Department I - C Plus Plus

Modern and Lucid C++ Advanced for Professional Programmers

Week 13 – Build Automation

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- **Recap Week 12**

- **Build Automation**

- **Structuring Projects**

● **Participants should …**

- ◼ know how to set up build automation for their own projects

- ◼ explain why projects should have build-automation in place

- ◼ know how to structure non-trivial projects

Recap Week 12

- **ABIs define how programs interact on a binary level**

  - Names of structures and functions

  - Calling conventions

  - Instruction sets

- **C++ does not define any specific ABI**

  - Because they are tightly coupled to the platform

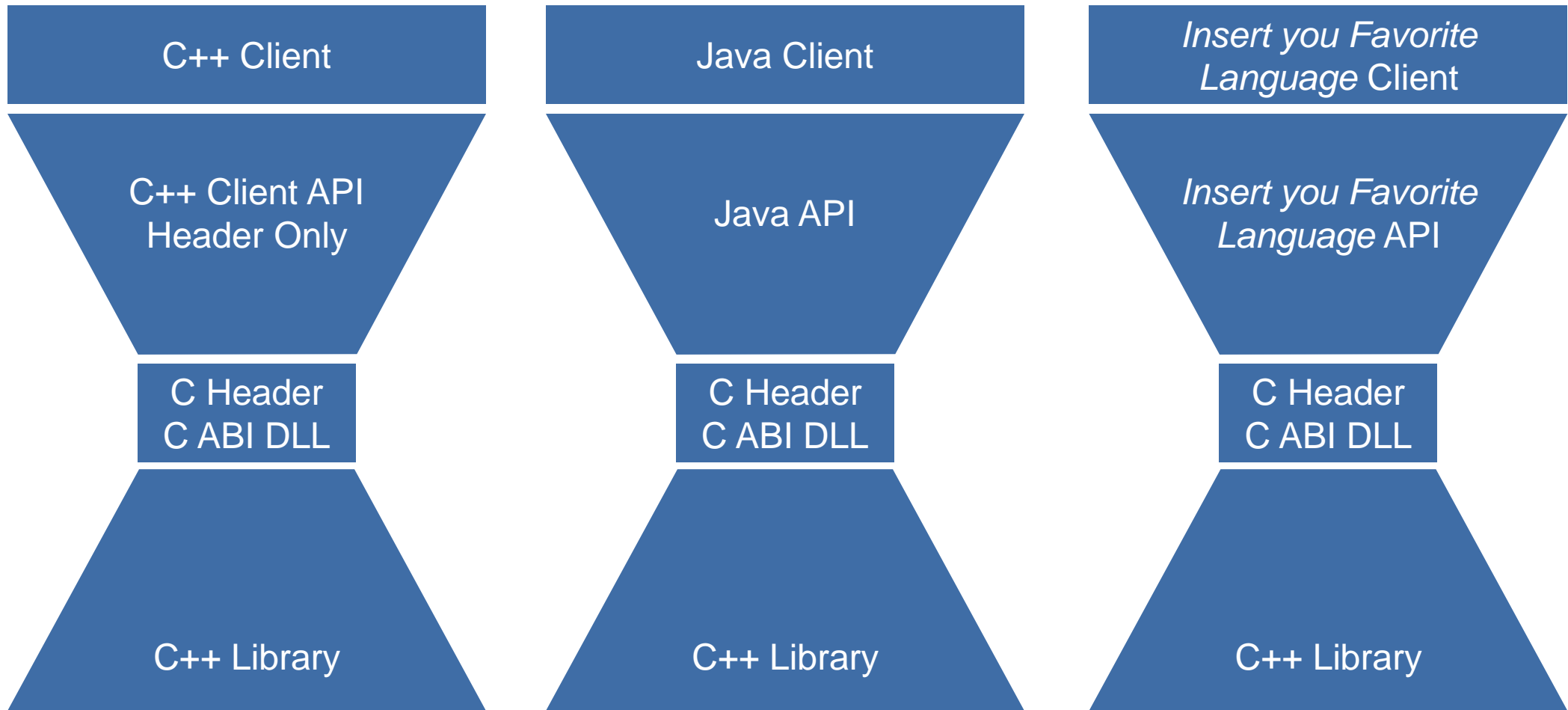- **ABIs change between OSes, compiler versions, library versions, etc.**

- **Case in point:**

  - GCC changed its ABI from:

    - Version 2.95 to 3.0

    - 3.0 to 3.1

    - 3.1 to 3.2

    - 3.3 to 3.4

    - 5.0 to 5.1

    - …

  - Different standard library implementations are usually incompatible

C++ Client

C++ Client API
Header Only

C Header
C ABI DLL

C++ Library

Java Client

Java API

C Header
C ABI DLL

C++ Library

Insert you Favorite Language Client

Insert you Favorite Language API

C Header
C ABI DLL

C++ Library

What Parts of C++ Can Be Used in an `extern "C"` Interface?

