Practical C++ Modules

Boris Kolpackov

build2.org

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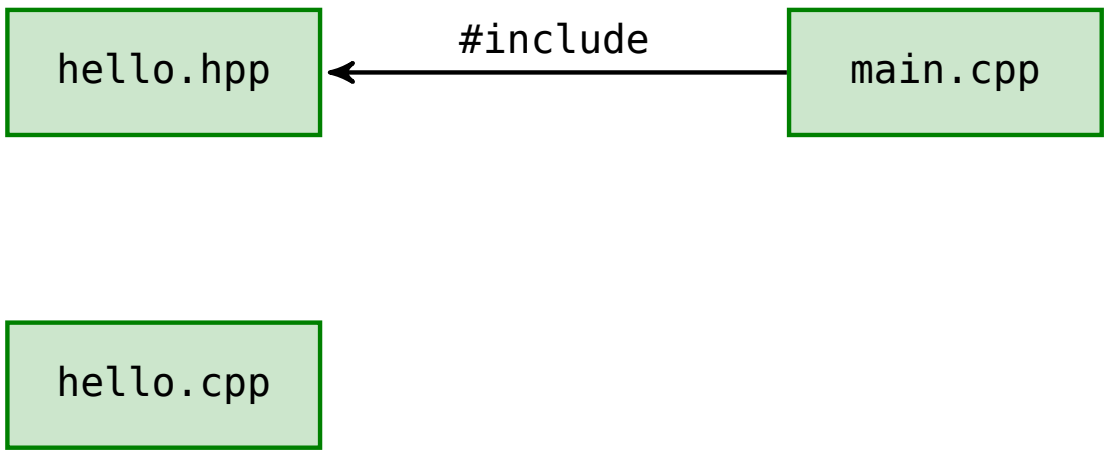
What & Why

Headers and Textual Inclusion

Headers and Textual Inclusion



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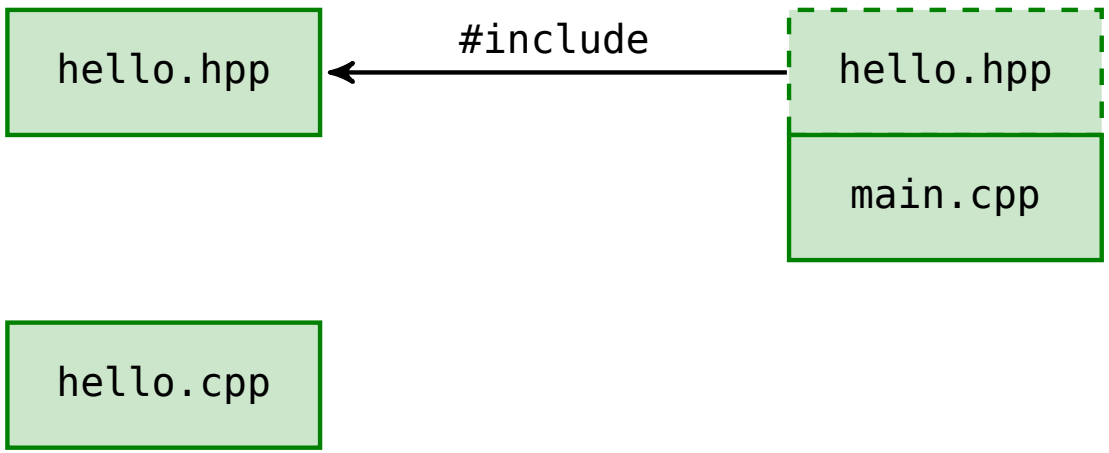

Header Disadvantages

- Compilation speed
- Header/Source split
- Lack of isolation
  - Our code can change headers
  - Headers can change our code
  - Headers can change each other
  - Dependency on implementation
- ODR violations
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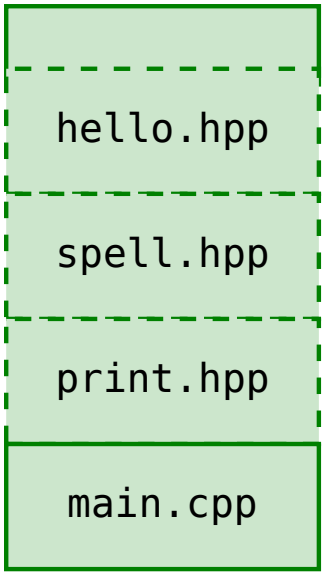
- Order dependency and cycles
- Interfacing with C++



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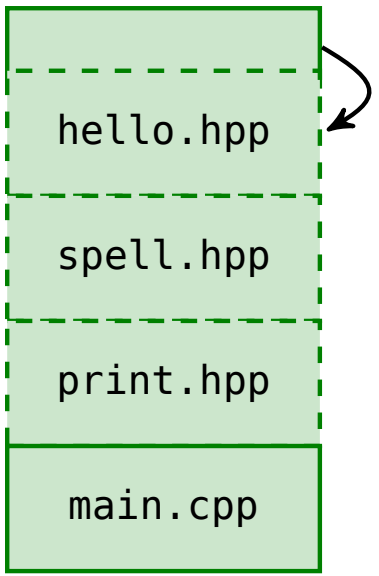

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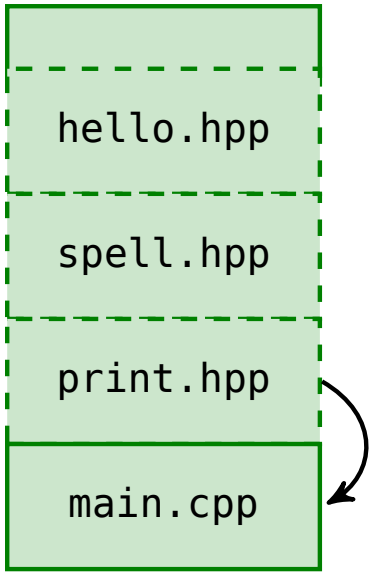

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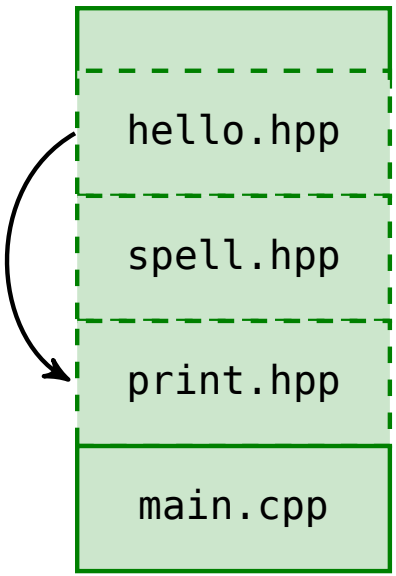

