

Moving Beyond One File

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Outline

- Why multiple files? [5 min]
- How to split up the code [30 min]
 - headers versus source
 - declarations versus definitions
- How to compile with multiple files [20 min]
 - command line
 - libraries vs executables

[5 min break]

- Project structure
- CMake for compiling multiple files [15 min]
- CMake for dependencies [15 min]

[5 min break]

- Lab exercises

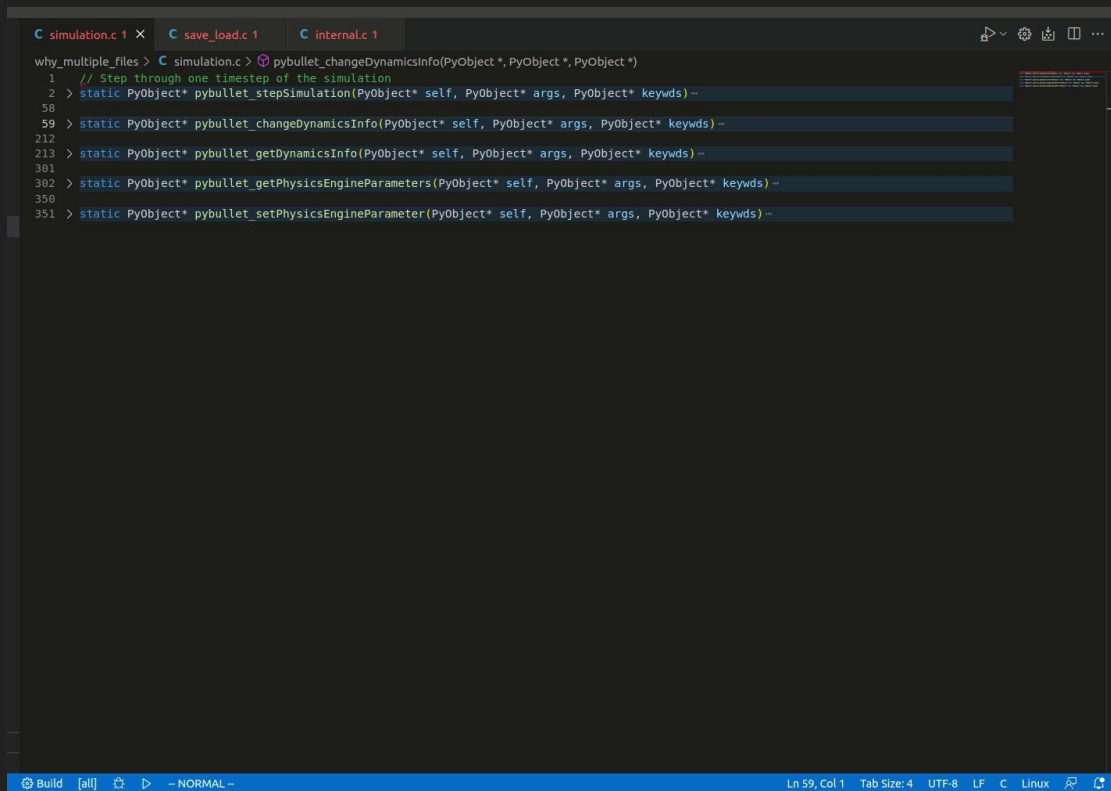
Why multiple files?

- Organization
 - Scrolling for ages is no fun
 - multiples files and folders make it easier mentally to handle the code
 - header files often belong in a separate folder

