Modern C++ for Computer Vision and Image Processing

Lecture 1: Build and Tools

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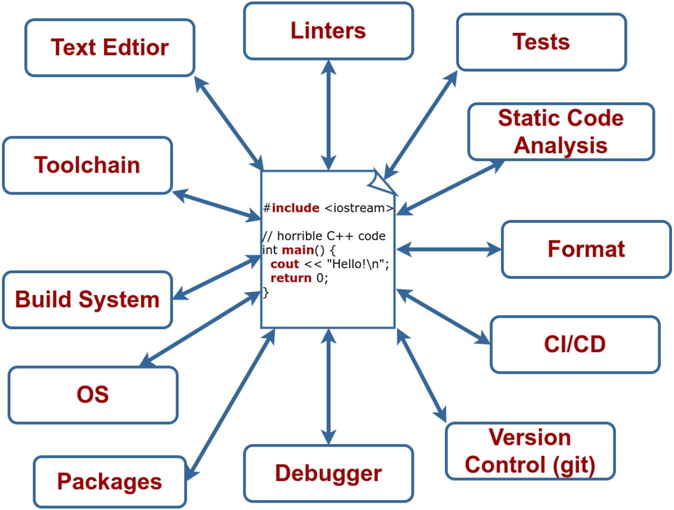
SW dev ecosystem

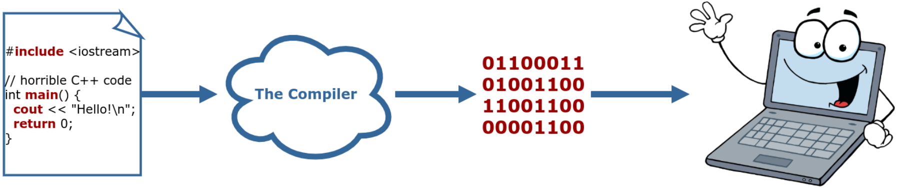


The compilation process

What is a compiler?

- A compiler is basically... a program.
- But not any program.
- Is in charge on transforming your horrible source code into binary code.
- Binary code, `0100010001`, is the language that a computer can understand.

What is a compiler?



Compilation made easy

The easiest compile command possible:

- `clang++ main.cpp`
- This will build a program called `a.out` that it's ready to run.

Will be always this easy?

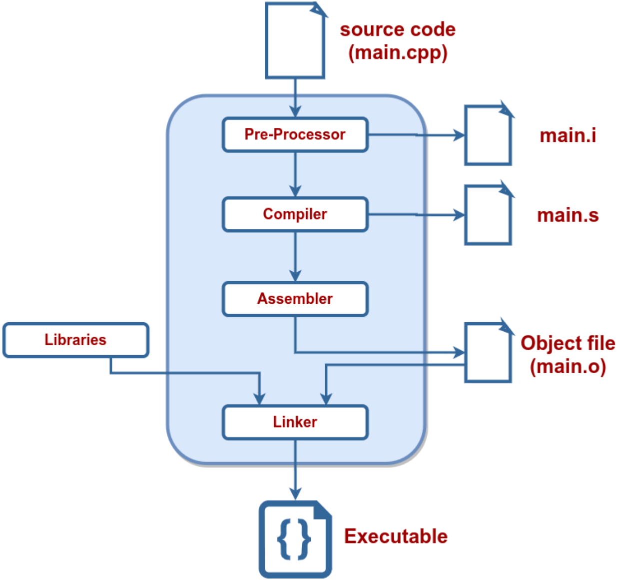
- Of course, not.

