C++ Modules - Getting Started Today

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Meeting C++ 2024

Introduction

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A familiar example...

— *File:* `my_function.hpp`

```
char const* my_function();
```

— *File:* `my_function.cpp`

```
char const* my_function() {
  return "Hello from function!";
}
```

— *File:* `main.cpp`

```
#include <my_function.hpp>
#include <print>

int main() {
  std::println("{}", my_function());
}
```

#include can happen anywhere

— *File:* a.hpp

```
inline int my_function
#include <a_impl.hpp>
```

— *File:* a_impl.hpp

```
{
  return 42;
}
```

Including files twice does not work

— *File:* `a.hpp`

```
class A {};
```

— *File:* `main.cpp`

```
#include <a.hpp>
#include <a.hpp>  // redefiniton error!

int main() {
}
```

Included files are not isolated from the surrounding state

— *File:* `a.hpp`

```
class A {
private:
  char const* u_cant_touch_this() {
    return "Preprocessor hits me so hard";
  }
};
```

— *File:* `main.cpp`

```
#define private public
#include <a.hpp>
#undef private
int main() {
  std::println("{}", A{}.u_cant_touch_this());
}
```

Included files do not need to be self-contained

— *File:* a.hpp

```
class A {
  std::vector<int> numbers;
};
```

— *File:* main.cpp

```
#include <vector>
#include <a.hpp>

int main() {
}
```

Include files are compiled again for each translation unit

— *File:* `a.cpp`

```
#include <massive_header.hpp>

// [...]
```

— *File:* `b.cpp`

```
#include <massive_header.hpp>

// [...]
```

Hello Modules!

— *File:* `module.cpp`

```
export module my_module;

export char const* my_function() {
  return "Hello Modules!";
}
```

— *File:* `main.cpp`

```
#include <print>
import my_module;

int main() {
  std::println("{}", my_function());
}
```

Exporting things

```
// functions
export int getNumber();

// types
export class SomeType;

// templates
export template<typename T>
T combine(T n1, T n2);
export template<typename T>
class MyTemplatedType;
```

Exporting things

```
export namespace a {
  void is_exported();
}
namespace a {
  void is_not_exported();
}

namespace a {
  void will_be_exported_in_b();
}
export namespace b {
  export using ::a::will_be_exported_in_b;
}
```

Exporting things

```
export {
  void will_be_exported();

  void will_also_be_exported();

  struct WillAlsoBeExported {
    // [...]
  };

  // the following will not compile:
  static void no_internal_linkage();
}
```

Exporting things

— *File:* `module1.cpp`

```
export module A;

export int foo() { return 42; }
```

— *File:* `module2.cpp`

```
export module B;

export import A;
```

— *File:* `main.cpp`

```
import B;
int main() {
  return foo();
}
```

Not exported does not mean unreachable

— *File:* `module.cpp`

```
export module m;
struct NotExported { int i = 42; };
export NotExported getNotExported()
{ return {}; }
```

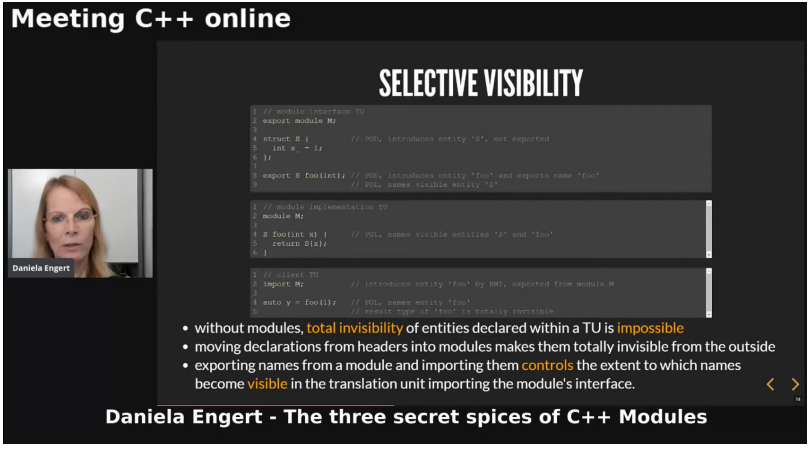
— *File:* `main.cpp`

```
import m;
int main() {
  int const ii = getNotExported().i;
}
```

