Department I - C Plus Plus

# Modern and Lucid C++ Advanced for Professional Programmers

## Week 13 – Hourglass Interfaces

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FS2019

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# Hourglass Interfaces

based on Stefanus DuToit "Hourglass Interfaces" talk at CppCon 2016

[https://www.youtube.com/watch?v=PVYdHDm0q6Y](https://www.youtube.com/watch?v=PVYdHDm0q6Y)

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# Library Interfaces

- **DLL APIs work best (and cross-platform compatible) with C only**
  - We ignore the Windows burden of providing DLL-export and DLL-import syntax
- **C++ can provide C-compatible function interfaces using `extern "C"` in front of a declaration**
- **C-APIs are error-prone and can be tedious to use**
- **C++ exceptions do not pass nicely across a C-API**
- **Foreign language bindings (e.g. for Python etc) often expect C-APIs**
- **API - Application Programming Interface**
  - If stable, you do not need to change your code, if something changes
- **ABI - Application Binary Interface**
  - If stable, you can use and share DLLs/shared libraries without recompilation
- **Not universally applicable, but very common**

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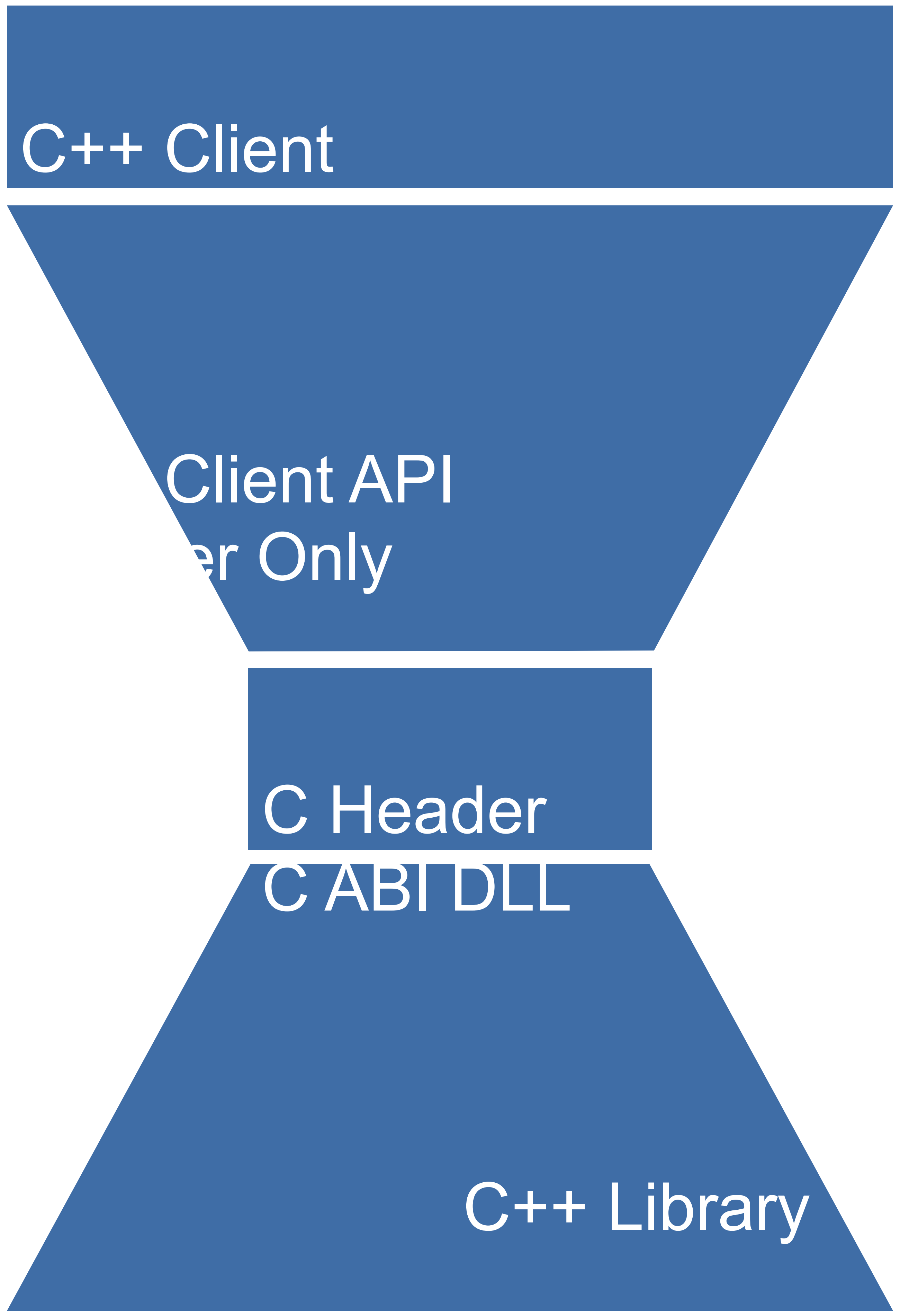
# Hourglass Interface