Why multiple files?

```
C pybullet.c 1 x
why_multiple_files > C pybullet.c > pybullet_internalSetMatrix(PyObject*, float[16])
54 // #define PYBULLET_USE_NUMPY
55 > #ifdef PYBULLET_USE_NUMPY-
56 #endif
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60 > #if PY_MAJOR_VERSION >= 3-
61 #endif
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65 static PyObject* SpamError;
66 #define B3_MAX_NUM_END_EFFECTORS 128
67 #define MAX_PHYSICS_CLIENTS 1024
68 static b3PhysicsClientHandle sPhysicsClients1[MAX_PHYSICS_CLIENTS] = {0};
69 static int sPhysicsClientsGUI[MAX_PHYSICS_CLIENTS] = {0};
70 static int sNumPhysicsClients = 0;
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72 > b3PhysicsClientHandle getPhysicsClient(int physicsClientId)-
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76 > static double pybullet_internalGetFloatFromSequence(PyObject* seq, int index)-
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114 > static int pybullet_internalGetIntFromSequence(PyObject* seq, int index)-
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132 > static const char* pybullet_internalGetCStringFromSequence(PyObject* seq, int index)-
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158 // internal function to set a float matrix[16]-
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160 > static int pybullet_internalSetMatrix(PyObject* objMat, float matrix[16])-
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191 // internal function to set a float vector[3]-
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193 > static int pybullet_internalSetVector(PyObject* objVec, float vector[3])-
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225 // vector - double[2] which will be set by values from objVec
226 > static int pybullet_internalSetVector2d(PyObject* objVec, double vector[2])-
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253 // vector - double[3] which will be set by values from objVec
254 > static int pybullet_internalSetVector3d(PyObject* objVec, double vector[3])-
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271 // vector - double[4] which will be set by values from objVec
272 > static int pybullet_internalSetVector4d(PyObject* objVec, double vector[4])-
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288 > static int pybullet_internalGetVector3FromSequence(PyObject* seq, int index, double vec[3])-
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316 > static int pybullet_internalGetVector4FromSequence(PyObject* seq, int index, double vec[4])-
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344 // Step through one timestep of the simulation
345 > static PyObject* pybullet_stepSimulation(PyObject* self, PyObject* args, PyObject* keywords)-
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464 > static PyObject* pybullet_performCollisionDetection(PyObject* self, PyObject* args, PyObject* keywords)-
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```

Why multiple files?



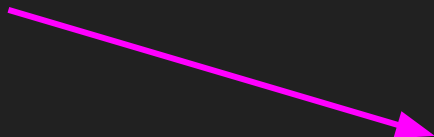
The screenshot shows a code editor with three tabs: `simulation.c 1`, `save_load.c 1`, and `internal.c 1`. The active file is `simulation.c`, which contains the following C code:

```
why_multiple_files > C simulation.c> pybullet_changeDynamicsInfo(PyObject *, PyObject *, PyObject *)
1 // Step through one timestep of the simulation
2 > static PyObject* pybullet_stepSimulation(PyObject* self, PyObject* args, PyObject* keywds)--
58
59 > static PyObject* pybullet_changeDynamicsInfo(PyObject* self, PyObject* args, PyObject* keywds)--
212
213 > static PyObject* pybullet_getDynamicsInfo(PyObject* self, PyObject* args, PyObject* keywds)--
301
302 > static PyObject* pybullet_getPhysicsEngineParameters(PyObject* self, PyObject* args, PyObject* keywds)--
350
351 > static PyObject* pybullet_setPhysicsEngineParameter(PyObject* self, PyObject* args, PyObject* keywds)--
```

The editor interface includes a toolbar at the top right with icons for search, settings, and other functions. The bottom status bar shows the current line and column (Ln 59, Col 1), tab size (4), encoding (UTF-8), and the operating system (Linux).

How to split up the code?

- Header Files (.h)
 - declarations
- Source Files (.cpp)
 - definitions



C declarations.h ×

```
why_multiple_files > C declarations.h > Robot > set_joint_configuration(std::vector<double> q)  
1  #include <vector>  
2  #include <string>  
3  
4  int const MAX_STEPS;  
5  
6  int add_int(int a, int b);  
7  
8  class Robot  
9  {  
10  
11  public:  
12      Robot(std::string name);  
13  
14      void set_joint_configuration(std::vector<double> q);  
15  };  
16
```

C++ definitions.cpp ×

```
why_multiple_files > C++ definitions.cpp > set_joint_configuration(std::vector<double> q)  
1  #include "declarations.h"  
2  
3  int const MAX_STEPS = 100;  
4  
5  int add_int(int a, int b)  
6  {  
7      return a + b;  
8  }  
9  
10 Robot::Robot(std::string name) {  
11 }  
12  
13 void Robot::set_joint_configuration(std::vector<double> q) {  
14 }
```

How to split up the code?

Functions:

```
double sqrt(double x) { ... }
```

Becomes...

Declaration (in the .h):

```
double sqrt(double x);
```

Definition (in the .cpp):

```
double sqrt(double x) { ... }
```

How to split up the code?

What about classes?

Let's practice!

C declarations.h ×

```
why_multiple_files > C declarations.h > Robot > set_joint_configuration(std::vector<double> q);  
1  #include <vector>  
2  #include <string>  
3  
4  int const MAX_STEPS;  
5  
6  int add_int(int a, int b);  
7  
8  class Robot  
9  {  
10  
11  public:  
12      Robot(std::string name);  
13  
14      void set_joint_configuration(std::vector<double> q);  
15  };  
16
```

C++ definitions.cpp ×

```
why_multiple_files > C++ definitions.cpp > set_joint_configuration(std::vector<double> q);  
1  #include "declarations.h"  
2  
3  int const MAX_STEPS = 100;  
4  
5  int add_int(int a, int b)  
6  {  
7      return a + b;  
8  }  
9  
10 Robot::Robot(std::string name) {  
11 }  
12  
13 void Robot::set_joint_configuration(std::vector<double> q) {  
14 }
```


Compiling with multiple files

Building C++ code (even with only one file)

1. Compile
2. Link

You can compile one or more files into an executable using:

```
g++ main.cpp -o my_program
```

For multiple files, one executable:

```
g++ main.cpp lib1.cpp lib2.cpp -o my_program
```

Compiling with multiple files

Let's practice!

Compiling with multiple files - Libraries

But usually we want to split up our code into libraries. Why?

- faster, otherwise you have to recompile all the code every time!
- reusable, you gave use other people's libraries or they can use yours

So what is a library?

- A collection of compiled code that you don't run directly, but use from other code

Compiling with multiple files - Libraries

Libraries: `.a`, `.so`, `.lib`, `.dll`

cannot be run

can be used by
other code

made up of `.h`
and `.cpp` files

Executables: `no ext`, `.exe`

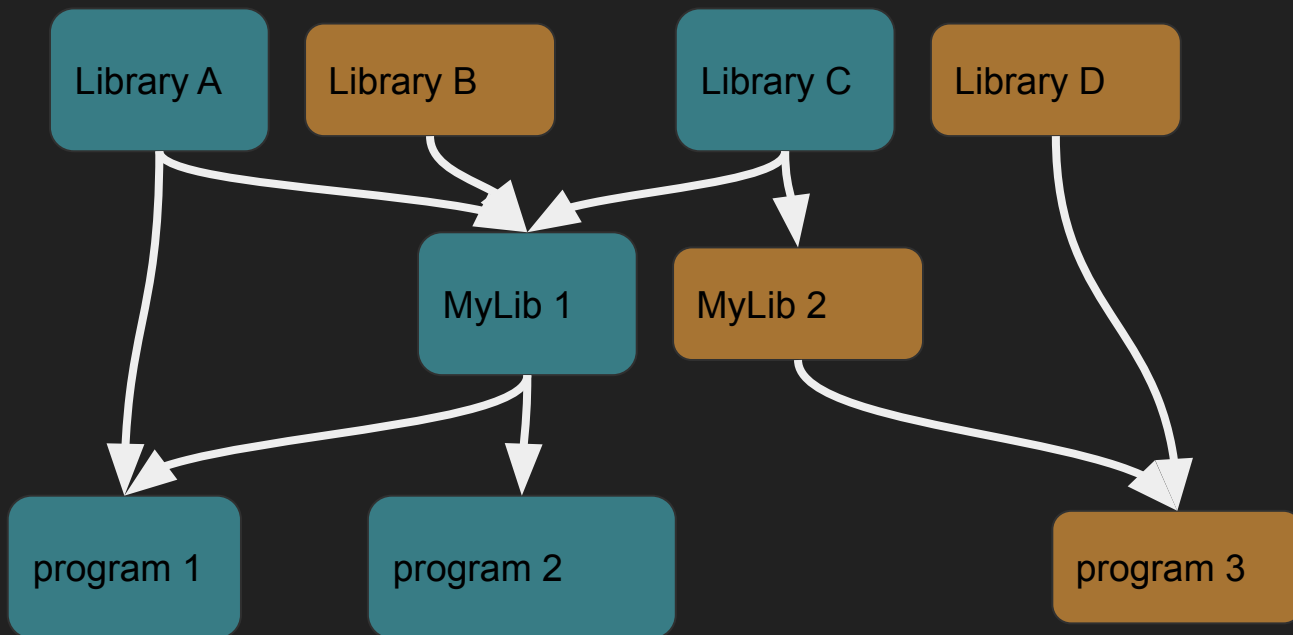
can be run

cannot be used
by other code

Compiling with multiple files

Outside the simple coding of course, libraries are how everything works!

The illustration below is actually *simpler* than many C++ projects



Compiling with multiple files