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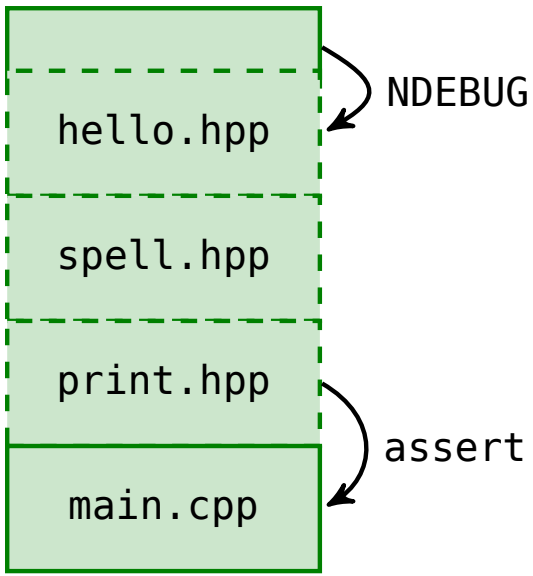
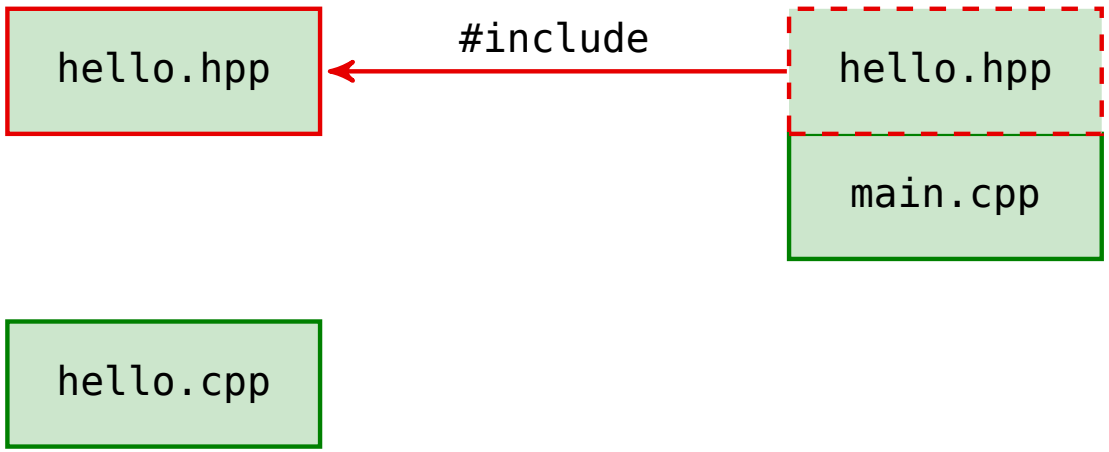


Header Advantages

- Embarrassingly Parallel
- Familiar
- Flexible & Hackable
- Toolable (to a degree)

From Headers to Modules



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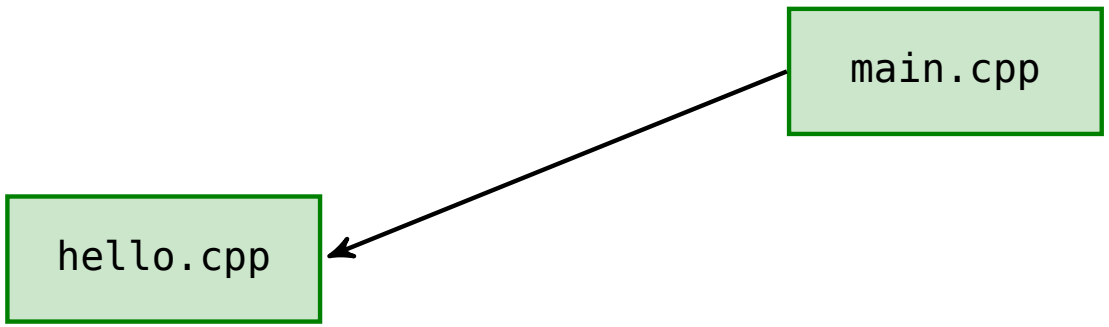

Module Importation

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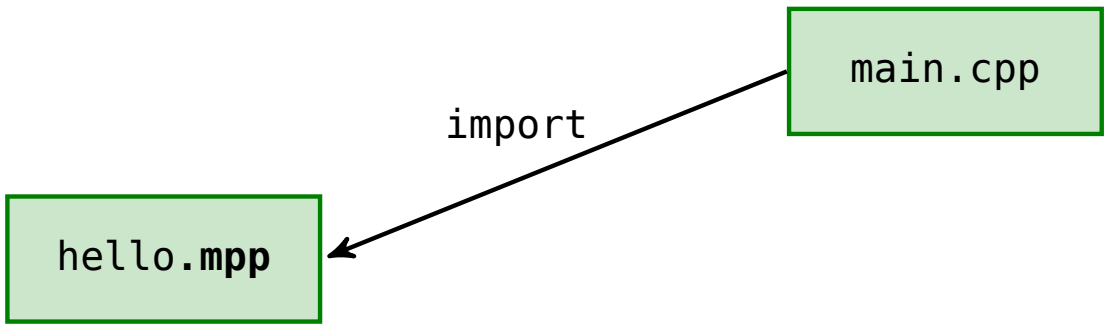

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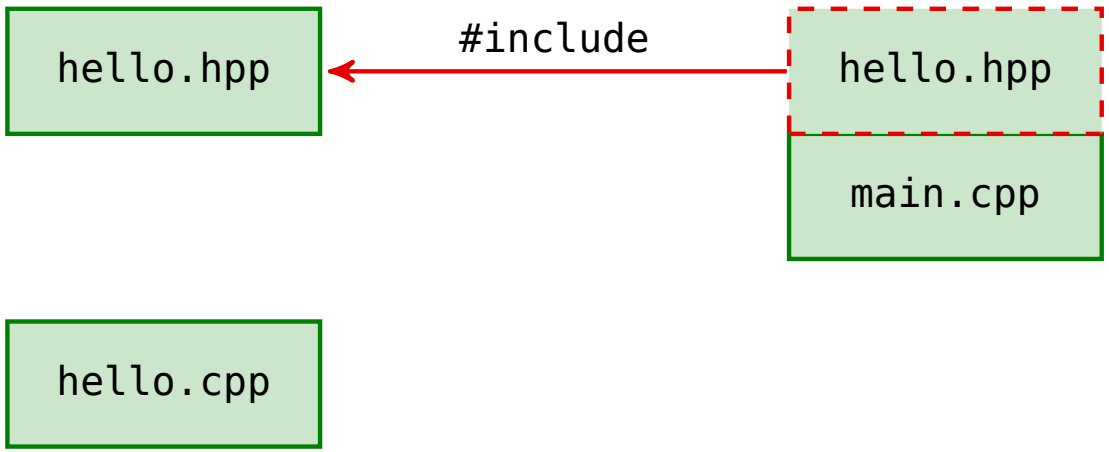