This is not new!

```
auto getS()
{ struct S { int i = 42; }; return S{}; }
```

Daniela Engert - The three secret spices of C++ Modules - Visibility, Reachability, Linkage



Different shapes of modules

Primary Module Interface Unit

— *File:* `my_module.cpp`

```
export module my_module;

export char const* my_function() {
  return "Hello Modules!";
}
```

Module Implementation Unit

— *File:* my_module.cpp

```
export module my_module;

export char const* my_function();
```

— *File:* my_module_impl.cpp

```
module my_module;

char const* my_function() {
  return "Hello Modules!";
}
```

Module Interface Partitions

— *File:* my_module.cpp

```
export module mice;

export import :pinky;
export import :the_brain;
```

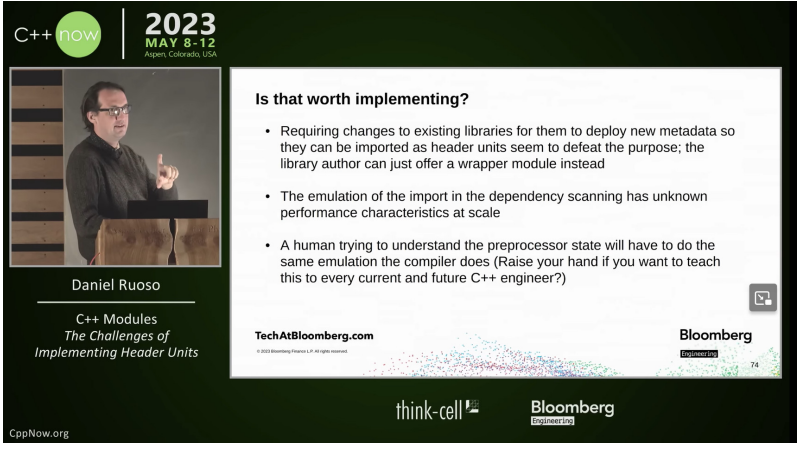
— *File:* my_module_p1.cpp

```
export module mice:pinky;
export void narf() {}
```

— *File:* my_module_p2.cpp

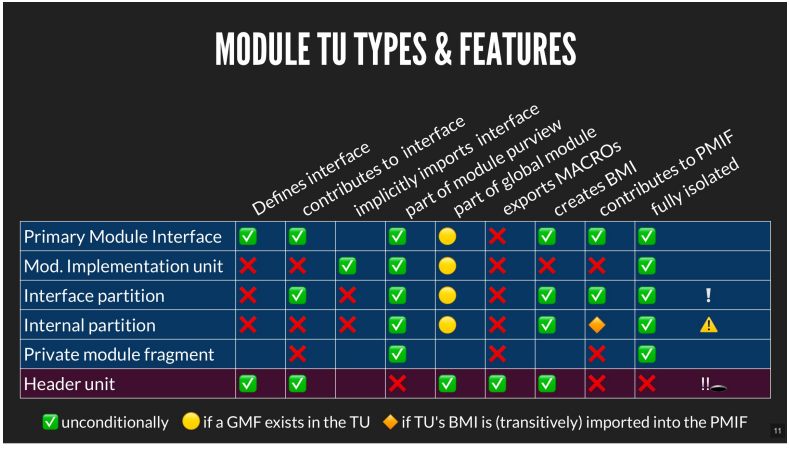
```
export module mice:the_brain;
export void take_over_the_world() {}
struct SecretMasterplan {};
```

We're not talking about Header Units



If you want to know more...