The Compiler: Behind the scenes

The compiler performs 4 distinct actions to build your code:

1. Pre-process
2. Compile
3. Assembly
4. Link

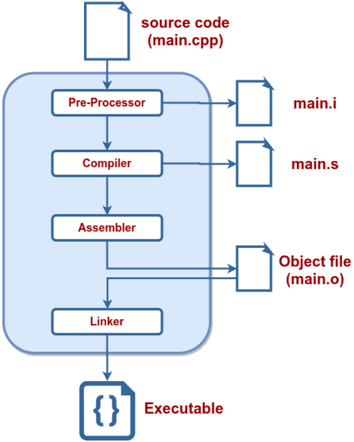
The Compiler: Behind the scenes



Compiling step-by-step

1. Preprocess:

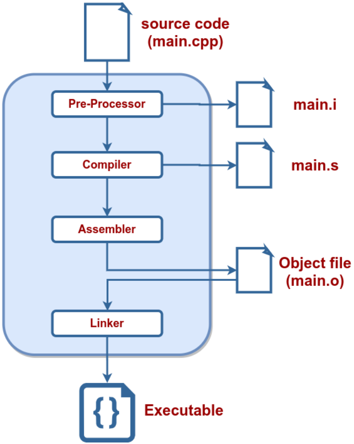
- `clang++ -E main.cpp > main.i`



Compiling step-by-step

2. Compilation:

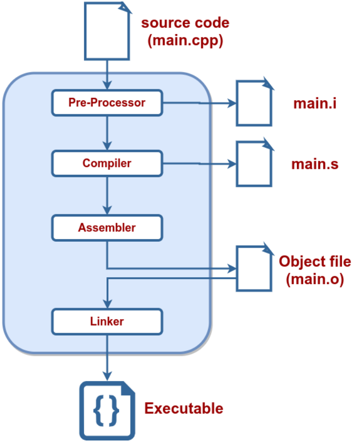
- `clang++ -S main.i`



Compiling step-by-step

3. Assembly:

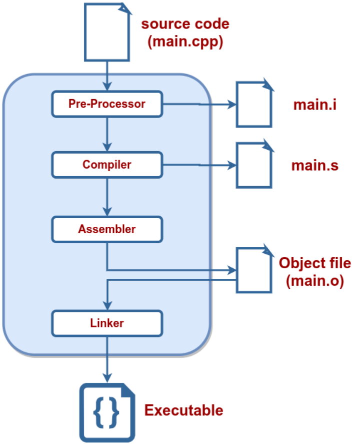
- `clang++ -c main.s`



Compiling step-by-step

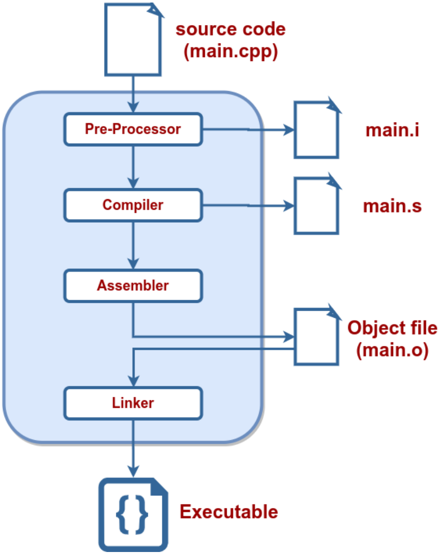
4. Linking:

- `clang++ main.o -o main`



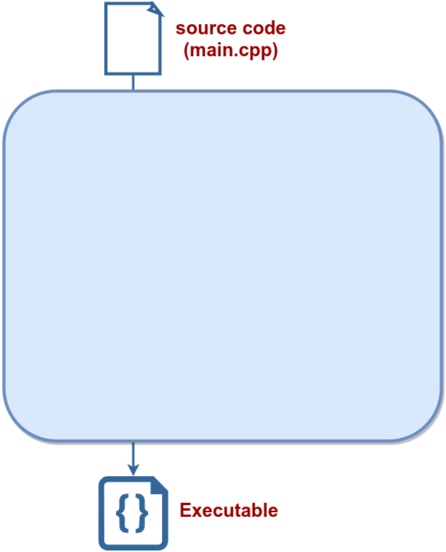
Compiling recap

1. `clang++ -E main.cpp`
2. `clang++ -S main.i`
3. `clang++ -c main.s`
4. `clang++ main.o`



Compiling recap

1. `clang++ main.cpp`



Compilation flags

- There is a lot of flags that can be passed while compiling the code
- We have seen some already: `-std=c++17`, `-o`, etc.