- **Shape of an hourglass**



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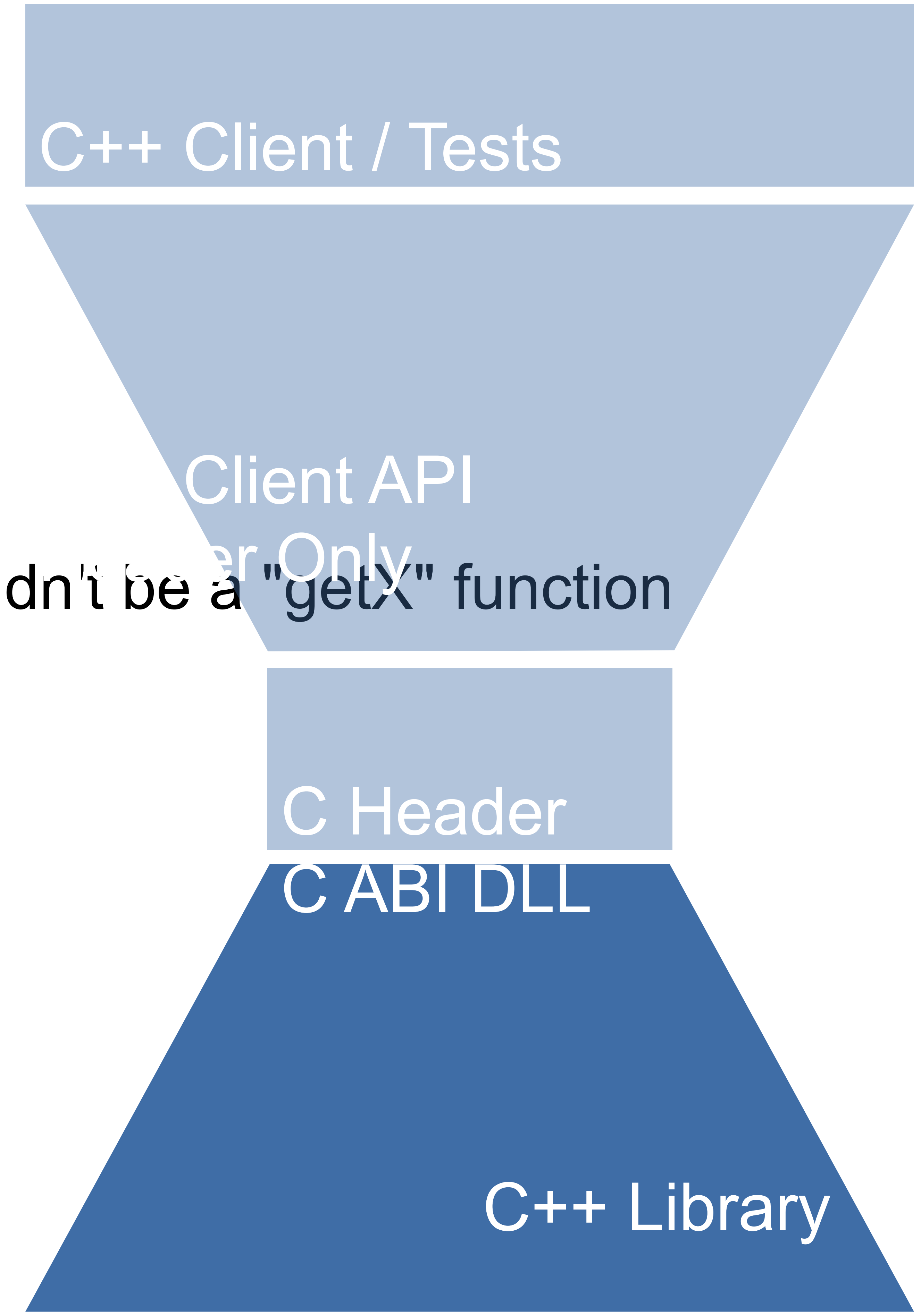
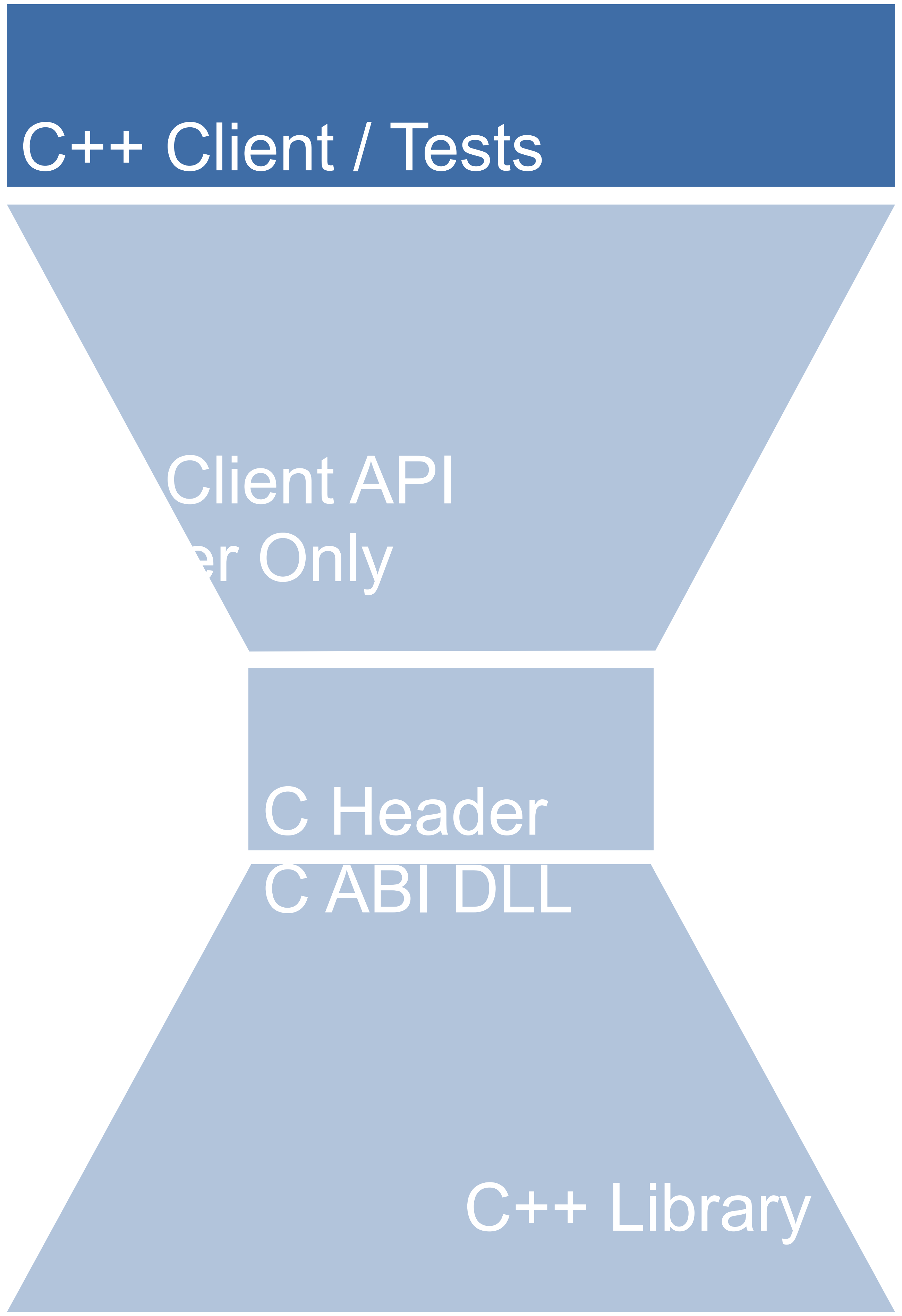
- **Let's add some functionality to our Wizard**
  - doMagic() – still casts a spell ("wootsh") or uses a potion ("zapp")
  - learnSpell() – learns a new spell (by name)
  - maxAndStorePotion() – creates a potion and puts it to the inventory
  - getName() – function to make Java programmers happy, otherwise there wouldn't be a "getX" function

```
struct Wizard {
  Wizard(std::string name = "Rincewind")
    : name{name}, wand{} {
  }
  char const * doMagic(std::string const & wish);
  void learnSpell(std::string const & newspell);
  void mixAndStorePotion(std::string const & potion);
  char const * getName() const {
```



