some do not.

```

#include <iostream>

#include <cxxopts.hpp>
#include <nlohman/json.hpp>
#include <fmt/format.h>
#include <spdlog/spdlog.h>
#include <catch2>

#include "my_lib.h"
#include "config.hpp"

int main() {

```

```

...
std::cout << "CXXOPTS: # chose any included lib, to prove you have access to their info

<< CXXOPTS__VERSION_MAJOR << "."
<< CXXOPTS__VERSION_MINOR << "."
<< CXXOPTS__VERSION_PATCH << "." # if you have access to these variable,
                                # you have successfully imported and configure the lib
                                # for you project.

...
}

```

1.15.12 Git Submodules vs Fetch Content

If the repo is not a CMakeProject, you should use Git Submodules. Valid for GitHub and GitLab. In this case, define its own library target, I think. Not explained in detail.

If it is a CMake project on GitHub or Gitlab, use FetchContent. It is easier to use, you don't need to mess with header libraries or anything. We can simply use the makeAvailable and prepare function.

The instructor highly recommends FetchContent!

1.15.13 CPM - C Package Manager

1.15.14 Conan

1.15.15 VCPKG

1.16 Dependency Graphs

In a makefile, or any script, use the command `-graphviz`. Dependency and prepare are the flag needed to run the command.

```

dependency:
    cd build && cmake .. --graphviz=grap.dot && dot -Tpng graph.dot -o grapImage.png
                                // not yet an image when .dot
                                // but easy to transform

prepare:
    rm -rf build
    mkdir build

                                // unrelated to dependency graph.

```

The house symbol is the executable. Rectangle are external libraries. Losanges shapes are internal libraries.


```

# Configuration for Doxygen for use with CMake
# Only options that deviate from the default are included
# To create a new Doxyfile containing all available options, call 'doxygen -g'

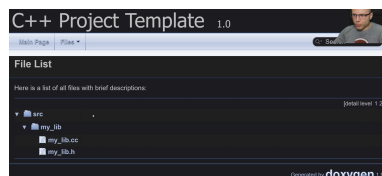
#-----
# Project related configuration options
#-----
DOXYFILE_ENCODING      = UTF-8
PROJECT_NAME           = "C++ Project Template"
PROJECT_NUMBER         = 1.0
PROJECT_BRIEF          =
PROJECT_LOGO           =
OUTPUT_DIRECTORY      = ./
OUTPUT_LANGUAGE        = English
MARKDOWN_SUPPORT       = YES

#-----
# Build related configuration options
#-----
EXTRACT_ALL            = YES
RECURSIVE              = YES
GENERATE_HTML          = YES
GENERATE_LATEX         = NO

#-----
# Configuration options related to the input files
#-----
INPUT                  = ../src \
INPUT                  = ../include
INPUT_ENCODING         = UTF-8
FILE_PATTERNS          = *.c \
                        *.cc \
                        *.cpp \
                        *.c++ \
                        *.h \
                        *.hpp \
                        *.h++ \
                        *.md \
                        *.dox \
                        *.doc \
                        *.txt

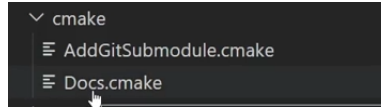
```

When ready, generate the html with the command Doxygen, inside the docs folder (where the doxyfile is located). It creates an html dir. it has the index.html automatically. The webpage looks like this:



1.17.3 Document Custom Target

We need to add the documentation to our cmake project.



In our root CMakeLists.txt, we add.

```
include(AddGitSubmodule)
include(FetchContent)
include(Docs)                # this is our new dir.
```

1.17.4 Doc.cmake

Cmake needs to find Doxygen, because we are using it for our docs. In Docs.cmake,

```
find_package(Doxygen)
if (DOXYGEN_FOUND)
    add_custom_target( # This is just an utility target
                      # With it, we can interact with it,
                      # in the terminal

    docs
    ${DOXYGEN_EXECUTABLE}
    WORKING_DIRECTORY ${CMAKE_SOURCE_DIR}/docs

                      # CMAKE_SOURCE_DIR is always the directory of the
                      # root CMakeLists.txt file
                      # our root directory

                      # CMAKE_BINARY_DIR is always our build directory

endif()
```

Now Documentation can be built separately, independently of the main project app built process.

1.18 Catch2 - Unit Testing

1.18.1 Function testing example

Adding Unit test to our codebase, with the catch2 library. Unit tests are useful to test functions from the library.

There is a tutorial on the github catch2 page. As an example, it provides this factorial function example, to try.