Other useful options:

- Enable all warnings, treat them as errors: `-Wall`, `-Wextra`, `-Werror`
- Optimization options:
  - `-O0` — no optimizations **[default]**
  - `-O3` or `-Ofast` — full optimizations
- Keep debugging symbols: `-g`

Play with them with Compiler Explorer: `https://godbolt.org/`

Libraries

What is a Library

- Collection of symbols.
- Collection of function implementations.

Libraries

- **Library:** multiple object files that are logically connected
- Types of libraries:
  - **Static:** faster, take a lot of space, become part of the end binary, named: `lib*.a`
  - **Dynamic:** slower, can be copied, referenced by a program, named `lib*.so`
- Create a static library with

  `ar rcs libname.a module.o module.o …`
- Static libraries are just archives just like `zip/tar/…`

Declaration and definition

- Function declaration can be separated from the implementation details
- Function **declaration** sets up an interface

```cpp
void FuncName(int param);
```

- Function **definition** holds the implementation of the function that can even be hidden from the user

```cpp
void FuncName(int param) {
  // Implementation details.
  cout << "This function is called FuncName! ";
  cout << "Did you expect anything useful from it?";
}
```

Header / Source Separation

- Move all declarations to header files (`*.hpp`)
- Implementation goes to `*.cpp` or `*.cc`

```cpp
// some_file.hpp
Type SomeFunc(... args...);

// some_file.cpp
#include "some_file.hpp"
Type SomeFunc(... args...) {}  // implementation

// program.cpp
#include "some_file.hpp"
int main() {
  SomeFunc(/* args */);
  return 0;
}
```

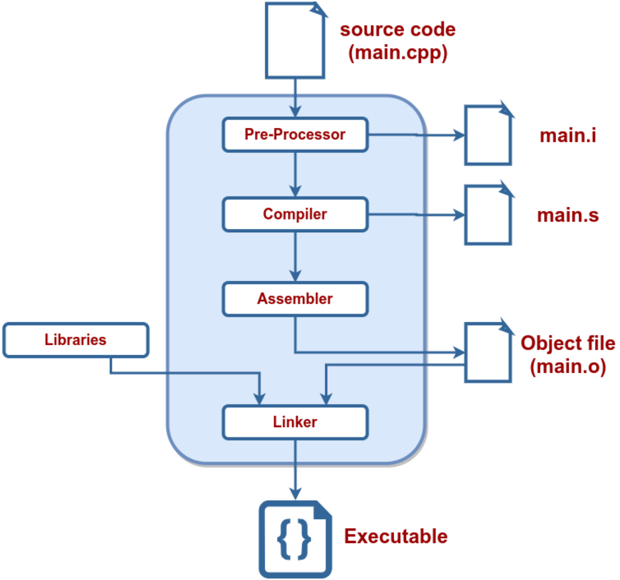
Just build it as before?

```
clang++ -std=c++17 program.cpp -o main
```

Error:

```
/tmp/tools_main-0eacf5.o: In function `main':
tools_main.cpp: undefined reference to `SomeFunc()'
clang: error: linker command failed with exit code 1
(use -v to see invocation)
```

What is linking?



What is linking?

- The library is a binary object that contains the **compiled implementation** of some methods
- Linking maps a function declaration to its compiled implementation
- To use a library we **need:**
  1. A header file `library_api.h`
  2. The compiled library object `libmylibrary.a`

How to build libraries?

```
folder/
    --- tools.hpp
    --- tools.cpp
    --- main.cpp
```

Short: we separate the code into modules

Declaration: `tools.hpp`

```cpp
#pragma once  // Ensure file is included only once
void MakeItSunny();
void MakeItRain();
```

How to build libraries?

Definition: `tools.cpp`

```
#include "tools.hpp"
#include <iostream>
void MakeItRain() {
  // important weather manipulation code
  std::cout << "Here! Now it rains! Happy?\n";
}
void MakeItSunny() { std::cerr << "Not available\n"; }
```

Calling: `main.cpp`

```
#include "tools.hpp"
int main() {
  MakeItRain();
  MakeItSunny();
  return 0;
}
```

Use modules and libraries!