# Testing Wizard

- **Testing a wizard provides the same view a client has**



```
using wizard_client::Wizard;

void canCreateDefaultWizard() {
  Wizard const magician{};
  ASSERT_EQUAL("Rincewind",magician.getName());
}

void canCreateWizardWithName() {
  Wizard const magician{ "Petrosilius Zwackelmann" };
  ASSERT_EQUAL("Petrosilius Zwackelmann", magician.getName());
}

void wizardLearnsSpellAndCanRecall() {
  Wizard magician{};
  magician.learnSpell("Expelliarmus");
```

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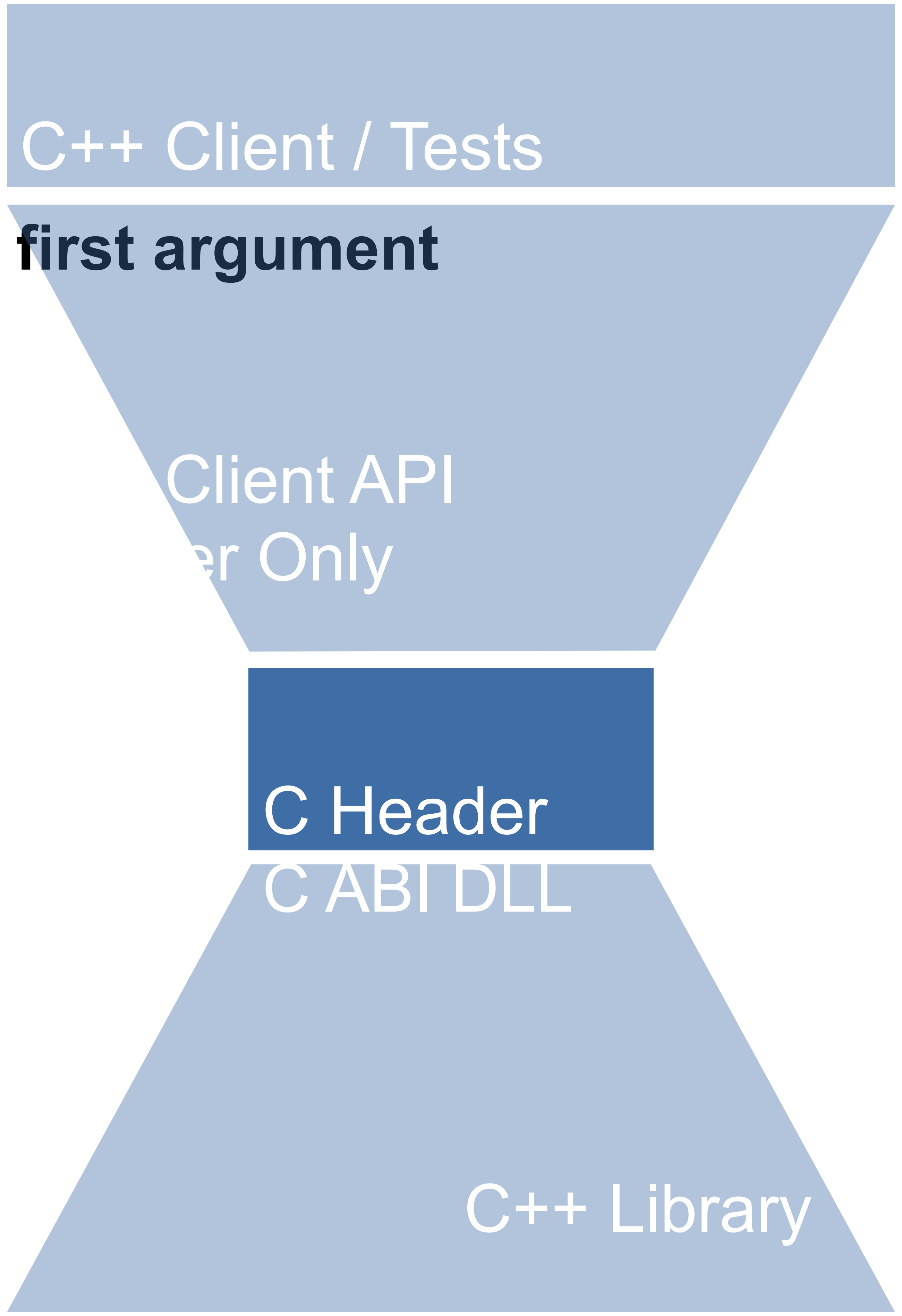
# Background C API