7

- **Functions, but not templates or variadic**

  - No overloading in C!

- **C primitive types (`char, int, double, void`)**

- **Pointers, including function pointers**

- **Forward-declared structs**

  - Pointers to those are opaque types!

  - Are used for abstract data types

- **Enums (unscoped - without class or base type!)**

- **If using from C must embrace it with `extern "C"` when compiling it with C++**

  - Otherwise names do not match, because of mangling

`Wizard.h`

```cpp
#ifdef __cplusplus
extern "C" {
#endif

typedef struct Wizard * wizard;
typedef struct Wizard const * cwizard;
wizard createWizard(char const * name,
                    error_t * out_error);
void disposeWizard(wizard toDispose);

// ...
// Comments are ok too, as the preprocessor
// eliminates them anyway

#ifdef __cplusplus
}
#endif
```

```
extern "C" {
void printInt(int number);
}
```

```
public interface CplaLib extends Library {
    CplaLib INSTANCE = (CplaLib) Native.load("cpla", CplaLib.class);

    void printInt(int number);
}
```

- **Function names and parameter types must match**

    ■ However: The types are not validated! Even at runtime! (They are not part of the signature in C!)

- **Parameter names don't matter**

- **Plain (non-opaque) struct types must inherit from `Structure`**

  - You must override `getFieldOrder()`

  - Can use the tag-interface `Structure.ByValue`

- **Opaque struct types should inherit from `Pointer`**

  - Provide a constructor using the `create…()` function

- **Managing lifetime is not trivial**

  - Using `dispose…()` API functions in finalizers is not recommended

  - Either provide a dispose method on you Java type

 - Or implement `AutoClosable` and use you objects with try-with-resources

Motivation

- **Imagine that…**

  - ... you plan on building a large product (maybe your Thesis/Term Project?)

  - … your product consists of multiple parts

  - … you need to have build products at any moment (ship early, ship often)

  - … you need to target multiple platforms

  - … others need to build your code (maybe on different platforms)

  - … you work in a team

  - … everyone uses their favorite IDE or editor

- **With what you know now, does that sound like fun?**

- **Sounds made up or too theoretical?**
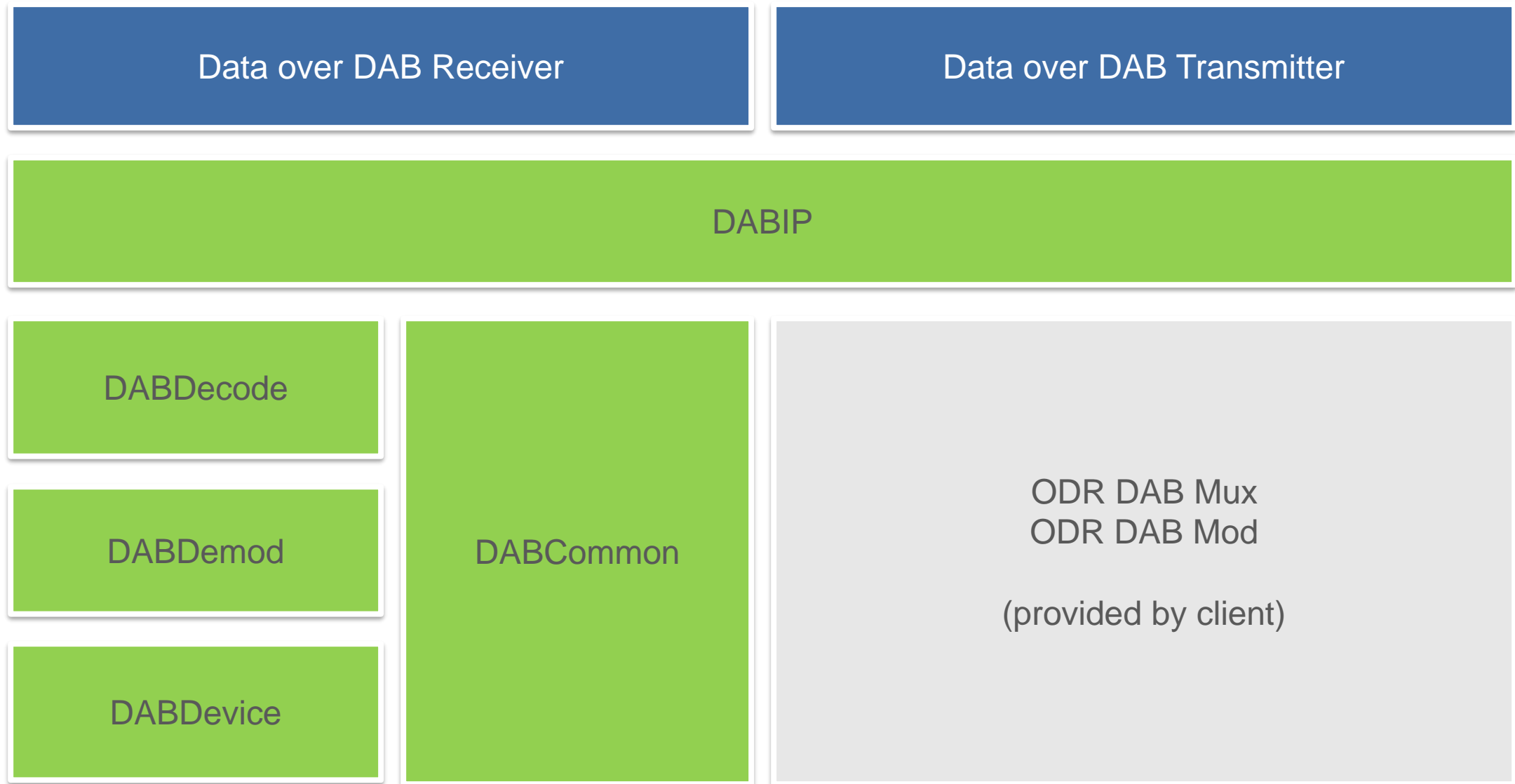
- **Five libraries**