Compile modules:

```
c++ -std=c++17 -c tools.cpp -o tools.o
```

Organize modules into libraries:

```
ar rcs libtools.a tools.o <other_modules>
```

Link libraries when building code:

```
c++ -std=c++17 main.cpp -L . -ltools -o main
```

Run the code:

```
./main
```

Build Systems

Building by hand is hard

- 4 commands to build a simple hello world example with 2 symbols.
- How does it scales on big projects?
- Impossible to mantain.
- Build systems to the rescue!

What are build systems

- Tools.
- Many of them.
- Automate the build process of projects.
- They began as `shell` scripts
- Then turn into `MakeFiles`.
- And now into MetaBuild Sytems like `CMake`.
  - Accept it, `CMake` is not a build system.
  - It’s a build system generator
  - You need to use an actual build system like `Make` or `Ninja`.

What I wish I could write

Replace the build commands:

1. c++ -std=c++17 -c tools.cpp -o tools.o
2. ar rcs libtools.a tools.o <other_modules>
3. c++ -std=c++17 main.cpp -L . -ltools

For a script in the form of:

```
add_library(tools tools.cpp)
add_executable(main main.cpp)
target_link_libraries(main tools)
```

Use CMake to simplify the build

- One of the most popular build tools
- Does not build the code, generates files to feed into a build system
- Cross-platform
- Very powerful, still build receipt is readable

Build a CMake project

- **Build process** from the user's perspective
  1. `cd <project_folder>`
  2. `mkdir build`
  3. `cd build`
  4. `cmake ..`
  5. `make`
- The build process is completely defined in `CMakeLists.txt`
- And childrens `src/CMakeLists.txt`, etc.

First CMakeLists.txt

```
cmake_minimum_required(VERSION 3.1) # Mandatory.
project(first_project)              # Mandatory.
set(CMAKE_CXX_STANDARD 17)          # Use c++17.

# tell cmake where to look for *.hpp, *.h files
include_directories(include/)

# create library "libtools"
add_library(tools src/tools.cpp) # creates libtools.a

# add executable main
add_executable(main src/tools_main.cpp) # main.o

# tell the linker to bind these objects together
target_link_libraries(main tools) # ./main
```

CMake is easy to use

- All build **files are in one place**
- The build **script is readable**
- Automatically **detects changes**
- After doing changes:
  1. `cd <project_folder>/build`
  2. `make`

Typical project structure

```
|-- project_name/
|    |-- CMakeLists.txt
|    |-- build/   # All generated build files
|    |-- results/ # Executable artifacts
|    |    |-- bin/
|    |        |-- tools_demo
|    |    |-- lib/
|    |        |-- libtools.a
|    |-- include/ # API of the project
|    |    |-- project_name
|    |        |-- library_api.hpp
|    |-- src/
|    |    |-- CMakeLists.txt
|    |    |-- project_name
|    |        |-- CMakeLists.txt
|    |        |-- tools.hpp
|    |        |-- tools.cpp
|    |        |-- tools_demo.cpp
|    |-- tests/  # Tests for your code
|    |    |-- test_tools.cpp
|    |    |-- CMakeLists.txt
|    |-- README.md  # How to use your code
```

Compilation options in CMake

```cmake
set(CMAKE_CXX_STANDARD 17)

# Set build type if not set.
if(NOT CMAKE_BUILD_TYPE)
  set(CMAKE_BUILD_TYPE Debug)
endif()
# Set additional flags.
set(CMAKE_CXX_FLAGS "-Wall -Wextra")
set(CMAKE_CXX_FLAGS_DEBUG "-g -O0")
```

- `-Wall -Wextra`: show all warnings
- `-g`: keep debug information in binary
- `-O<num>`: optimization level in `{0, 1, 2, 3}`
  - `0`: no optimization
  - `3`: full optimization

Useful commands in CMake

- Just a scripting language
- Has features of a scripting language, i.e. functions, control structures, variables, etc.
- All variables are string
- Set variables with `set(VAR VALUE)`
- Get value of a variable with `${VAR}`
- Show a message `message(STATUS "message")`
- Also possible `WARNING`, `FATAL_ERROR`

Build process

- `CMakeLists.txt` defines the whole build
- CMake reads `CMakeLists.txt` **sequentially**
- **Build process:**
  1. `cd <project_folder>`
  2. `mkdir build`
  3. `cd build`
  4. `cmake ..`
  5. `make -j2  # pass your number of cores here`

Everything is broken, what should I do?