- **Abstract data types can be represented by pointers**
  - Ultimate abstract pointer `void *`
- **Member functions map to functions taking the abstract data type pointer as first argument**
- **Requires Factory and Disposal functions to manage object lifetime**
- **Strings can only be represented by `char *`**
  - Need to know who will be responsible for memory
  - Make sure not to return pointers to temporary objects!
- **Exceptions do not work across a C API**



# C API for Wizard

- **A Wizard can only be accessed through a pointer (const and non-const)**
  - Construction and destruction through functions
- **An error pointer stores messages of exceptions**
  - Functions that may fail need an error pointer parameter for reporting exceptions
  - Errors need to be cleaned up when not used anymore
- **Member functions take a Wizard (pointer) as first parameter**

Wizard.h

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


typedef struct Error * error_t;
char const * error_message(error_t error);
void error_dispose(error_t error);
```

```
char const *doMagic(wizard w,
                    char const * wish,
                    error_t *out_error);
```

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

- **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

```
#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
}
```

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# Implementing the Opaque Wizard Type

- **Wizard class must be implemented**
- **To allow full C++ including templates, we need to use a "trampoline" class**
  - It wraps the actual Wizard implementation

Wizard.cpp

```
extern "C" {
struct Wizard { // C linkage trampoline
  Wizard(char const * name)
    : wiz{name} {
  }
  unseen::Wizard wiz;
};
```

WizardHidden.h

```
namespace unseen {
struct Wizard {
  // ...
  Wizard(std::string name = "Rincewind")
    : name{name}, wand{} {
  }
  char const * doMagic(std::string const & wish);
  void learnSpell(std::string const & newspell);
  void mixAndStorePotion(std::string const & potion);
  char const * getName() const {
    return name.c_str();
```

Note: The Hairpoll example of Stefanus Du Toit has non-standard code in the trampoline

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# Dealing with Exceptions

- **Remember the 5 ways to deal with errors!**
- **You can’t use references in C API, must use pointers to pointers**
- **In case of an error, allocate error value on the heap**
  - You must provide a disposal function to clean up
- **You can use C++ types internally (`std::string`)**
- **It is safe to return the `char const *`**
  - because caller owns the object providing the memory

Wizard.h

```
typedef struct Error * error_t;
char const * error_message(error_t error);
void error_dispose(error_t error);
```

```
wizard createWizard(char const * name,
                    error_t * out_error);
```

Wizard.cpp

```
extern "C" {
struct Error {
  std::string message;
};

const char * error_message(error_t error) {
  return error->message.c_str();
}
```

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# Creating Error Messages from Exceptions

- **Call the function body and catch exceptions**
- **Map them to an Error object**
- **Set the pointer pointed to by out_error**
  - Use pointer to pointer as reference to pointer
  - Passed `out_error` must not be `nullptr`!

Wizard.cpp