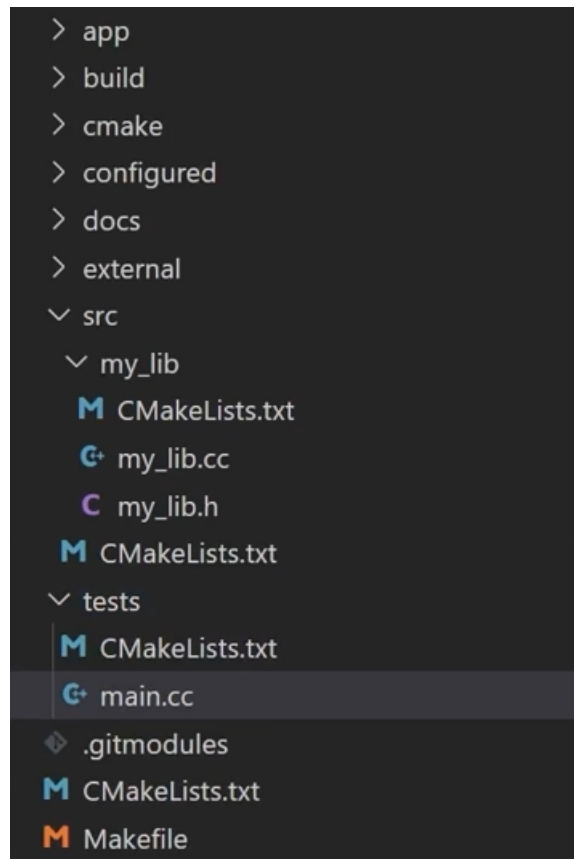
```
unsigned int factorial( unsigned int number ) {
    return number <= 1 ? number : factorial(number-1)*number;
}
```

// the instructor changes it to


```
std::uint32_t factorial(std::uint32_t number)
{
    return number <= 1 ? number : factorial(number-1) * number;
}
```

1.18.2 Test Directory

To introduce unit testing, we create a new directory: tests.



In our root CMakeLists.txt.

```
add_subdirectory(configured)
add_subdirectory(external)
add_subdirectory(src)
add_subdirectory(app)
add_subdirectory(tests) # adding tests
```

The idea is to have our main executable, our library(lib) and our unit test executable. The main and the Unit executable we'll both use our library, but we will test with Unit. Unit will test if all our implemented functions work without bugs.

1.18.3 Tests Set-up, CMakeLists.txt

```
set(TEST_MAIN "unit_tests")      # this is the name of our testing executable
set(TEST_SOURCES "main.cpp")     # Here, the tests are in one file only
                                # It could be divided into more files
                                # Header files for example

set(TEST_INCLUDES "./")
add_executable(${TEST_MAIN} ${TEST_SOURCES})
target_include_directories(${TEST_MAIN} PUBLIC ${TEST_INCLUDES})
target_link_libraries(${TEST_MAIN} PUBLIC ${LIBA} Catch2::Catch2)

                                # Our library is linked, LIBA
                                # This is how we will test it
```

1.18.4 Defining Tests

To test the factorial function, this is the test definition given as example.

```
#define CATCH_CONFIG_MAIN // This tells Catch to provide a main() - only do this in one file
                          // No need to write int main() {}, this does it.
#include "catch2/catch.hpp"

#include "my_lib.h"        // Will be called in my_lib.h

TEST_CASE( "Factorials are computed", "[factorial]" ) {
    REQUIRE( Factorial(1) == 1);
    REQUIRE( Factorial(2) == 2);
    REQUIRE( Factorial(3) == 6);
    REQUIRE( Factorial(10) == 362880 );
}
```

This function needs to be called in my_lib.h

```
std::uint32_t factorial(std::uint32_t number);
```

1.18.5 Command Line Testing Option

It is convenient to have a command line option to activate or deactivate our testing build. In our root CMakeLists.txt file, we add an option. In our CMakeLists.txt in the tests directory, we add an if statement.

```
option(ENABLE_TESTING "Enable a Unit Testing Build" ON)
```

```
# in tests directory's CMakeLists.txt
```

```
if (ENABLE_TESTING)
    set(TEST_MAIN "unit_tests")
    set(TEST_SOURCES "main.cpp")
    set(TEST_INCLUDES "./")

    add_executable(${TEST_MAIN} ${TEST_SOURCES})
```

```
    target_include_directories(${TEST_MAIN} PUBLIC ${TEST_INCLUDES})
    target_link_libraries(${TEST_MAIN} PUBLIC ${LIBA} Catch2::Catch2)
endfi()
```

1.18.6 On Testing Libraries in General

The specific words (Test_case, require, etc.) may vary a bit, but they all have the same logic. When you are familiar with one, you will be able to use another testing library.

You have a test case,

```
TEST_CASE()
```

You can give it a name and a short-name(abbreviated)

```
TEST_CASE( "Factorials are computed", "[factorial]" )
```

you can test a function with a keyword like require, or require_equal. Giving an input, the result should be 0

```
REQUIRE( factorial(0) == 0)
```

1.19 Public, Interface and Private

1.20 Adding Compiler Warnings

1.21 Sanitizers

1.22 IPO LTO

1.22.1 IPO LTO in CMake