Modern C++ for Computer Vision and Image Processing

Igor Bogoslavskyi

UNIVERSITÄT BONN

igg

Outline

Compilation flags and debugging

Functions

Header / Source Separation

Libraries

CMake Intro

Compilation flags

- There is a lot of flags that can be passed while compiling the code
- We have seen some already: `-std=c++11`, `-o`, etc.

Other useful options:

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

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

Debugging tools

- The best option is to use `gdb`
- Insanely popular and powerful
- No build-in gui
- Use `gdbgui` for a user-friendly interface
- Install `gdbgui` from `pip`:
  `sudo pip3 install --upgrade gdbgui`

Tutorials, documentation and source code: `https://gdbgui.com/`

Functions

```cpp
ReturnType FuncName(ParamType1 in_1, ParamType2 in_2) {
  // Some awesome code here.
  return return_value;
}
```

- Code can be organized into functions
- Functions **create a scope**
- **Single return value** from a function
- Any number of input variables of any types
- Should do **only one** thing and do it right
- Name **must** show what the function does
- GOOGLE-STYLE name functions in `CamelCase`
- GOOGLE-STYLE **write small functions**

Google style: https://google.github.io/styleguide/cppguide.html#Write_Short_Functions

Good function example

```cpp
#include <vector>
using namespace std;
vector<int> CreateVectorOfFullSquares(int size) {
  vector<int> result(size); // Vector of size `size`
  for (int i = 0; i < size; ++i) { result[i] = i * i; }
  return result;
}

int main() {
  auto squares = CreateVectorOfFullSquares(10);
  return 0;
}
```

- Is small enough to see all the code at once
- Name clearly states what the function does
- Function **does a single thing**

Bad function example

CODING HORROR

```cpp
#include <vector>
using namespace std;
vector<int> Func(int a, bool b) {
  if (b) { return vector<int>(10, a); }
  vector<int> vec(a);
  for (int i = 0; i < a; ++i) { vec[i] = a * i; }
  if (vec.size() > a * 2) { vec[a] /= 2.0f; }
  return vec;
}
```

- Name of the function means nothing
- Names of variables mean nothing
- Function does not have a single purpose

Declaration and definition

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

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

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

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

Passing big objects

- By default in C++, objects are copied when passed into functions
- If objects are big it might be slow
- **Pass by reference** to avoid copy

```
void DoSmth(std::string huge_string);   // Slow.
void DoSmth(std::string& huge_string);  // Faster.
```

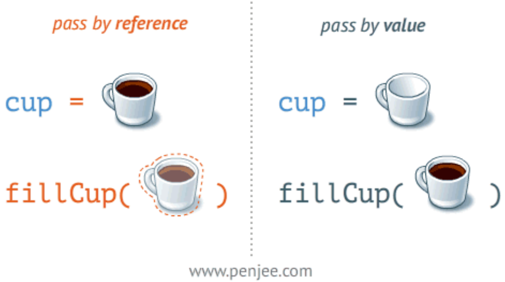
CODING HORROR

Is the string still the same?

```
string hello = "some_important_long_string";
DoSmth(hello);
```

Unknown without looking into `DoSmth()`!

Pass by reference intuition



- **Pass by reference**:
  - `void fillCup(Cup &cup);`
  - `cup` is full
- **Pass by value**:
  - `void fillCup(Cup cup);`
  - A copy of `cup` is full
  - `cup` is still empty

Solution: use const references

- Pass **const** reference to the function
- Great speed as we pass a reference
- Passed object stays intact

```
void DoSmth(const std::string& huge_string);
```

- Use `snake_case` for all function arguments
- Non-const refs are mostly used in older code written before C++11
- They can be useful but destroy readability
- GOOGLE-STYLE Avoid using non-const refs

Google style: https://google.github.io/styleguide/cppguide.html#Reference_Arguments

Function overloading

- Compiler infers a function from arguments
- Cannot overload based on return type
- Return type plays no role at all
- GOOGLE-STYLE Avoid non-obvious overloads

```cpp
#include <iostream>
#include <string>
using namespace std;
string Func(int num) { return "int"; }
string Func(const string& str) { return "string"; }
int main() {
  cout << Func(1) << endl;
  cout << Func("hello") << endl;
  return 0;
}
```

Google style: https://google.github.io/styleguide/cppguide.html#Function_Overloading

Default arguments

- Functions can accept default arguments
- Only **set in declaration** not in definition
- **Pro**: simplify function calls
- **Cons**:
  - Evaluated upon every call
  - Values are hidden in declaration
  - Can lead to unexpected behavior when overused
- `GOOGLE-STYLE` Only use them when readability gets much better