  - All depending on a common infrastructure library

- **Two executables**

  - Depend on some or all of the libraries

- **Two target-platforms**

  - Linux on x86_64 and armv7

  - OS X

- **Code will change owners**

- **4 months time-frame**

Build Automation

- **Build automation and Reproducibility**

  - No "Wait for <insert name here> to build the package"!

  - No "Builds on my machine"!

- **Productivity**

- **Project Layout / Maintainability**

  - Independent code should live in a separate project

 - Link- and compile-time dependencies must be easy to resolve

- **Shareability**

- **There are many IDEs and Editors available**

  - ■ An you should make use of them!

- **Most IDEs have a concept of "Projects" (Project Layout / Maintainability)**

  - ■ Click "Build" to get your program/library (Productivity)

- **But…**

  - ■ … do we want to run an IDE on our build server? (Build automation)

  - ■ … does the IDE run on other Platforms? (Shareability)

  - ■ … how are compiler/linker flags stored and shared? (Reproducibility)

  - ■ … are project files of X compatible with Y? (Shareability)
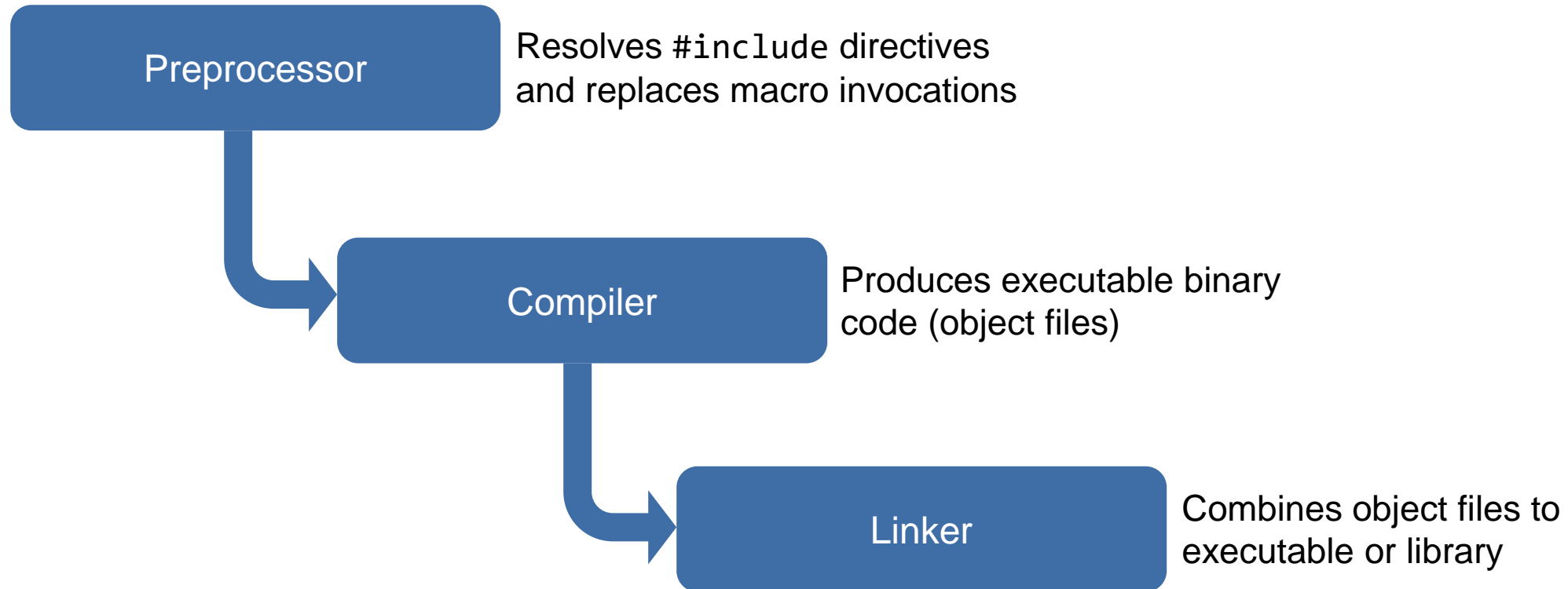
- **The compiler generates object files**