Daniela Engert - So you want to use C++ Modules... cross-platform? (NDC TechTown 2023)



Building modules code with CMake

Building with CMake - Old School

```
cmake_minimum_required(VERSION 3.28)
project(my_project)

add_executable(my_executable)
target_sources(my_executable PUBLIC
  ${PROJECT_SOURCE_DIR}/my_src.cpp
  ${PROJECT_SOURCE_DIR}/inc/my_header1.hpp
  ${PROJECT_SOURCE_DIR}/inc/my_header2.hpp
)
target_include_directories(my_executable PUBLIC
  ${PROJECT_SOURCE_DIR}/inc)
```

Building with CMake - File Sets (since v3.23)

```
cmake_minimum_required(VERSION 3.23)
project(my_project)

add_executable(my_executable)
target_sources(my_executable PUBLIC
    ${PROJECT_SOURCE_DIR}/my_src.cpp
  PUBLIC
  FILE_SET HEADERS
  BASE_DIRS ${PROJECT_SOURCE_DIR}/inc
  FILES
    ${PROJECT_SOURCE_DIR}/inc/my_header1.hpp
    ${PROJECT_SOURCE_DIR}/inc/my_header2.hpp
)
```

Building with CMake - Modules (since v3.28)

```
cmake_minimum_required(VERSION 3.28)
project(my_project)
set(CMAKE_CXX_STANDARD 20)

add_executable(my_executable)
target_sources(my_executable PUBLIC
    ${PROJECT_SOURCE_DIR}/my_src.cpp
  PUBLIC
  FILE_SET CXX_MODULES
  FILES
    ${PROJECT_SOURCE_DIR}/mod/my_module.cpp
)
```

Use the latest tools!

- Absolute latest CMake (at least 3.28, at least 3.30 for `import std`)
- Latest Visual Studio 2022 (at least toolset version 19.34)
- Ninja 1.11
- Clang at least 17, prefer 19
- gcc at least 14, consider trunk

Even with the latest tools there are still plenty of bugs and inconsistent behavior between compilers!

A few things to keep in mind

Module source file or regular source file?

- If it has an `export module` somewhere → Module
- If it is a module partition → Module
- Otherwise → Regular.

Which file extension?

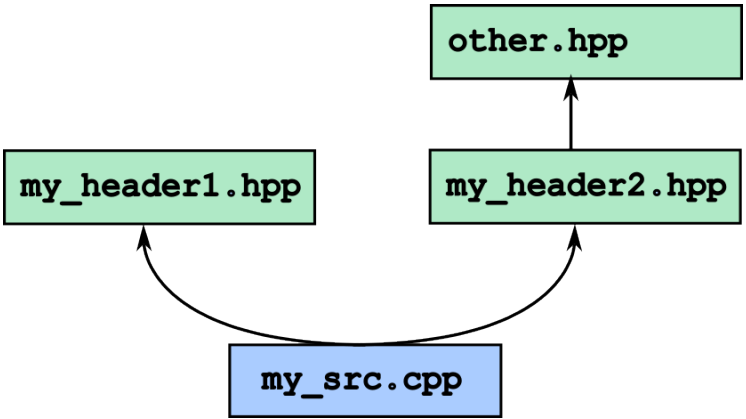
- Many different extensions started appearing in the compilers: `.ixx`, `.cppm`, `.cxxm`, `.c++m`, `.ccm`.
- With CMake you don't need to use any of them!
- If you decide to use them, be sure to *only* use them for module source files (as defined above)

What is a build system anyway?