```
template<typename Fn>
bool translateExceptions(error_t * out_error, Fn && fn)
try {
  fn();
  return true;
} catch (const std::exception& e) {
  *out_error = new Error{e.what()};
  return false;
} catch (...) {
  *out_error = new Error{"Unknown internal error"};
  return false;
}
```

```
wizard createWizard(const char * name,
```

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# Error Handling at Client Side

- **Client-side C++ usage requires mapping error codes back to exceptions**
  - Unfortunately exception type doesn’t map through
  - But can use a generic standard exception
    - `std::runtime_error`, keep the message
  - Dedicated RAII class for disposal
- **Temporary object with throwing destructor**
  - Strange but possible
  - Automatic type conversion passes the address of its guts (opaque)
  - Tricky, take care you don’t leak when creating the object!

WizardClient.h

```
struct ErrorRAII {
  ErrorRAII(error_t error) : opaque {error} {}
  ~ErrorRAII() {
    if (opaque) {
      error_dispose(opaque);
    }
  }
  error_t opaque;
};

struct ThrowOnError {
  ThrowOnError() = default;
  ~ThrowOnError() noexcept(false) {
    if (error.opaque) {
```

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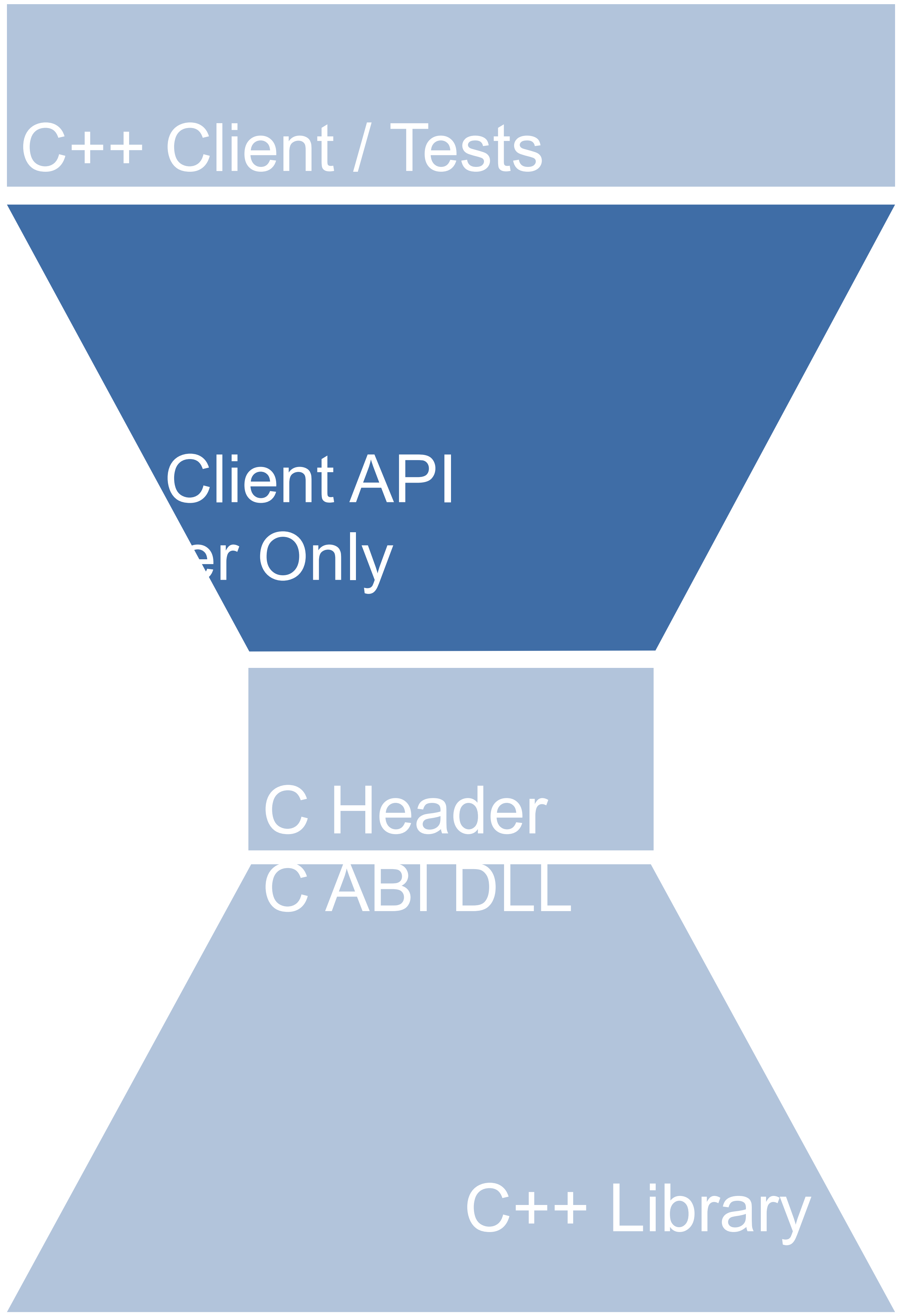
# Using ThrowOnError in Client API



WizardClient.h