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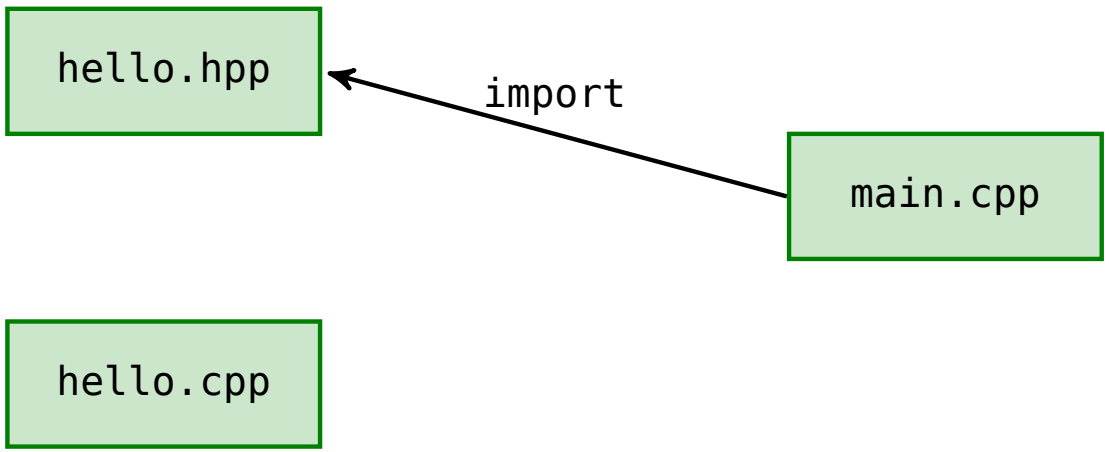

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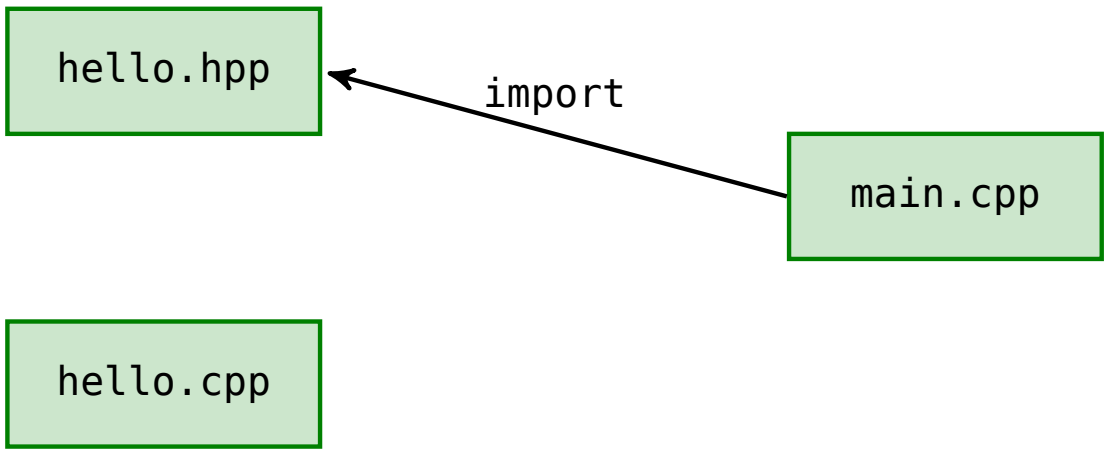

Header Importation

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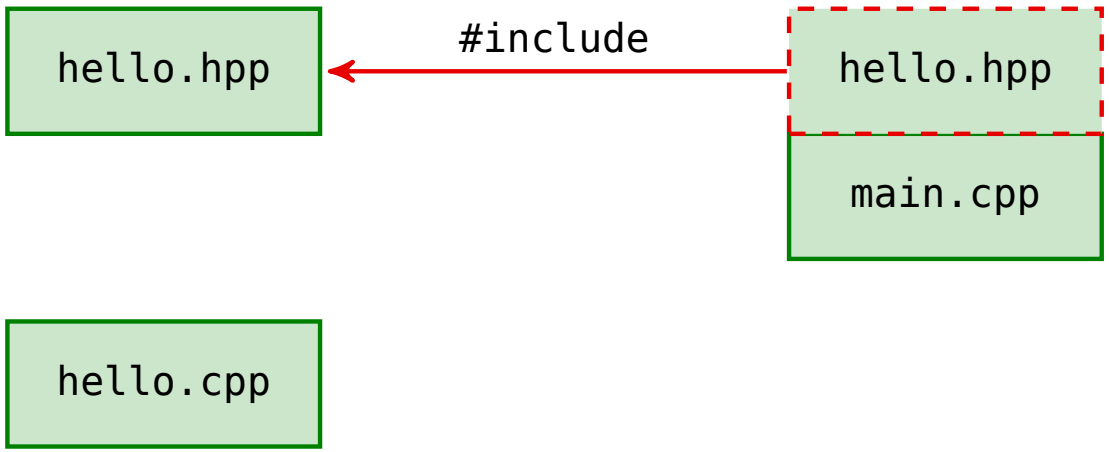

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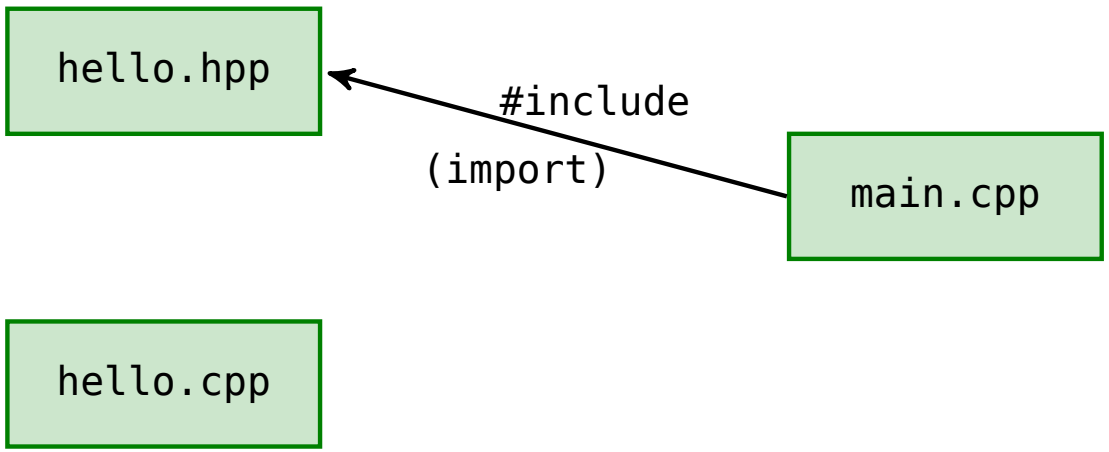
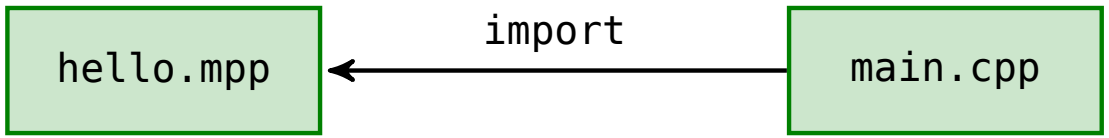