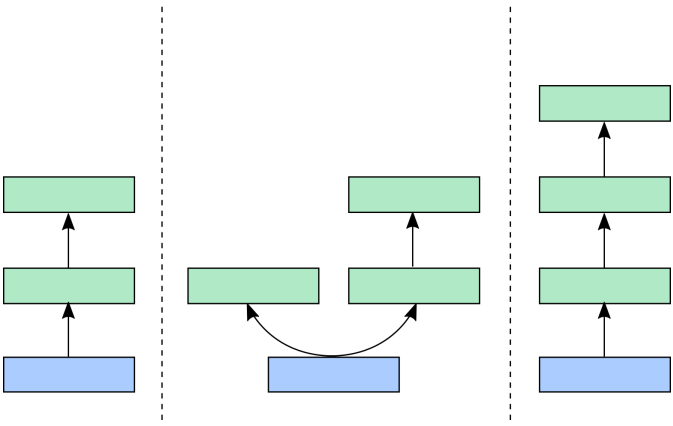
```
$ g++ -o my_src.o -I . -c my_src.cpp

$ g++ my_executable.o -o my_executable
```

Tracking dependencies



Tracking dependencies



Old-school: Manual tracking

Makefile

```
my_src.o: my_src.cpp my_header1.hpp my_header2.hpp other.hpp
main.o: main.cpp main.hpp my_header1.hpp my_header2.hpp

my_executable: main.o my_src.o
  $(CXX) -o my_executable main.o my_src.o
```

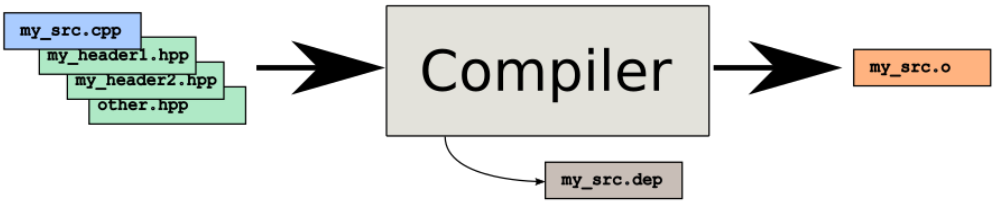
Tracking changes to header files

```
$ g++ -o my_src.dep -I . -M -c my_src.cpp
```

— *File:* `my_src.dep`

```
my_src.o: my_src.cpp \
  my_header1.hpp
  my_header2.hpp
  other.hpp
```

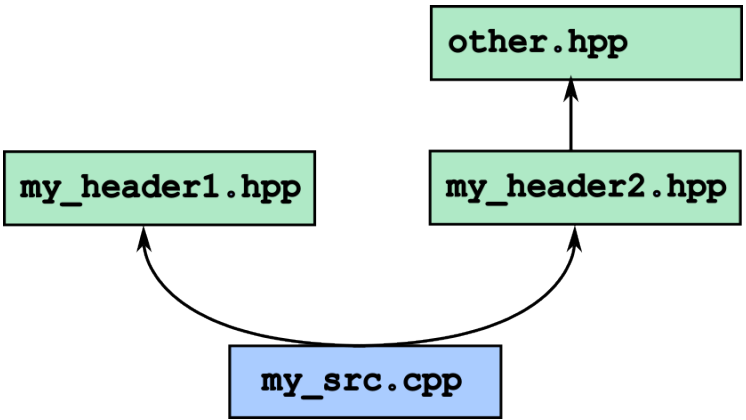
Tracking changes to header files



— *File:* `my_src.dep`

```
my_src.o: my_src.cpp \
  my_header1.hpp
  my_header2.hpp
  other.hpp
```

What changes for the build system?



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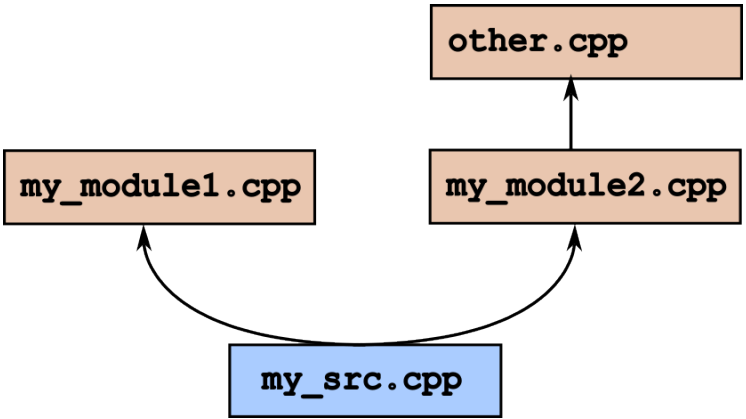