```
chrome => /opt/google/chrome/chrome (interpreter => /lib64/ld-linux-x86-64.so.2)
libdl.so.2 => /lib/x86_64-linux-gnu/libdl.so.2
libpthread.so.0 => /lib/x86_64-linux-gnu/libpthread.so.0
libgobject-2.0.so.0 => /lib/x86_64-linux-gnu/libgobject-2.0.so.0
libffi.so.7 => /lib/x86_64-linux-gnu/libffi.so.7
libglib-2.0.so.0 => /lib/x86_64-linux-gnu/libglib-2.0.so.0
libpcrc.so.3 => /lib/x86_64-linux-gnu/libpcrc.so.3
libnss3.so => /lib/x86_64-linux-gnu/libnss3.so
libplc4.so => /lib/x86_64-linux-gnu/libplc4.so
libplds4.so => /lib/x86_64-linux-gnu/libplds4.so
libnssutil3.so => /lib/x86_64-linux-gnu/libnssutil3.so
libsmime3.so => /lib/x86_64-linux-gnu/libsmime3.so
libnspr4.so => /lib/x86_64-linux-gnu/libnspr4.so
libatk-1.0.so.0 => /lib/x86_64-linux-gnu/libatk-1.0.so.0
libatk-bridge-2.0.so.0 => /lib/x86_64-linux-gnu/libatk-bridge-2.0.so.0
libcups.so.2 => /lib/x86_64-linux-gnu/libcups.so.2
libgssapi_krb5.so.2 => /lib/x86_64-linux-gnu/libgssapi_krb5.so.2
libkrb5.so.3 => /lib/x86_64-linux-gnu/libkrb5.so.3
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libk5crypto.so.3 => /lib/x86_64-linux-gnu/libk5crypto.so.3
libcom_err.so.2 => /lib/x86_64-linux-gnu/libcom_err.so.2
libkrb5support.so.0 => /lib/x86_64-linux-gnu/libkrb5support.so.0
libavahi-common.so.3 => /lib/x86_64-linux-gnu/libavahi-common.so.3
libavahi-client.so.3 => /lib/x86_64-linux-gnu/libavahi-client.so.3
libgnutls.so.30 => /lib/x86_64-linux-gnu/libgnutls.so.30
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libidn2.so.0 => /lib/x86_64-linux-gnu/libidn2.so.0
libunistring.so.2 => /lib/x86_64-linux-gnu/libunistring.so.2
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libnettle.so.7 => /lib/x86_64-linux-gnu/libnettle.so.7
libhogweed.so.5 => /lib/x86_64-linux-gnu/libhogweed.so.5
libgmp.so.10 => /lib/x86_64-linux-gnu/libgmp.so.10
libz.so.1 => /lib/x86_64-linux-gnu/libz.so.1
libgio-2.0.so.0 => /lib/x86_64-linux-gnu/libgio-2.0.so.0
libgmodule-2.0.so.0 => /lib/x86_64-linux-gnu/libgmodule-2.0.so.0
libmount.so.1 => /lib/x86_64-linux-gnu/libmount.so.1
libblkid.so.1 => /lib/x86_64-linux-gnu/libblkid.so.1
libselinux.so.1 => /lib/x86_64-linux-gnu/libselinux.so.1
libpcre2-8.so.0 => /lib/x86_64-linux-gnu/libpcre2-8.so.0
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libdrm.so.2 => /lib/x86_64-linux-gnu/libdrm.so.2