Include Translation

Modularization Options

- Module importation
- Header importation
- Include translation (to Header importation)

Modules Build Mechanics



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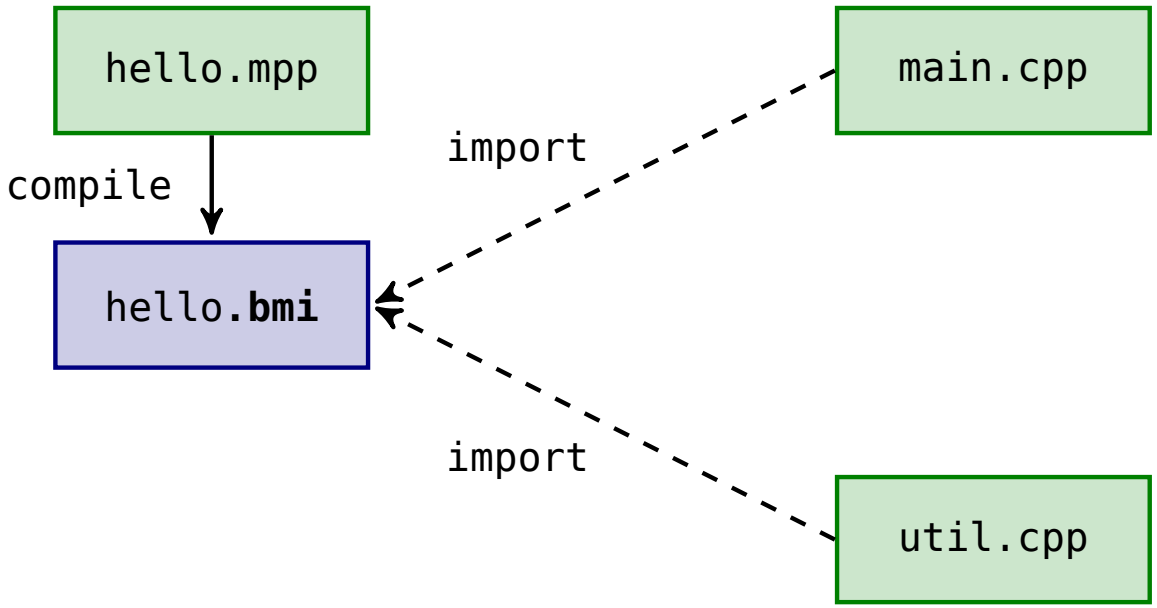

Binary Module Interface (BMI)

Modularization Options

- Include translation (to Header importation)
- Header importation
- Module importation

Include Translation

- No modification required on either side
- But header should be *importable*
- All C++20 `std` headers are importable...
- ... (except for `<c*>` C wrapper headers)

Include Translation

How does it actually work?

Importable Headers

- Modular in the broader sense:
  - Does not rely on pre-definitions (macros, declarations)
  - Or post-undefinitions (macros)
- Example: header that requires pre-inclusion of another header
- Example: header that implements X-macro technique
- Internal linkage is Ok as long as not used outside header
- Example: Schwartz counter

Include Translation: Problems Solved

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Header Importation

main.cpp

```
#include ”hello.hpp”

int main ()
{
  // ...
}
```

main.cpp

```
import ”hello.hpp”;

int main ()
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  // ...
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Header Importation

- Only consumer modifications required
- Header should be importable
- Remaining `#includes` are Ok...
- ...But not automatically translated

Header Importation: Problems Solved

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Module Importation

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#pragma once
#include <string>
namespace hello {
  void say (std::string);
}
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hello.cpp