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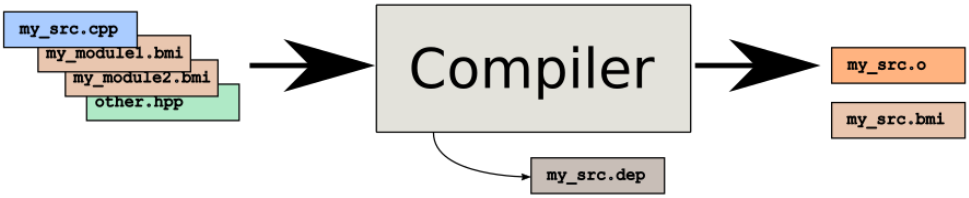

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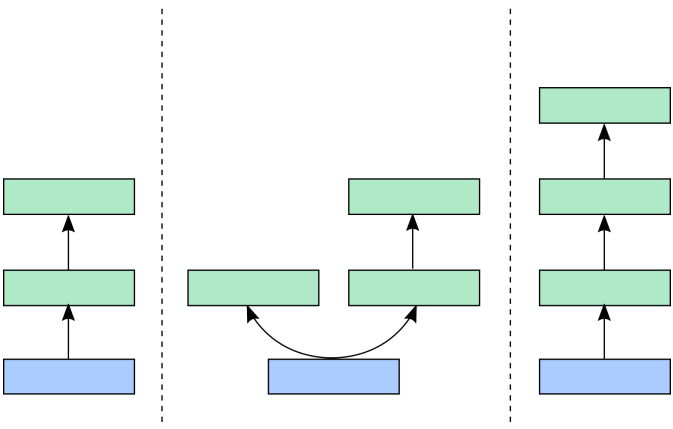

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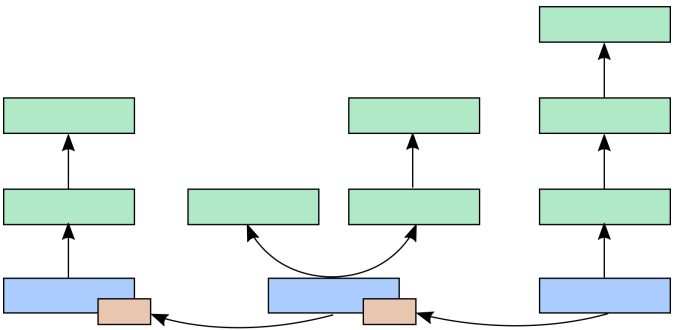
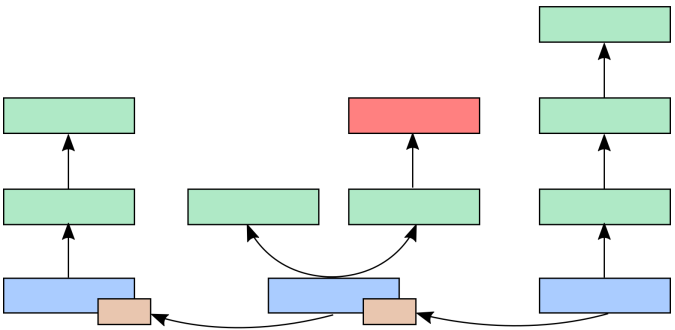


What changes for the build system?

```
add_executable(my_executable)
target_sources(my_executable PUBLIC
    ${PROJECT_SOURCE_DIR}/my_src.cpp
  PUBLIC
  FILE_SET CXX_MODULES
  BASE_DIRS ${PROJECT_SOURCE_DIR}
  FILES
    ${PROJECT_SOURCE_DIR}/my_module1.cpp
    ${PROJECT_SOURCE_DIR}/my_module2.cpp
    ${PROJECT_SOURCE_DIR}/other.cpp
)
```

What changes for the build system?