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libsystemd.so.0 => /lib/x86_64-linux-gnu/libsystemd.so.0
librt.so.1 => /lib/x86_64-linux-gnu/librt.so.1
liblzma.so.5 => /lib/x86_64-linux-gnu/liblzma.so.5
liblz4.so.1 => /lib/x86_64-linux-gnu/liblz4.so.1
libgcrypt.so.20 => /lib/x86_64-linux-gnu/libgcrypt.so.20
libgpg-error.so.0 => /lib/x86_64-linux-gnu/libgpg-error.so.0
libexpat.so.1 => /lib/x86_64-linux-gnu/libexpat.so.1
libm.so.6 => /lib/x86_64-linux-gnu/libm.so.6
libX11.so.6 => /lib/x86_64-linux-gnu/libX11.so.6
libXcomposite.so.1 => /lib/x86_64-linux-gnu/libXcomposite.so.1
libXdamage.so.1 => /lib/x86_64-linux-gnu/libXdamage.so.1
libXext.so.6 => /lib/x86_64-linux-gnu/libXext.so.6
libXfixes.so.3 => /lib/x86_64-linux-gnu/libXfixes.so.3
libXrandr.so.2 => /lib/x86_64-linux-gnu/libXrandr.so.2
libXrender.so.1 => /lib/x86_64-linux-gnu/libXrender.so.1
libgbm.so.1 => /lib/x86_64-linux-gnu/libgbm.so.1
libwayland-server.so.0 => /lib/x86_64-linux-gnu/libwayland-server.so.0
libxcb.so.1 => /lib/x86_64-linux-gnu/libxcb.so.1
libXau.so.6 => /lib/x86_64-linux-gnu/libXau.so.6
libXdmcp.so.6 => /lib/x86_64-linux-gnu/libXdmcp.so.6
libbsd.so.0 => /lib/x86_64-linux-gnu/libbsd.so.0
libxcbcommon.so.0 => /lib/x86_64-linux-gnu/libxcbcommon.so.0
libpango-1.0.so.0 => /lib/x86_64-linux-gnu/libpango-1.0.so.0
libfribidi.so.0 => /lib/x86_64-linux-gnu/libfribidi.so.0
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libfreetype.so.6 => /lib/x86_64-linux-gnu/libfreetype.so.6
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libcairo.so.2 => /lib/x86_64-linux-gnu/libcairo.so.2
libpixman-1.so.0 => /lib/x86_64-linux-gnu/libpixman-1.so.0
libfontconfig.so.1 => /lib/x86_64-linux-gnu/libfontconfig.so.1
libuuid.so.1 => /lib/x86_64-linux-gnu/libuuid.so.1
libxcb-shm.so.0 => /lib/x86_64-linux-gnu/libxcb-shm.so.0
libxcb-render.so.0 => /lib/x86_64-linux-gnu/libxcb-render.so.0
libasound.so.2 => /lib/x86_64-linux-gnu/libasound.so.2
libatspi.so.0 => /lib/x86_64-linux-gnu/libatspi.so.0
libgcc_s.so.1 => /lib/x86_64-linux-gnu/libgcc_s.so.1
libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6
ld-linux-x86-64.so.2 => /lib64/ld-linux-x86-64.so.2
```

A note on #include...

When you write `#include <vector> ...`

It copies and pastes the code from a file called “vector” into your code exactly where you wrote `#include`

5 min break

Next up:

- Project structure
- CMake

Project Structure