```
#include "hello.hpp"
#include <iostream>
namespace hello {
  void say (std::string) {
    ... }
}
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main.cpp

```
#include "hello.hpp"
int main () {
  hello::say ("World");
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hello.mpp

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export module hello;
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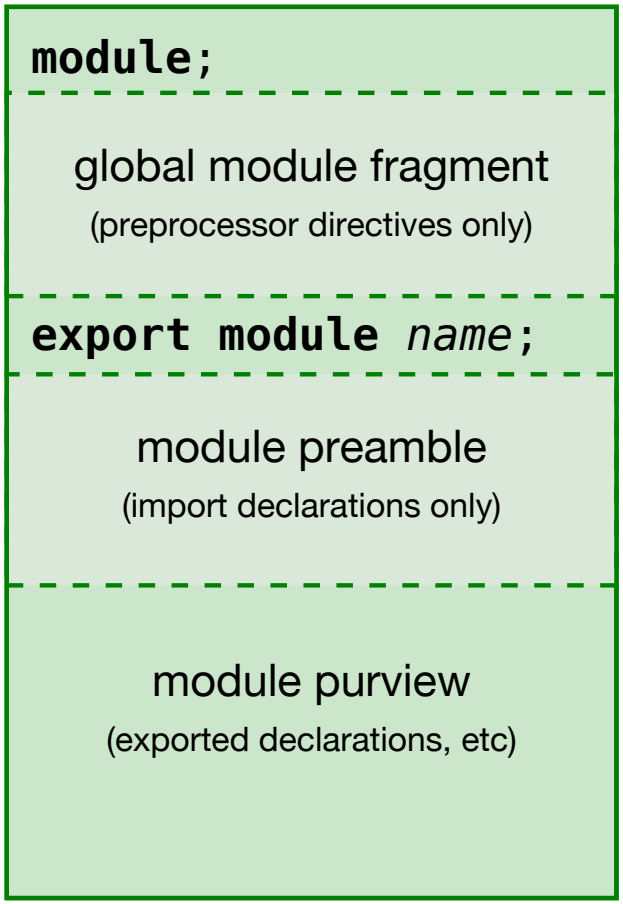

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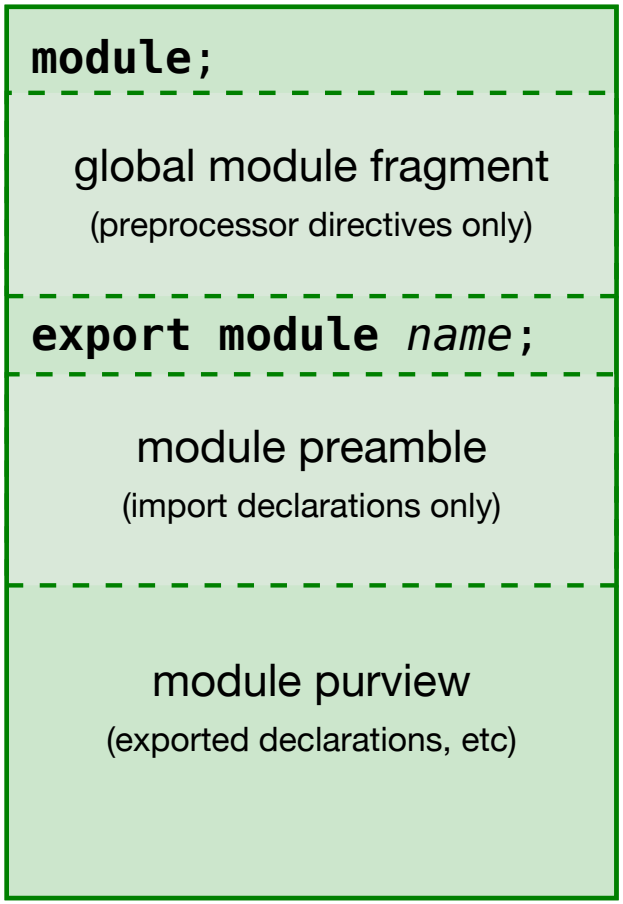

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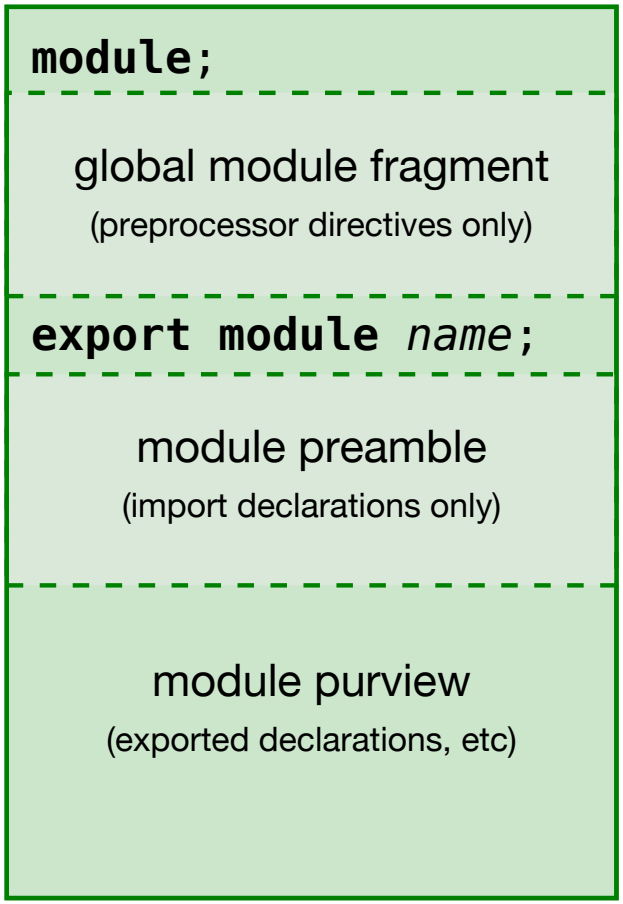

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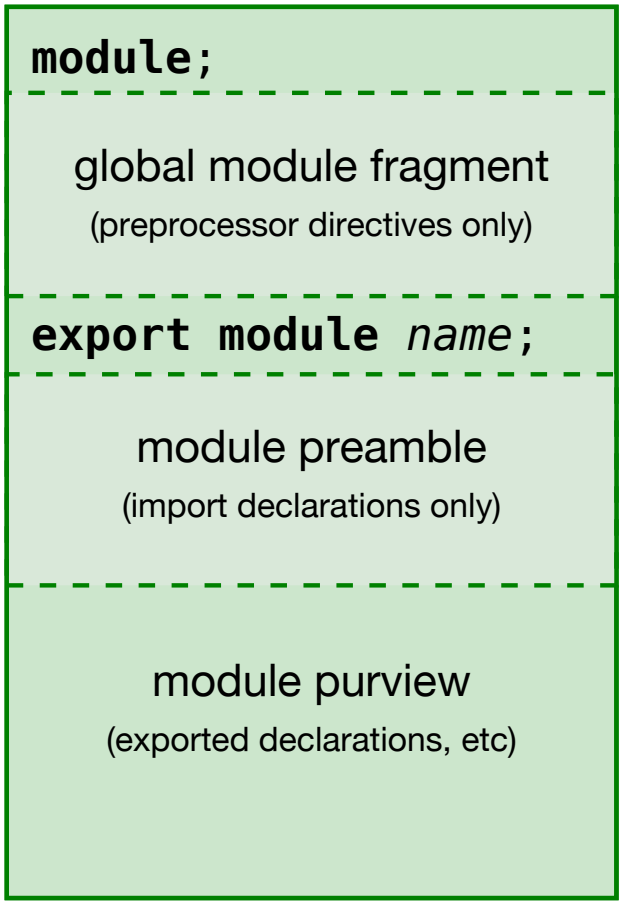

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What's wrong with this?

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```
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Including headers in module purview is a bad idea

(Unless you know what you are doing)

Module Interface and Implementation

hello.mpp

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export module hello;

import <string>;
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export namespace hello {
  void say (std::string) {
    ... }
}
```

Module Interface and Implementation

hello.mpp

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```

Module Interface and Implementation

- Interface can (still) define non-inline functions/variables
- We can have multiple implementation units...
- ...But only one (primary) interface unit
- Interface partitions: split interface
- Implementation partitions: “module-private interface”

To Split or Not to Split

Pros:

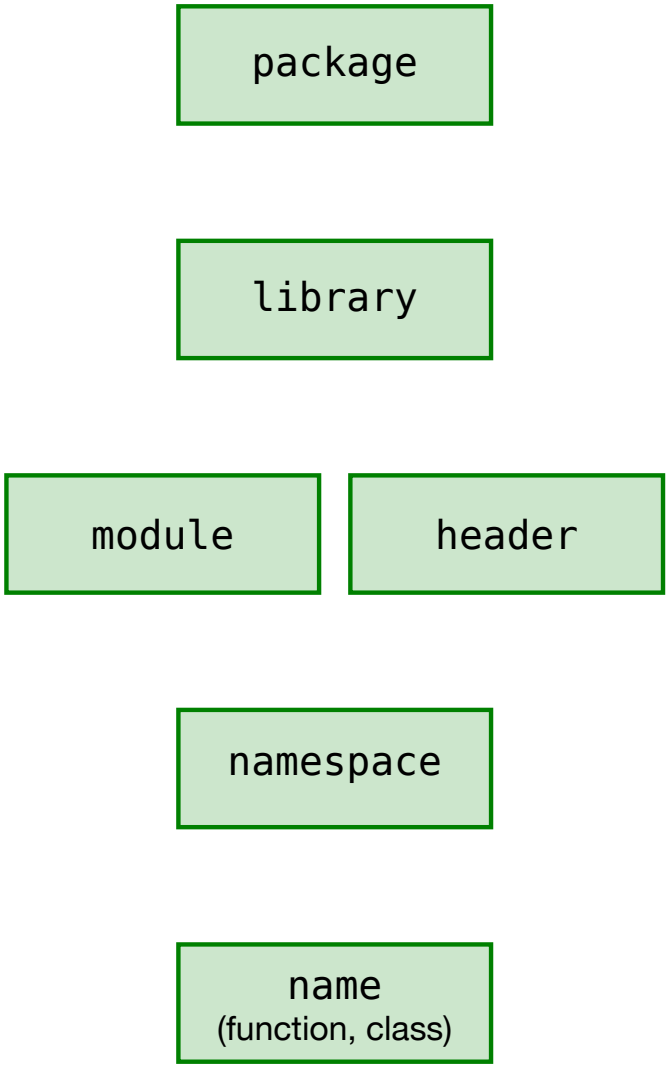
- DRY
- *Module interface-only* libraries