  - `gcc -c packet_parser.cpp`

    - Output: "packet_parser.o"

  - Could specify multiple at a time

    - `gcc -c packet_parser.cpp packet_generator.cpp -o parser_and_generator.o`

- **Object files get linked together**

  - `gcc -shared -l libdabdemod.so packet_parser.o packet_generator.o …`

  - `gcc my_awesome_function.o main.o –o my_awesome_app`

- **Write a script that…**

  ◻ Compiles each source file

  ◻ Links all object files together

  ◻ Repeats that for every target

- **Profit!**

```bash
#!/bin/bash

# Build libdabip
gcc -c package_parser.cpp
gcc -c package_generator.cpp
…
gcc –shared -o libdabip package_parser.o
…

# Build libdabdecode
gcc -c ensemble.cpp
gcc -c subchannel.cpp
…
gcc -shared -o libdabdecode ensemble.o …

# Build <you get the idea>
```

- **Write a script that…**

  - ◻ Compiles each source file

  - ◻ Links all object files together
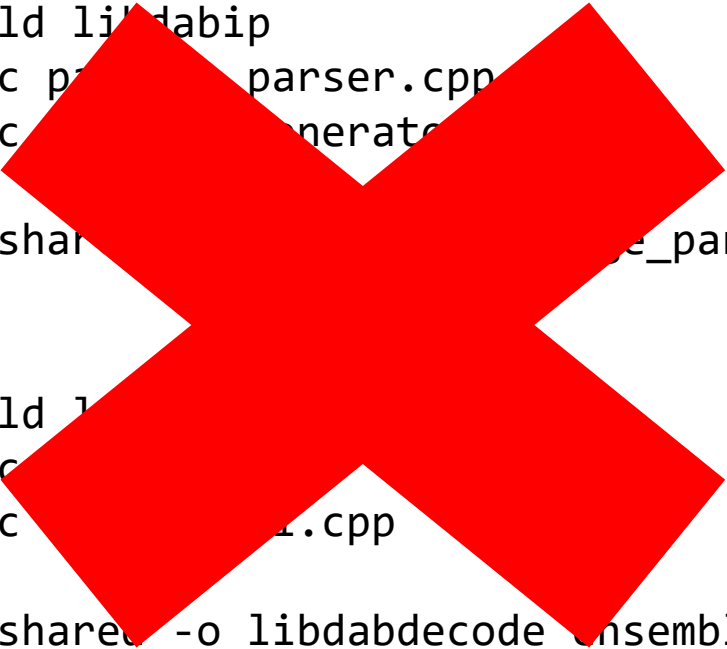
  - ◻ Repeats that for every target

- **DON'T! Because…**

  - ◻ … every source file get built every time!

  - ◻ … the commands tend to be platform specific

  - ◻ … build order must be managed manually

  - ◻ … scripts tend to become messy over time

```bash
#!/bin/bash

# Build libdabip
gcc -c p        parser.cpp
gcc -c          nerat
…
gcc -shar              e_parser.o
…

# Build l
gcc -c
gcc -c          1.cpp
…
gcc -shared -o libdabdecode  nsemble.o …

# Build <you get the idea>
```

- **Building non-trivial projects is an old problem**

- **There are plenty of existing tools:**

  - GNU make

  - Scons

  - Ninja

  - CMake

  - autotools

  - …

- **Don't reinvent the wheel! Other people are doing that for you…**

- **Incremental builds**

- **Parallel builds**

- **Automatic (intra-project) dependency resolution**

- **Package management**

- **Automatic test execution**

- **Platform independence**

- **Additional processing of build products**

  - E.g. code signing, minification, …

- **Make-style Build Tools**

  - Run build scripts

  - Produce your final products

  - Often verbose

 - Use a language agnostic configuration language

- **Build Script Generators**

  - Generate configurations for Make-style Build Systems or Build Scripts

  - Configuration independent of actual build tool

  - Advanced features (download dependencies, etc.)