- Sometimes you want a clean build
- It is very easy to do with CMake
  1. `cd project/build`
  2. `make clean` [remove generated binaries]
  3. `rm -rf *` [make sure you are in build folder]
- Short way(If you are in `project/`):
  - `rm -rf build/`

Use pre-compiled library

- Sometimes you get a compiled library
- You can use it in your build
- For example, given `libtools.so` it can be used in the project as follows:

```
find_library(TOOLS
             NAMES tools
             PATHS ${LIBRARY_OUTPUT_PATH})
# Use it for linking:
target_link_libraries(<some_binary> ${TOOLS})
```

CMake `find_path` and `find_library`

- We can use an external library
- Need headers and binary library files
- There is an easy way to find them
- **Headers:**

```
find_path(SOME_PKG_INCLUDE_DIR include/some_file.hpp
          <path1> <path2> ...)
include_directories(${SOME_PKG_INCLUDE_DIR})
```

- **Libraries:**

```
find_library(SOME_LIB
             NAMES <some_lib>
             PATHS <path1> <path2> ...)
target_link_libraries(target ${SOME_LIB})
```

find_package

- find_package calls multiple find_path and find_library functions
- To use find_package(<pkg>) CMake must have a file Find<pkg>.cmake in CMAKE_MODULE_PATH folders
- Find<pkg>.cmake defines which libraries and headers belong to package <pkg>
- Pre-defined for most popular libraries, e.g. OpenCV, libpng, etc.

CMakeLists.txt

```
cmake_minimum_required(VERSION 3.1)
project(first_project)

# CMake will search here for Find<pkg>.cmake files
SET(CMAKE_MODULE_PATH
    ${PROJECT_SOURCE_DIR}/cmake_modules)

# Search for Findsome_pkg.cmake file and load it
find_package(some_pkg)

# Add the include folders from some_pkg
include_directories(${some_pkg_INCLUDE_DIRS})

# Add the executable "main"
add_executable(main small_main.cpp)
# Tell the linker to bind these binary objects
target_link_libraries(main ${some_pkg_LIBRARIES})
```

cmake_modules/Findsome_pkg.cmake

```
# Find the headers that we will need
find_path(some_pkg_INCLUDE_DIRS include/some_lib.hpp <FOLDER_WHERE_TO_SEARCH>)
message(STATUS "headers: ${some_pkg_INCLUDE_DIRS}")

# Find the corresponding libraries
find_library(some_pkg_LIBRARIES
             NAMES some_lib_name
             PATHS <FOLDER_WHERE_TO_SEARCH>)
message(STATUS "libs: ${some_pkg_LIBRARIES}")
```

Watch for Homeworks

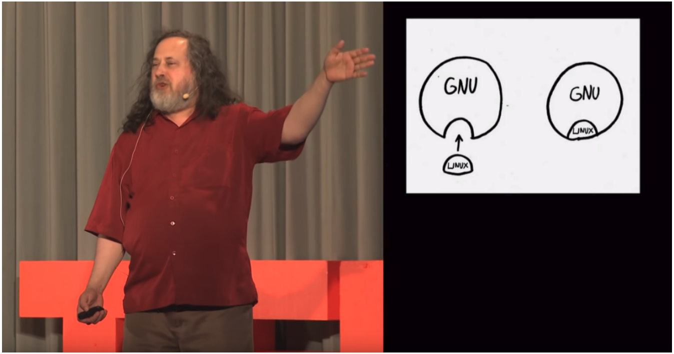
https://youtu.be/hwP7WQkmECE

Watch for Homeworks

https://youtu.be/OZEGnam2M9s

Suggested Video

"Free software, free society" by Richard Stallman



https://youtu.be/Ag1AKIl_2GM

References

- **CMake Documentation**
  cmake.org/cmake/help/v3.10/
- **GCC Manual**
  gcc.gnu.org/onlinedocs/gcc-9.3.0/gcc/
- **Clang Manual**
  releases.llvm.org/10.0.0/tools/clang/docs/index.html