Google style: `https://google.github.io/styleguide/cppguide.html#Default_Arguments`

Example: default arguments

```cpp
#include <iostream>  // std::cout, std::endl
using namespace std;
string SayHello(const string& to_whom = "world") {
  return "Hello " + to_whom + "!";
}
int main() {
  cout << SayHello() << endl;
  cout << SayHello("students") << endl;
  return 0;
}
```

Don't reinvent the wheel

- When using `std::vector`, `std::array`, etc. try to avoid writing your own functions.
- Use `#include <algorithm>`
- There is a lot of functions in `std` which are at least as fast as hand-written ones:

```
std::vector<float> v;
// Filling the vector omitted here.
std::sort(v.begin(), v.end()); // Sort ascending.
float sum = std::accumulate(v.begin(), v.end(), 0.0f);
float product = std::accumulate(
  v.begin(), v.end(), 1.0f, std::multiplies<float>());
```

Algorithms in standard library: `http://en.cppreference.com/w/cpp/algorithm`

Header / Source Separation

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

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

// some_file.cpp
#include "some_file.h"
Type SomeFunc(... args ...) { /* code */ }

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

How to build this?

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

Short: we separate the code into modules

Declaration: `tools.h`

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

How to build this?

Definition: tools.cpp

```
#include <iostream>
#include "tools.h"
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.h"
int main() {
  MakeItRain();
  MakeItSunny();
  return 0;
}
```

Just build it as before?

```
c++ -std=c++11 main.cpp -o main
```

Error:

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

Use modules and libraries!

Compile modules:

```
c++ -std=c++11 -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++11 main.cpp -L . -ltools -o main
```

Run the code:

```
./main
```

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/…`

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 a header and the compiled library** object

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
- The library creation and linking can be rewritten as follows:

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

Typical project structure

```
|-- project_name/
|     |-- CMakeLists.txt
|     |-- build/  # All generated build files
|     |-- bin/
|     |     |-- tools_demo
|     |-- lib/
|     |     |-- libtools.a
|     |-- src/
|     |     |-- CMakeLists.txt
|     |     |-- project_name
|     |           |-- CMakeLists.txt
|     |           |-- tools.h
|     |           |-- tools.cpp
|     |           |-- tools_demo.cpp
|     |-- tests/  # Tests for your code
|     |     |-- test_tools.cpp
|     |     |-- CMakeLists.txt
|     |-- readme.md  # How to use your code
```

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`

First working CMakeLists.txt

```
project(first_project)                    # Mandatory.
cmake_minimum_required(VERSION 3.1) # Mandatory.
set(CMAKE_CXX_STANDARD 11)             # Use c++11.
# tell cmake to output binaries here:
set(EXECUTABLE_OUTPUT_PATH ${PROJECT_SOURCE_DIR}/bin)
set(LIBRARY_OUTPUT_PATH ${PROJECT_SOURCE_DIR}/lib)
# tell cmake where to look for *.h files
include_directories(${PROJECT_SOURCE_DIR}/src)
# create library "libtools"
add_library(tools src/tools.cpp)
# add executable main
add_executable(main src/tools_main.cpp)
# tell the linker to bind these objects together
target_link_libraries(main tools)
```

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`

Use CMake in your builds

- Build process is standard and simple
- No need to remember sequence of commands
- All generated build files are in one place
- CMake detects changes to the files
- Do this after changing files:
  1. `cd project/build`
  2. `make -j2  # pass your number of cores here`

Set compilation options in CMake

```
set (CMAKE_CXX_STANDARD 14)
# Set build type if not set.
if(NOT CMAKE_BUILD_TYPE)
  set(CMAKE_BUILD_TYPE Release)
endif()
# Set additional flags.
set(CMAKE_CXX_FLAGS "-Wall -Wextra")
set(CMAKE_CXX_FLAGS_DEBUG "-g -O0")
set(CMAKE_CXX_FLAGS_RELEASE "-O3")
```

- -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

Remove build folder for performing a clean build

- 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 -r *` [make sure you are in build folder]

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})
```

References

- **Compiler Explorer:** https://godbolt.org/
- **Gdbgui:** https://gdbgui.com/
- **Gdbgui tutorial:** https://www.youtube.com/watch?v=em842geJhfk
- **CMake website:** https://cmake.org/
- **Modern CMake Tutorial:** https://www.youtube.com/watch?v=eC9-iRN2b04