- **Well-known tool to build all kinds of projects**

  - ◾ Many IDEs "understand" make projects

- **Workflow description in Makefile via "Target" rules**

  - ◾ Each target may have one or more prerequisites…

  - ◾ …and execute one or more commands to…

  - ◾ …generate one or more results

- **Targets are then executed "top-down"**

- **A Target is only executed if required**

```
target: prereq_target

prereq_target: prereq_file other_target
    command_to_generate_output

other_target:
```
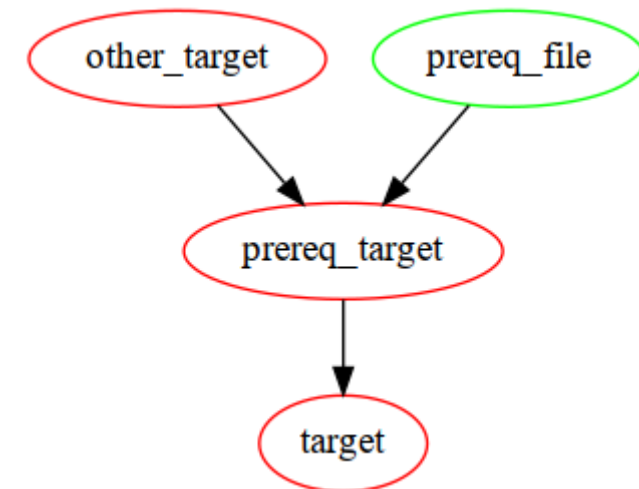
- **Pros:**

  - Very generic automation tool

  - Powerful pattern matching mechanism

  - Builds only what is needed, when its needed

- **Cons:**

  - Often platform-specific commands
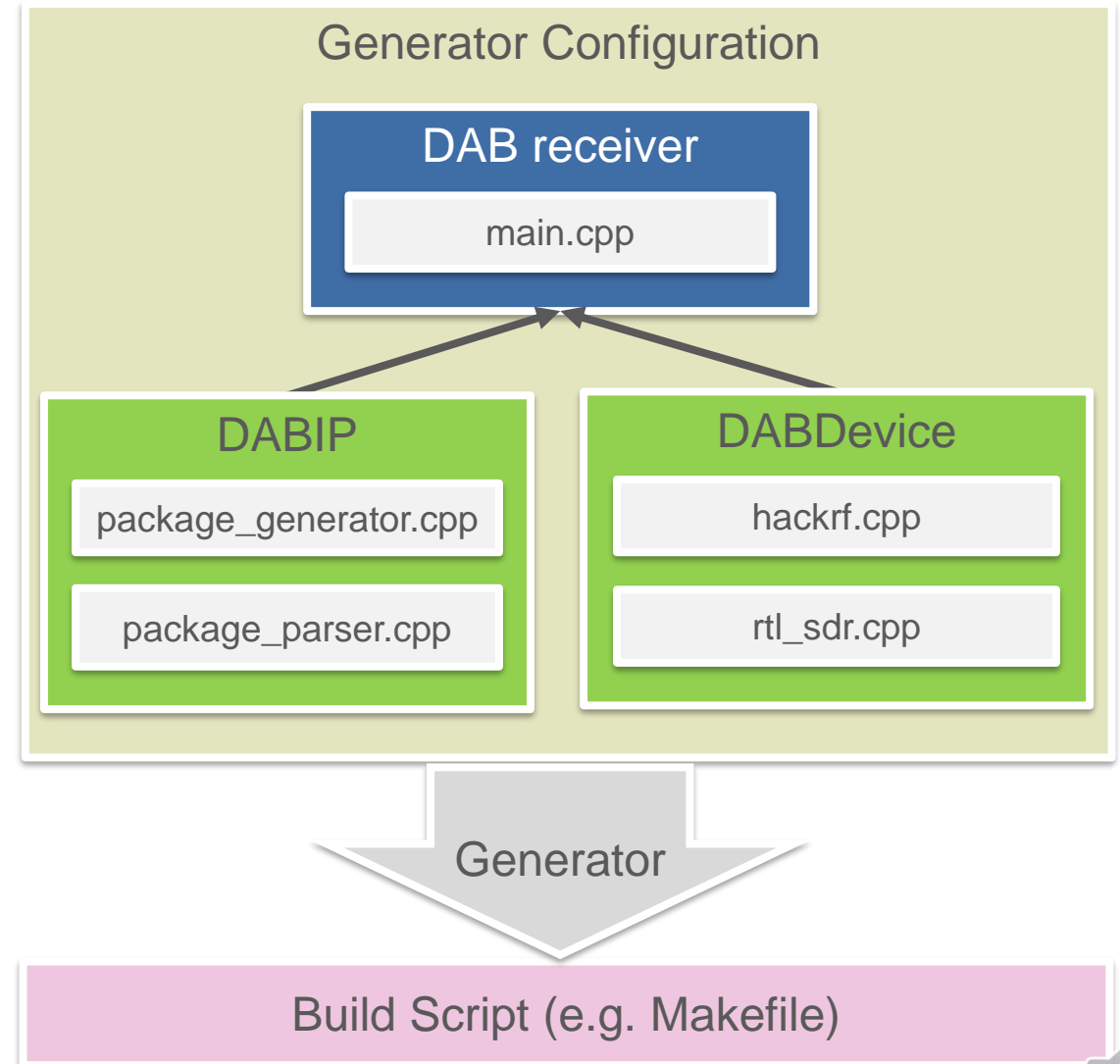
  - Need to specify how to do things