```
my_project/  
  include/  
    my_project/  
      utilities.h  
      logging.h  
      geometry/  
        shapes.h  
        area.h  
  src/  
    geometry/  
      shapes.cpp  
      area.cpp  
    kinematics.cpp  
    main.cpp
```

CMake

compile commands

```
g++ main.cpp lib.cpp -o my_program
```

CMake

```
add_executable(my_program main.cpp lib.cpp)
```

CMake

compile commands

```
g++ lib.cpp -o lib.a
```

```
g++ main.cpp lib.a -o my_program
```

CMake

```
add_library(lib lib.cpp)
```

```
add_executable(my_program main.cpp)
```

```
target_link_libraries(my_program PUBLIC lib)
```

CMake

The real power is when the project gets big, and has external dependencies! ... also, it works on Windows!

```
my_project/  
  include/  
    my_project/  
      utilities.h  
      logging.h  
      geometry/  
        shapes.h  
        area.h  
  
  src/  
    geometry/  
      shapes.cpp  
      area.cpp  
    kinematics.cpp  
    main.cpp
```

compile commands

```
g++ src/geometry/shapes.cpp src/geometry/area.cpp  
    -o build/libgeometry.a
```

```
g++ src/kinematics.cpp -o build/libkinematics.a
```

```
g++ main.cpp -o main
```

CMake

The real power is when the project gets big, and has external dependencies! ... also, it works on Windows!

compile commands

```
g++ src/geometry/shapes.cpp
    src/geometry/area.cpp
    -o build/libgeometry.a

g++ src/kinematics.cpp
    -o build/libkinematics.a

g++ main.cpp -o main
```

CMake

```
add_library(geometry src/geometry/shapes.cpp
    src/geometry/area.cpp)

add_library(kinematics src/kinematics.cpp)

add_executable(main main.cpp)

target_link_libraries(main geometry kinematics)
```

CMake

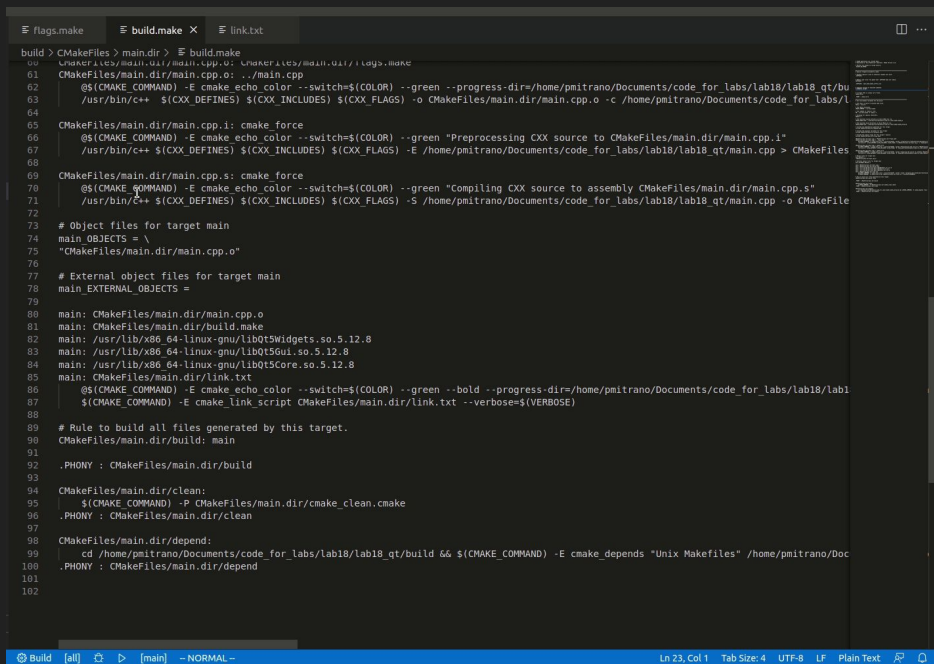
two commands you always need at the top of the main CMakeLists.txt:

```
cmake_minimum_required(3.10)  # this is a version number  
project(my_project_name)
```

CMake

The real power is when the project gets big, and has external dependencies! ... also, it works on Windows!

Look how much you'd have to write to do use a library like Qt...