Cons:

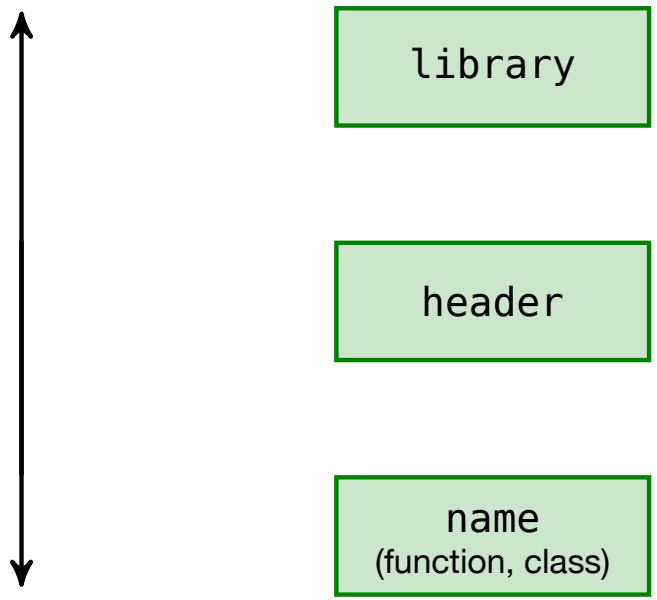
- Unnecessary recompilation
- Reduced interface readability
- Extra dependencies (implementation imports)
- Reduced interface compilation speed

Judgment Call

Physical Design Mechanisms



Module Granularity



Cost of importing modules is negligible

Module Granularity

Too big:

- Unnecessary recompilations
- Hard to navigate

Too small:

- Tedious to import
- Also hard to navigate

Module Granularity

Combine related and commonly-used entities

(generally good design)

Module Granularity

Combine related and commonly-used entities

(generally good design)

Use re-export to create “aggregate modules”

hello.mpp

```
export module hello;

export import hello.format;
export import hello.print;
```

Module Name

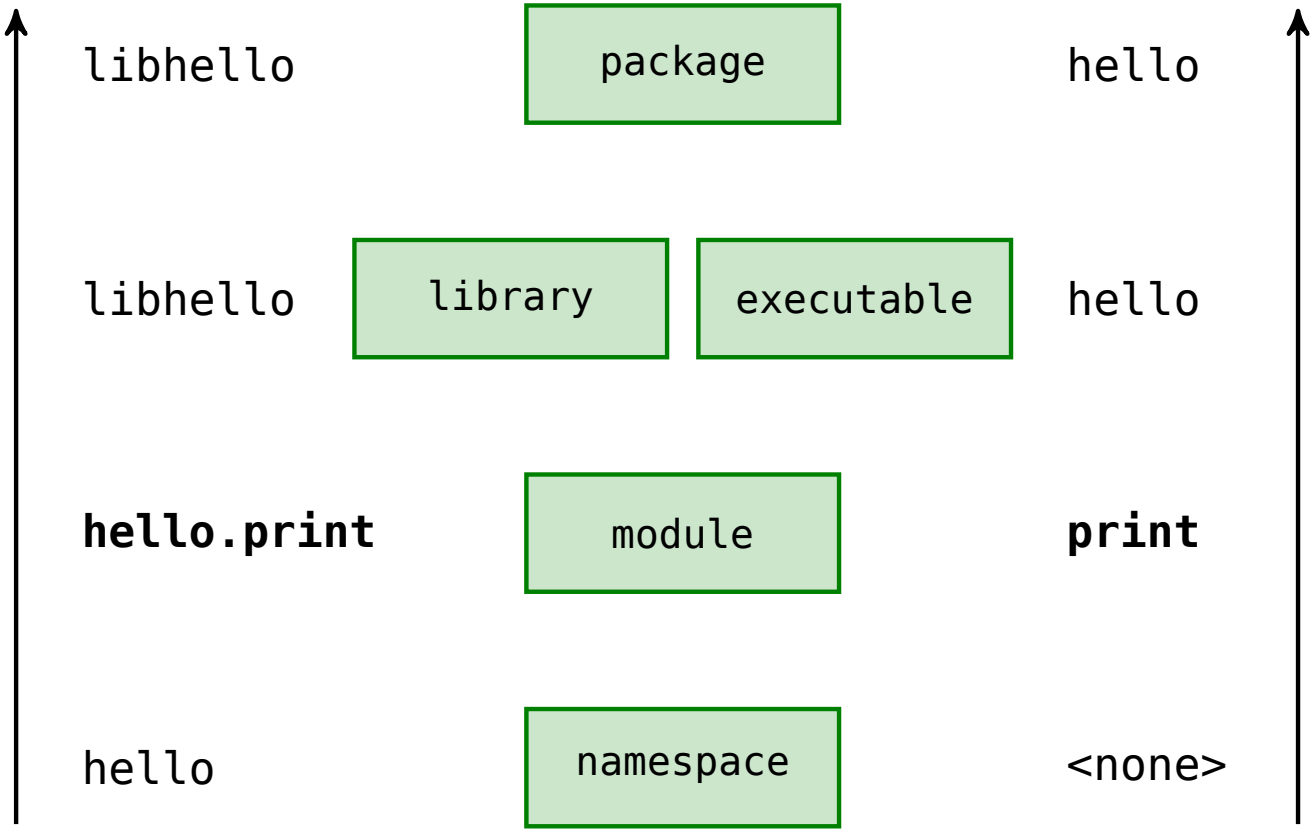
```
export module hello;

export module hello.format;
export module hello.print;

export module hello.print.iostream;
```

- Sequence of dot-separated identifiers
- On a separate “name plane”
- Do not collide with namespace/type/function names
- No specified hierarchical semantics (yet)