- **Idea: Take a step back**

  - Define what we want to achieve, not how to do it

  - Work on a higher level

  - Let the create the actual build configurations

- **Platform independent build specification**

- **Tool Independent**

  - Often can generate IDE projects

  - Support multiple build tools

Generator Configuration

DAB receiver

main.cpp

DABIP

package_generator.cpp

package_parser.cpp

DABDevice

hackrf.cpp

rtl_sdr.cpp

Generator

Build Script (e.g. Makefile)

- **Widely used. e.g.:**

  - Netflix

  - LLVM

  - vcpkg (Microsoft)

- **Built-in support for many languages**

  - C, C++, Java, C#, Swift, …

  - Can be extended if needed

- **Custom configuration language**

- **Platform independent**

```cpp
// main.cpp

#include <iostream>

int main() {
  std::cout << "This is my awesome app!\n";
}
```

```cmake
# CMakeLists.txt

project("my_app" LANGUAGES CXX)

add_executable("my_app"
  "main.cpp"
)
```

```
$ mkdir build
$ cd build
$ cmake ..
$ cmake --build .
```

Hint: **Always** use "`cmake --build .`" NOT "`make`" to build your CMake project! Why?

- **cmake_minimum_required(…) sets the minimum required CMake version**

  - Implicitly defines available feature set

- **project(…) command defines …**

  - … the name of our project

  - … which languages we use

- **add_executable(…) defines binaries**

- **target_compile_features(…) defines which language features are used by the target**

- **set_target_properties(…) defines additional target properties**

```
cmake_minimum_required(VERSION "3.12.0")

project("my_app" LANGUAGES CXX)

add_executable("my_app"
  "main.cpp"
)

target_compile_features("my_app" PRIVATE
  "cxx_std_17"
)

set_target_properties("my_app" PROPERTIES
  CXX_STANDARD_REQUIRED YES
  CXX_EXTENSIONS NO
)
```

- **`add_library(…)` defines libraries**

  - ▪ Defaults to static libraries

  - ▪ Can be overridden at configuration time

    - ▪ `cmake -D BUILD_SHARED_LIBS=YES`

- **All features, include paths, dependencies should be `PUBLIC`**

```
cmake_minimum_required(VERSION "3.12.0")

project("my_lib" LANGUAGES CXX)

add_library("my_lib"
  "lib.cpp"
)

target_compile_features("my_lib" PUBLIC
  "cxx_std_17"
)

set_target_properties("my_lib" PROPERTIES
  CXX_STANDARD_REQUIRED YES
  CXX_EXTENSIONS NO
)
```

```cmake
cmake_minimum_required(VERSION "3.12.0")

project("my_lib" LANGUAGES CXX)

add_library("my_lib" "lib.cpp")

target_compile_features("my_lib" PUBLIC
  "cxx_std_17"
)

set_target_properties("my_lib" PROPERTIES
  CXX_STANDARD_REQUIRED YES
  CXX_EXTENSIONS NO
)

add_executable("my_app" "app.cpp")

target_link_libraries("my_app" PRIVATE "my_lib")
```

- **`target_compile_features` is used to define the language features required by the target**

  - C++ Standard:

    - `cxx_std_14`

    - `cxx_std_17`

    - ...

  - C++ Features:

    - `cxx_range_for`

    - ...

  - Can be `PUBLIC` or `PRIVATE`

  - Prefer requiring standards rather than specific features!

- **`target_include_directories` is used to define the include search path of the target**

  - Can define paths as being system includes or not

    - Default is non-system include path

    - Specify SYSTEM to define path as being a system include path (includes using <…>)

  - Can be PUBLIC or PRIVATE

- **`target_link_libraries` is used to define libraries required by a target**

  - Can be …

    - a target built by the current project

    - a target built by a sub-project

    - a system library (e.g. "stdc++fs")

  - Can be `PUBLIC` or `PRIVATE`

  - Applies `PUBLIC` features/dependencies/includes of the library

- **Variables can be defined using** `set(VAR_NAME VALUE)`

- **Variables are referenced using** `${VAR_NAME}`

- **CMake defines certain global variables. E.g.:**

  - `PROJECT_NAME` – The name of the current project

  - `PROJECT_SOURCE_DIR` – The "root" source directory of the current project

  - `PROJECT_BINARY_DIR` – The "root" output directory of the current project

- **Can be used in place of concrete values. E.g.:**

  - `add_executable(${PROJECT_NAME} "source1.cpp" "source2.cpp" …)`

- **CMake includes CTest**

  - ◼ Enable CTest using `enable_testing()`

  - ◼ Create a "Test Runner" executable

    - ◼ Make sure to include your suite sources!