```
struct ThrowOnError {
  ThrowOnError() = default;
  ~ThrowOnError() noexcept(false) {
    if (error.opaque) {
      throw std::runtime_error{error_message(error.opaque)};
    }
  }
  operator error_t*() {
    return &error.opaque;
  }
private:
  ErrorRAII error{nullptr};
};

struct Wizard {
```

# Completing the Client Side

- **Here the complete view of the client side Wizard class**
- **Calls "C" functions from global namespace**
  - Namespace prefix needed for synonyms to member functions
- **Header-only**
  - Inline functions delegating
- **Need to take care of passed and returned Pointers, esp. char ***
  - Do not pass/return dangling pointers!

WizardClient.h

```
struct Wizard {
  Wizard(std::string const & who = "Rincewind")
    : wiz {createWizard(who.c_str(), ThrowOnError{})} {
  }
  ~Wizard() {
    disposeWizard(wiz);
  }
  std::string doMagic(std::string const &wish) {
    return ::doMagic(wiz, wish.c_str(), ThrowOnError{});
  }
  void learnSpell(std::string const &spell) {
    ::learnSpell(wiz, spell.c_str());
  }
  void mixAndStorePotion(std::string const & potion) {
```

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# Really Hiding DLL Content (Compiler-Dependent)

- **With the Gnu compiler (and clang I presume)**
  - `-fvisibility=hidden`
    - Can be added to suppress exporting symbols
    - Must mark exported ABI functions with default visibility
- **Visibility refers to dynamic library/object file export of symbols**
  - Windows: `__declspec(dllexport)`
  - See also hairpoll demo project [https://youtu.be/PVYdHDm0q6Y](https://youtu.be/PVYdHDm0q6Y)
  - For more on gcc visibility (expert-level knowledge): see [https://gcc.gnu.org/wiki/Visibility](https://gcc.gnu.org/wiki/Visibility)

`WizardClient.h`

```
#define WIZARD_EXPORT_DLL
               __attribute__ ((visibility ("default")))

WIZARD_EXPORT_DLL
char const * error_message(error_t error);
WIZARD_EXPORT_DLL
void error_dispose(error_t error);

WIZARD_EXPORT_DLL
wizard createWizard(char const * name,
                    error_t *out_error);
WIZARD_EXPORT_DLL
void disposeWizard(wizard toDispose);
```

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# Wrap Up

- **Library API and ABI design can be tricky for third party users**
  - Only really a problem if not in-house or all open source
  - Even with open source libraries, re-compiles can be a burden
    - There are just too many compiler options
    - Plus DLL versioning
- **API stability can be important**
  - PIMPL idiom helps with avoiding client re-compiles (but should be considered a legacy)
  - Not easily applicable with heavily templated code -> that often is header-only
- **ABI stability is even more important when delivering DLLs/shared libraries**
  - Only relevant when not header-only
  - “C” linkage safe, but crippling - Hourglass-Interfaces allow shielding C++ clients from the crippled ABI
    - Still easy to make mistakes (which we always tried to avoid)

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