Naming Modules



Naming Modules

- Start with the library/project top namespace (if any)
- Finish with a name describing the module's functionality
- If for a single/primary entity (class, etc), use its name
- Provide "aggregate modules" for hierarchy

Module Naming Examples

- Library name: `libbutl`
- Library namespace: `butl`
- Library modules:

```
butl.base64                  butl.path
butl.char_scanner            butl.path_io
butl.const_ptr               butl.path_map
butl.diagnostics             butl.process
butl.fdstream                butl.sha256
butl.filesystem              butl.small_vector
butl.manifest_parser         butl.string_parser
butl.manifest_serializer     butl.string_table
butl.multi_index             butl.target_triplet
butl.openssl                 butl.timestamp
butl.pager                   butl.vector_view
```

Naming Module Files

- No mapping between module names and file names
- But clearly makes sense for them to be related

Naming Module Files: Extensions

Source/Header	Module Interface	Module Implementation
`.cpp/.hpp/.h`	`.mpp`	`.cpp`
`.cxx/.hxx/.h`	`.mxx`	`.cxx`
`.c++/.h++/.h`	`.m++`	`.c++`
`.cc/.hh/.h`	switch	switch
`.C/.H/.h`	switch	switch

Have a separate extension for interfaces

Naming Module Files: Base

```
export module hello;

export module hello.format;
export module hello.print;

export module hello.print.iostream;
```

```
libhello/
├── hello.mpp
├── hello-format.mpp
├── hello-print.mpp
└── hello-print-iostream.mpp
```

```
libhello/
├── hello.mpp
├── format.mpp
├── print.mpp
└── print-iostream.mpp
```

Naming Module Files

Embed sufficient amount of module name “tail”

into file names to unambiguously distinguish modules

within a library/project

Distributing Modules

What's in a BMI?

- Compiler specific, can be anything between
- ...stream of preprocessed tokens
- ...dump of an AST
- ...something close to object code
- Sensitive to most compiler options (even warning)

What to Install/Distribute?

BMIs are not a *distribution mechanism*

- BMIs should not be installed/distributed (maybe cached)
- Install/distribute module interfaces instead
- BTW, another reason to split interface/implementation

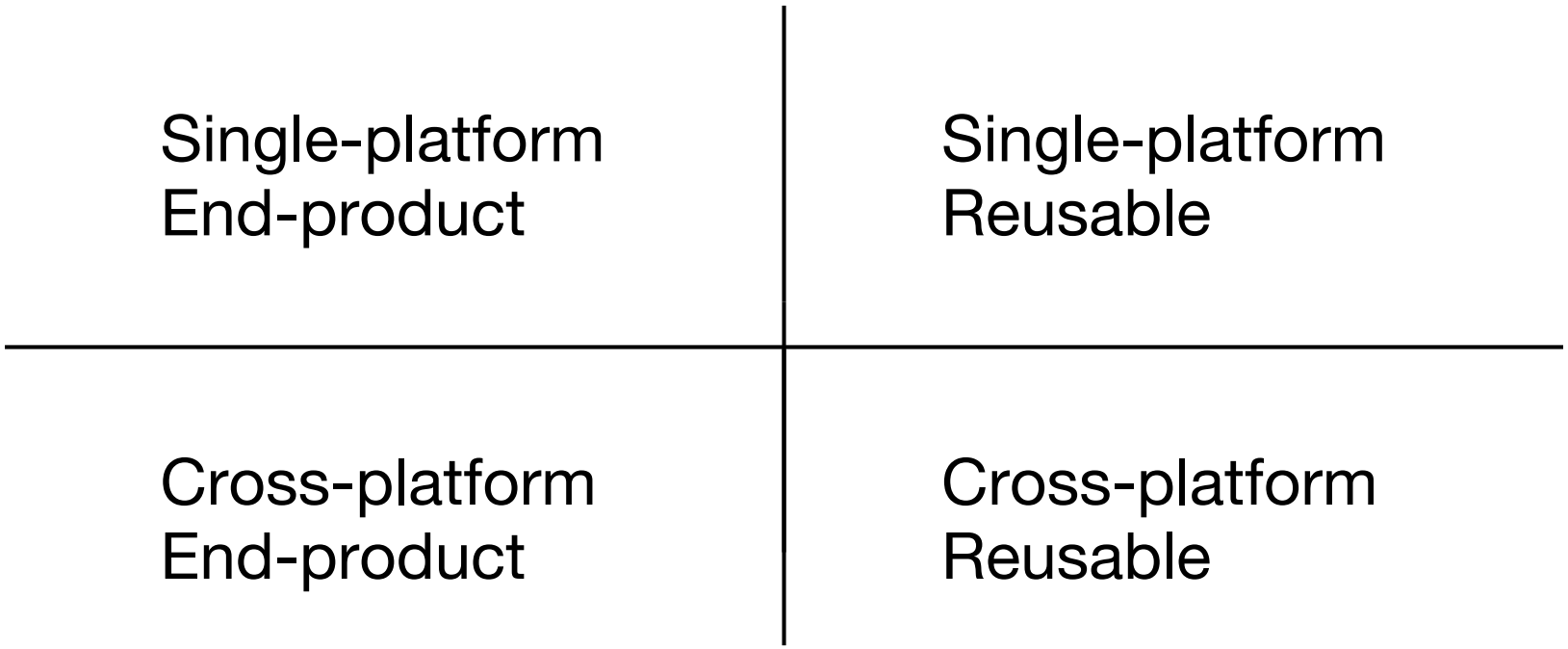
When

Modularization Options

How far do you want to go?