  - ◼ Configure build environment:

    ```
    $ cmake ..
    ```

  - ◼ Build the project:

    ```
    $ cmake --build .
    ```

  - ◼ Run `ctest`

    ```
    $ ctest --output-on-failure
    ```

```cmake
cmake_minimum_required(VERSION "3.12.0")

project("answer" LANGUAGES CXX)

enable_testing()

add_library("${PROJECT_NAME}"
  "answer.cpp"
)

add_executable("test_runner"
  "Test.cpp"
)

target_link_libraries("test_runner" PRIVATE
  "answer"
)

target_include_directories("test_runner" SYSTEM PRIVATE
  "cute"
)

add_test("tests" "test_runner")
```

- **CMake makes building project easy**

  - Platform specifics are handled behind the scenes

  - Declare **what** you want, not **how** to create it

  - CTest allows you to run your unit tests

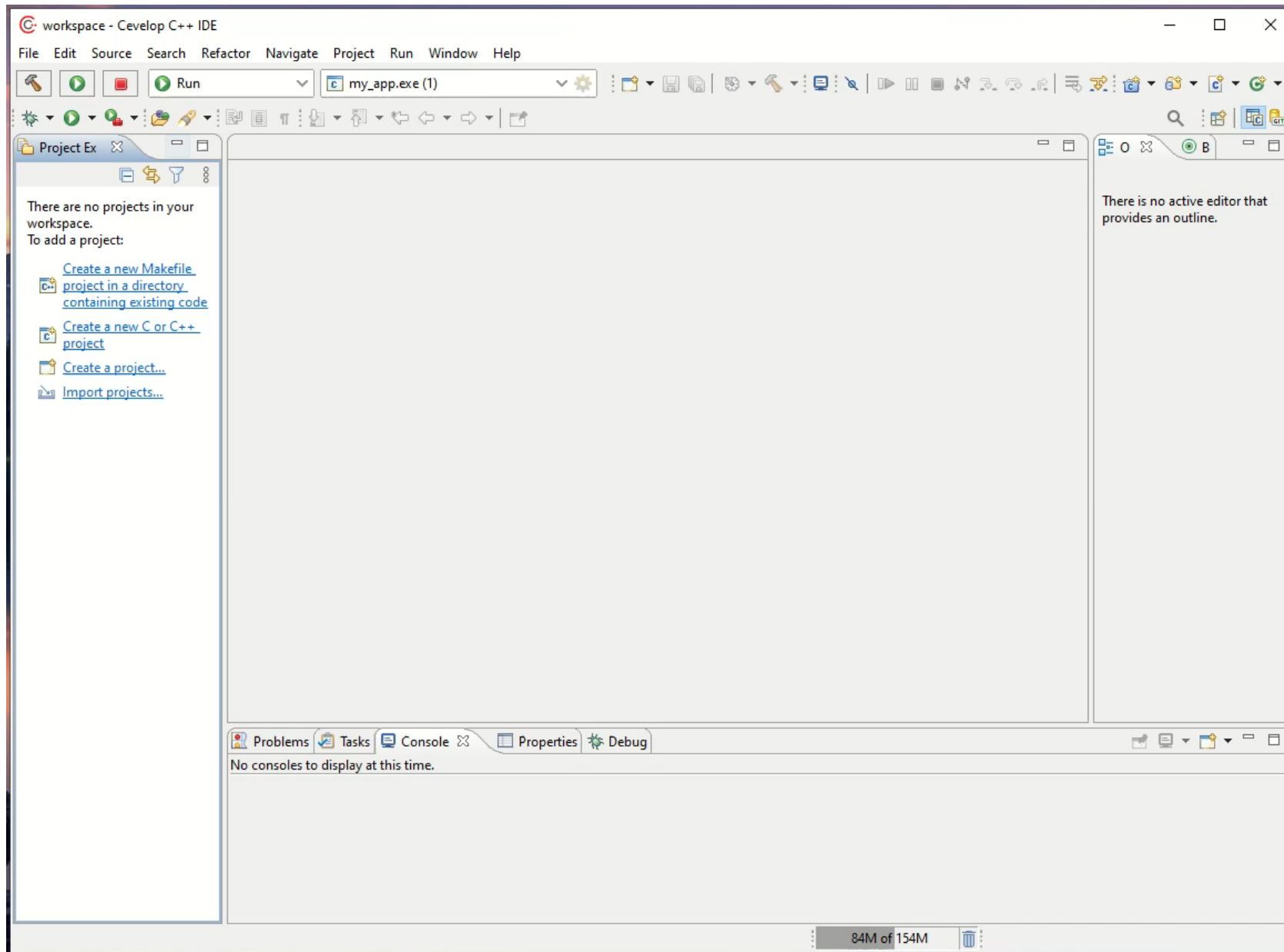- **You can choose what kind of build scripts you want:**

  ```
  $ cmake .. –G"Eclipse CDT4 - Unix Makefiles"
  ```

  ```
  $ cmake .. –G"MinGW Makefiles"
  ```