Some useful advice for starting out...

Interacting with headers - the global module fragment

```
export module A;

import std;

export std::vector<int> getVector() {
  return std::vector<int>{ 1, 2, 3, 4 };
}
```

Interacting with headers - the global module fragment

```
export module A;

import std;

export std::vector<int> getVector() {
  return std::vector<int>{ 1, 2, 3, 4 };
}
```

Interacting with headers - the global module fragment

```
module;

#include <vector>

export module A;

export std::vector<int> getVector() {
  return std::vector<int>{ 1, 2, 3, 4 };
}
```

Interacting with headers - the global module fragment

```
module;

#include <vector>

export module A;

export std::vector<int> getVector() {
  return std::vector<int>{ 1, 2, 3, 4 };
}
```

Interacting with headers - the global module fragment

```
module;

#include <vector>

export module A;

export std::vector<int> getVector() {
  return std::vector<int>{ 1, 2, 3, 4 };
}
```

Interacting with headers - the global module fragment

```
module;

#include <vector>

export module A;

export std::vector<int> getVector() {
  return std::vector<int>{ 1, 2, 3, 4 };
}
```

Beware of mixing headers and modules

— *File:* `my_module.cpp`

```
export module m;

import std;

export std::string f() { return "!"; }
```

— *File:* `main.cpp`

```
import m;


int main() {
  auto const s = f();
}
```

Beware of mixing headers and modules

— *File:* `my_module.cpp`

```
export module m;

import std;

export std::string f() { return "!"; }
```

— *File:* `main.cpp`

```
import m;


int main() {
  auto const s = f();
}
```

Beware of mixing headers and modules

— *File:* `my_module.cpp`

```
export module m;

import std;

export std::string f() { return "!"; }
```

— *File:* `main.cpp`

```
import m;


int main() {
  std::string const s = f();
}
```

Beware of mixing headers and modules

— *File:* `my_module.cpp`

```
export module m;

import std;

export std::string f() { return "!"; }
```

— *File:* `main.cpp`

```
import m;
#include <string>

int main() {
  std::string const s = f();
}
```

Names exported from a module become attached to the module

```
int the_answer() {
  return 42;
}
```

```
$ nm my_source.o
0000000000000000 T _Z10the_answerv
$ c++filt _Z10the_answerv
the_answer()
```

Names exported from a module become attached to the module

```
namespace my_namespace {
  int the_answer() {
    return 42;
  }
}
```

```
$ nm my_source.o
0000000000000000 T _ZN12my_namespace10the_answerEv
$ c++filt _ZN12my_namespace10the_answerEv
my_namespace::the_answer()
```

Names exported from a module become attached to the module

```
export module my_module;
int the_answer() {
  return 42;
}
```

```
$ nm my_source.o
0000000000000000 T _ZGIW9my_module
0000000000000000 T _ZW9my_module10the_answerv
$ c++filt _ZGIW9my_module
initializer nonefor module my_module
$ c++filt _ZW9my_module10the_answerv
the_answer@my_module()
```

When mixing, always put #includes first!

```
#include <string>

// Guideline: All #includes should
//  come before the first import!
import std;



int main() {
  std::string const s = f();
}
```

Modularizing legacy libraries - Include standard library early

— *File:* `lib.hpp`

```
#include <string>
std::string f();
```

— *File:* `libm.cpp`

```
export module lib;
export {
#include <lib.hpp>
}
```

Modularizing legacy libraries - Include standard library early

— *File:* `lib.hpp`

```
#include <string>
std::string f();
```

— *File:* `libm.cpp`

```
module;
#include <string>

export module lib;
export {
#include <lib.hpp>
}
```

Modularizing legacy libraries - Export names with `using`

— *File:* `lib.hpp`

```
class AwesomeType;
```

— *File:* `libm.cpp`

```
module;
#include <lib.hpp>
export module lib;
export using ::AwesomeType;
```