```
build > CMakeFiles > main.dir > build.make
60 CMakeFiles/main.dir/main.cpp.o: /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build.make
61 CMakeFiles/main.dir/main.cpp.o: /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build.make
62 @$(CMAKE_COMMAND) -E cmake_echo_color --switch=$(COLOR) --green --progress-dirs=/home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build.make
63 /usr/bin/c++ $(CXX_DEFINES) $(CXX_INCLUDES) $(CXX_FLAGS) -o CMakeFiles/main.dir/main.cpp.o -c /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build.make
64
65 CMakeFiles/main.dir/main.cpp.i: cmake_force
66 @$(CMAKE_COMMAND) -E cmake_echo_color --switch=$(COLOR) --green "Preprocessing CXX source to CMakeFiles/main.dir/main.cpp.i"
67 /usr/bin/c++ $(CXX_DEFINES) $(CXX_INCLUDES) $(CXX_FLAGS) -E /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build.make > CMakeFiles/main.dir/main.cpp.i
68
69 CMakeFiles/main.dir/main.cpp.s: cmake_force
70 @$(CMAKE_COMMAND) -E cmake_echo_color --switch=$(COLOR) --green "Compiling CXX source to assembly CMakeFiles/main.dir/main.cpp.s"
71 /usr/bin/c++ $(CXX_DEFINES) $(CXX_INCLUDES) $(CXX_FLAGS) -S /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build.make > CMakeFiles/main.dir/main.cpp.s
72
73 # Object files for target main
74 main_OBJECTS =
75 "CMakeFiles/main.dir/main.cpp.o"
76
77 # External object files for target main
78 main_EXTERNAL_OBJECTS =
79
80 main: CMakeFiles/main.dir/main.cpp.o
81 main: CMakeFiles/main.dir/build.make
82 main: /usr/lib/x86_64-linux-gnu/libQt5Widgets.so.5.12.8
83 main: /usr/lib/x86_64-linux-gnu/libQt5Gui.so.5.12.8
84 main: /usr/lib/x86_64-linux-gnu/libQt5Core.so.5.12.8
85 main: CMakeFiles/main.dir/link.txt
86 @$(CMAKE_COMMAND) -E cmake_echo_color --switch=$(COLOR) --green --bold --progress-dirs=/home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build.make
87 $(CMAKE_COMMAND) -E cmake_link_script CMakeFiles/main.dir/link.txt --verbose=$(VERBOSE)
88
89 # Rule to build all files generated by this target.
90 CMakeFiles/main.dir/build: main
91
92 .PHONY: CMakeFiles/main.dir/build
93
94 CMakeFiles/main.dir/clean:
95 $(CMAKE_COMMAND) -P CMakeFiles/main.dir/cmake_clean.cmake
96 .PHONY: CMakeFiles/main.dir/clean
97
98 CMakeFiles/main.dir/depend:
99 cd /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build && $(CMAKE_COMMAND) -E cmake_depends "Unix Makefiles" /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build /home/pmitrano/Documents/code_for_labs/lab18/lab18_qt/build
100 .PHONY: CMakeFiles/main.dir/depend
101
102
```

Include Paths

```
my_project/  
  include/  
    my_project/  
      utilities.h  
      logging.h  
      geometry/  
        shapes.h  
        area.h  
  
  src/  
    geometry/  
      shapes.cpp  
      area.cpp  
    kinematics.cpp  
    main.cpp
```

```
#include <include/my_project/utilities.h>
```

```
#include <my_project/utilities.h>
```

```
#include <../utilities.h>
```

```
#include <../my_project/utilities.h>
```

Which should we use?

Reading the CMake Documentation

 CMake » latest release (3.25.0-rc2) » Documentation » cmake-commands(7) » add_library

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add_library

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Add a library to the project using the specified source files.

Normal Libraries

```
add_library(<name> [STATIC | SHARED | MODULE]
            [EXCLUDE_FROM_ALL]
            [<source>...])
```

Adds a library target called `<name>` to be built from the source files listed in the command invocation. The `<name>` corresponds to the logical target name and must be globally unique within a project. The actual file name of the

CMake in VSCode

- We will go over this once together
- There are tutorials online if you forget
 - <https://code.visualstudio.com/docs/cpp/cmake-linux>

5 minute break

Next up:

- Lab exercises

Homework:

- Homework 5
- Read [Type deduction for objects using the auto keyword – Learn C++](#)