- **Declare the version of CMake required for your project**

  ```
  cmake_minimum_required(VERSION 3.14.0)
  ```
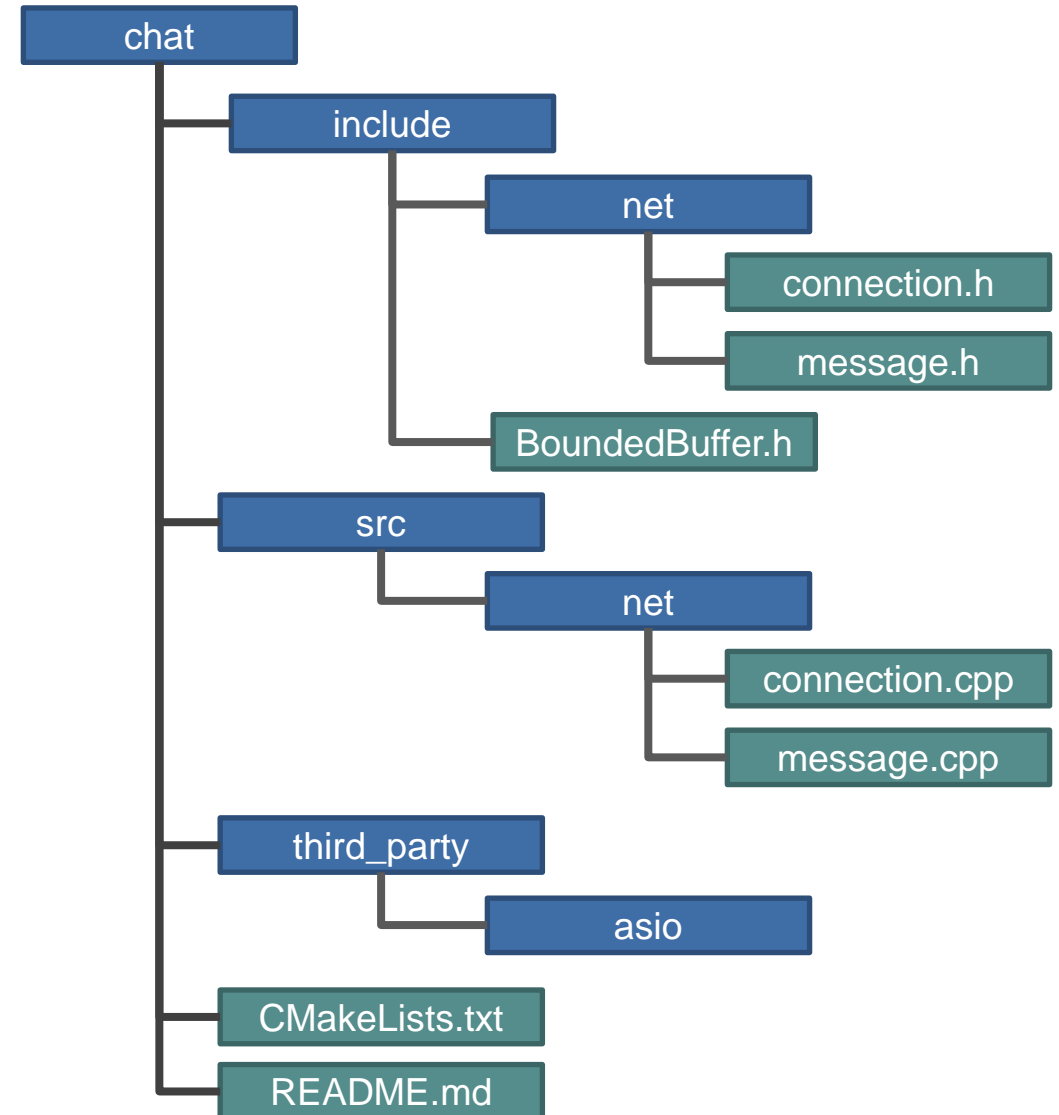
Project Layout

- **C++ does not enforce any Layout**

  - Can have all files in one directory…

  - … or each file in a separate directory …

  - … and anything in between

- **Best practices**

  - Separate headers from implementation files

  - Group files by submodule / functionality

  - Be **consistent!**

Don't let your projects look like this!

- **Headers live in the "include" folder**

  - Add subfolders for separate subsystems if needed

- **Implementation files live in the "src" folder**

  - Make sure that subfolder layout matches the "include" folder (**consistency**)

- **Put third-party projects/sources in a "third_party" or "lib" folder**

- **Test resource live in the "test" folder**

  - The test folder will have src, include, and third_party subfolders if required

- **Build configuration files should live in the root of your project**

```
chat
├── include
│   ├── net
│   │   ├── connection.h
│   │   └── message.h
│   └── BoundedBuffer.h
├── src
│   └── net
│       ├── connection.cpp
│       └── message.cpp
├── third_party
│   └── asio
├── CMakeLists.txt
└── README.md
```

Libraries may benefit from a slightly different layout

- You will need to ship your headers

- Your headers might have very generic names

Idea: Introduce another nesting level for your headers

- Use the name of your project

```
#include "message.h"
```
… becomes …
```
#include "chat/message.h"
```

- Helps avoid filename clashes