Modularizing legacy libraries - Detach from module

```
module;
// Global module fragment - can't export from here
void f1() {}

export module lib;
// Model purview - declaring here attaches to module
export void f2() {}


// Use extern to detach declaration
export extern "C++" void f3() {}
```

Modularizing legacy libraries - Preprocessor macros

— *File:* `libm.cpp`

```
export module lib;
#define AWESOME_MACRO 42
```

— *File:* `main.cpp`

```
import lib;

int main() {
  return AWESOME_MACRO;   // error! macros
                          // cannot be exported
}
```

Modularizing legacy libraries - Preprocessor macros

— *File:* `libm.cpp`

```
export module lib;
// ...
```

— *File:* `libm.hpp`

```
#define AWESOME_MACRO 42
```

— *File:* `main.cpp`

```
#include <libm.hpp>
import lib;

int main() {
  return AWESOME_MACRO;
}
```

Modularizing legacy libraries - Preprocessor macros

— *File:* `libm.cpp`

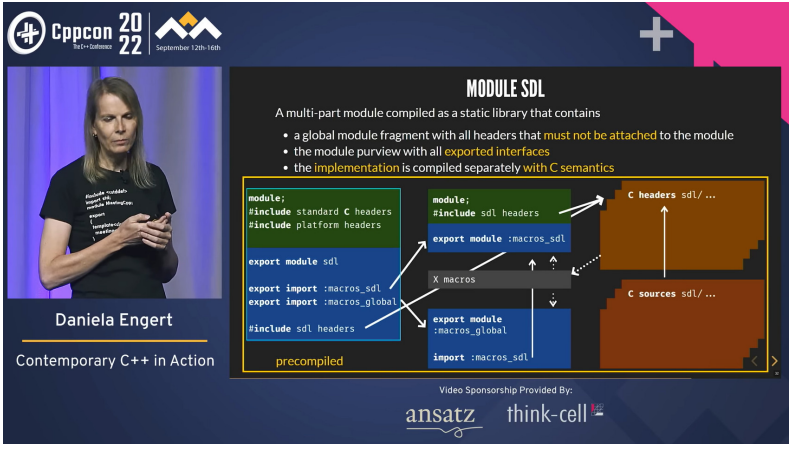
```
export module lib;
#define AWESOME_MACRO 42
export constexpr int AwesomeConstant =
    AWESOME_MACRO;
```

— *File:* `main.cpp`

```
import lib;

int main() {
  return AwesomeConstant;
}
```

Daniela Engert - Contemporary C++ in Action



Conclusion

- Modules are slowly maturing. Try them out today!
- There is still a lot of dark corners in the implementations, but the more people use them, the quicker those get fixed.
- Integrating header-based legacy code is challenging and requires some practice.
- There is a lot of low-hanging fruit there for people interested in contributing to compilers and tooling

Conclusion

- Modules are slowly maturing. Try them out today!
- There is still a lot of dark corners in the implementations, but the more people use them, the quicker those get fixed.
- Integrating header-based legacy code is challenging and requires some practice.
- There is a lot of low-hanging fruit there for people interested in contributing to compilers and tooling

Where to go from here...

- Daniela Engert - Modules: The Beginner's Guide (Meeting C++ 2019)
- Daniela Engert - A Short Tour of C++ Modules (CppCon 2021)
- Bill Hoffman - import CMake: Mastering C++ Modules (CppCon 2024)
- Bret Brown - Modern CMake Modules (CppCon 2021)
- vector-of-bool - Understanding C++ Modules (Blog post series)
- Modules on cppreference
- Boeckel, King, Maynard, Hoffman - How CMake supports Fortran modules and its applicability to C++ (WG21 D1483)

Thanks for your attention.

Modules *Hello World* example on Compiler Explorer:
https://godbolt.org/z/Ea54d1Ta3



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