- Include translation
- Header importation
- Module importation

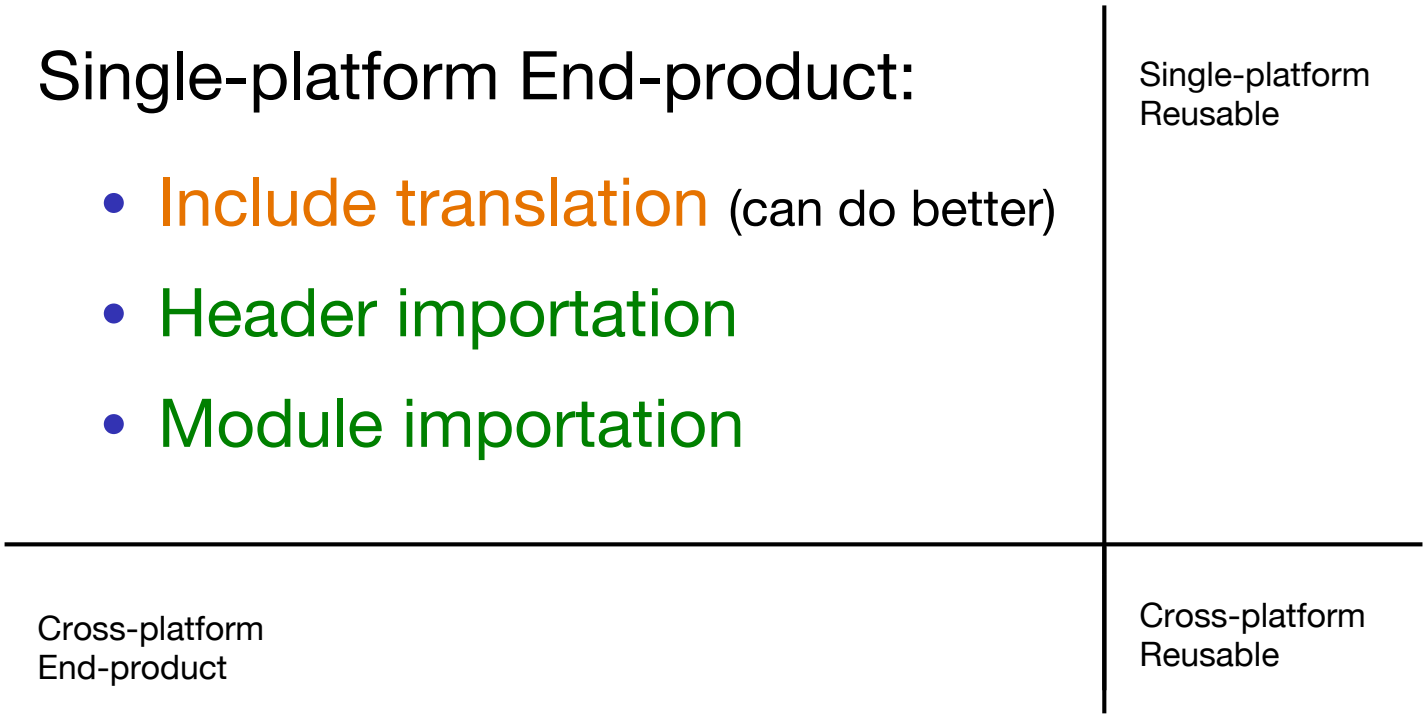
Types of C++ Projects



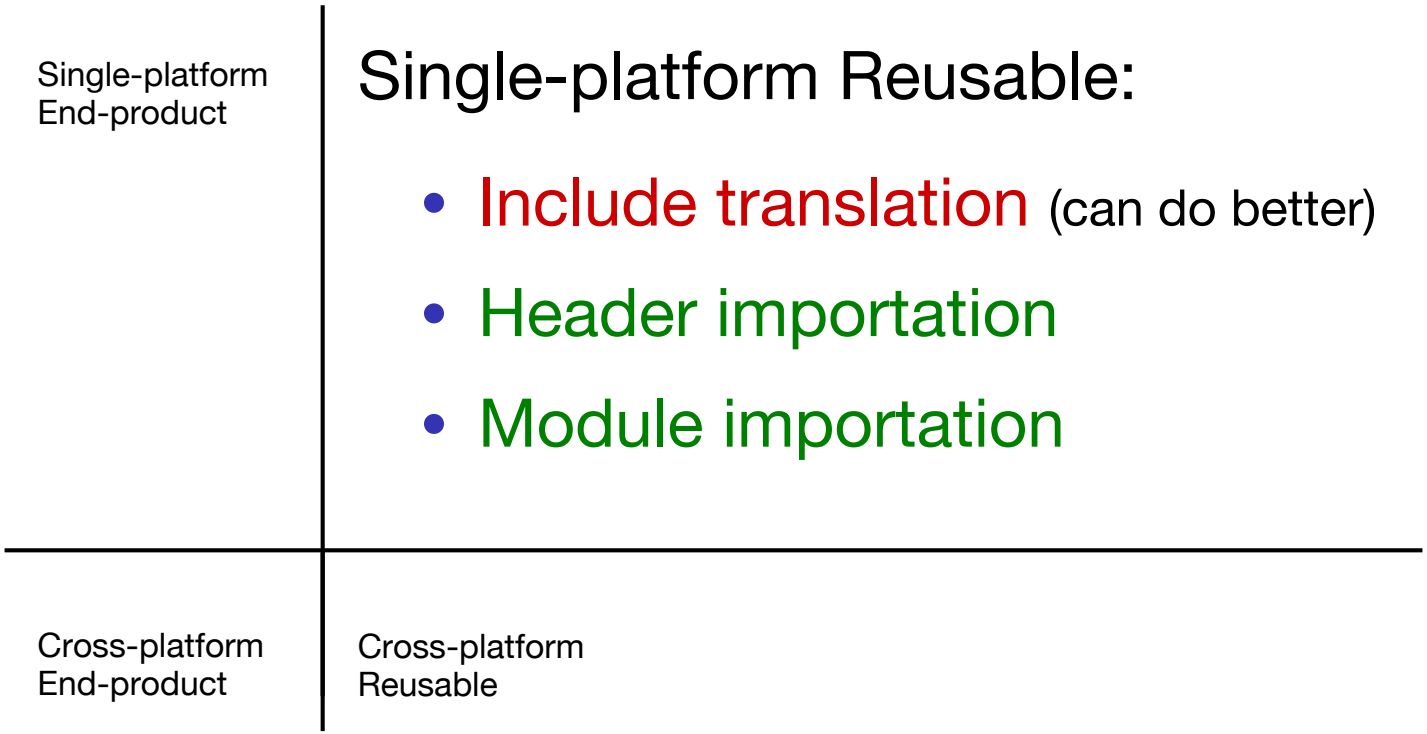
Single-platform End-product

Single-platform End-product:

- Include translation (can do better)
- Header importation
- Module importation



Single-platform Reusable



Cross-platform End-product

Single-platform
End-product

Single-platform
Reusable

Cross-platform End-product:

- Include translation
- Header importation (complexity)
- Module importation (portability)

Cross-platform
Reusable

Cross-platform Reusable

Single-platform End-product	Single-platform Reusable
Cross-platform End-product	Cross-platform Reusable: • Include translation • Header importation (portability) • Module importation (portability)

Cross-platform Reusable

Dual header/module interface?

Just say No!

See CppCon 2017 “Building C++ Modules” for details

When: the Standard

- Modules in C++20
- Importable standard library headers in C++20
- Modular standard library in C++23
- What about system headers?

When: the Compilers

- Still incomplete but improving rapidly
- There are bugs, especially in header importation
- Support for build systems is still lacking

When: the Build Systems

	Modules	Headers	Include Translation
build2	Yes	Yes (GCC)	Yes (GCC)
CMake	WIP		
Meson		“wait and see”	
autotools		“unlikely?”	
Bazel		?	
Buck		?	
IDEs		?	

Questions?

build2.org

Build System Manual → C++ Modules Support

Areas Not Covered:

- Name visibility vs reachability
- Private module fragment (`module :private;`)
- Interface and implementation partitions
- Exported `using` declarations (`export using X;`)
- What about `main()`?
- What about module versioning? Inline modules anyone?