Chapter 1

Section 1

Section 2

Chapter 2

Section 1

Section 2

Chapter 3

Section 1

Section 2

Chapter 4

Section 1

Section 2

Chapter 5

Section 1

Section 2

Chapter 6

Section 1

Section 2

Here is an inline example, $\pi(\theta)$,

an equation,

$$\nabla f(x) \in \mathbb{R}^n,$$

and a regular $ symbol.

Define $f(x)$:

$$f(x) = x^2$$
$$x \in \mathbb{R}$$

```
graph TD
  A[ Anyone ] -->|Can help | B( Go to github.com/yuzutech/kroki )
  B --> C{ How to contribute? }
  C --> D[ Reporting bugs ]
  C --> E[ Sharing ideas ]
  C --> F[ Advocating ]
```

pybind11——[illegible]C+11[illegible]Python

pybind11[illegible]C++[illegible]Python[illegible]Python[illegible]C++[illegible]C++[illegible]Python[illegible]David Abrahams[illegible]Boost.Python[illegible]

Boost.Python[illegible]Boost[illegible]Boost[illegible]C++[illegible]BUG[illegible]Boost[illegible]C++11[illegible]

[illegible]pybind11[illegible]Boost.Python[illegible]python[illegible]pybind11[illegible]4K[illegible]Python[illegible]2.7[illegible]3.5+[illegible]PyPy[illegible]C ++[illegible]C++11[illegible](lambda[illegible]Boost.Python[illegible]pybind11[illegible]python[illegible]

1.1 [illegible]

pybind11[illegible]C++[illegible]Python[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]ranges[illegible]
- [illegible]
- [illegible]
- STL[illegible]
- [illegible]
- Internal references with correct reference counting[illegible]

- □□□Python□□□□□□□□□□□□□□□□C++□□

1.2 □□□□□

□□□□□□□□□□□pybind11□□□□□□□□□□□□□

- □□Python2.7, 3.5+, PyPy/PyPy3 7.3□□□□□□□□□
- □□□□□□□□□□lambda□□□lambda□□□□□□□□□□Python□□□□□□
- pybind11□□C++11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□(pybind11 uses C++11 move constructors and move assignment operators whenever possible to efficiently transfer custom data types.)
- □□Python□buffer□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□C++□□□□□□Eigen□□NumPy□□□□□□□□□□□□□□□□□□
- pybind11□□□□□□□□□□□□□□□□□□□□□□□NumPy□□□□□□□□□□□
- □□□□□□□□□□□Python□□□□□□□□□□□□□
- □□□□□□□□□□□□□□□□□□□□□□□□□□□□
- □□Boost.Python□□□□□□□□□□□□□□□
- □□`constexpr`□□□□□□□□□□□□□□□□□□□□□□□□□
- □□□□□□C++□□□□Python pickle□unpickle□□□

1.3 □□□□□□

1. Clang/LLVM 3.3□□ (Apple Xcode's clang□□5.0.0□□□□)
2. GCC 4.8□□
3. Microsoft Visual Studio 2015 Update 3□□
4. Intel classic C++ compiler 18 or newer (ICC 20.2 tested in CI)
5. Cygwin/GCC (previously tested on 2.5.1)
6. NVCC (CUDA 11.0 tested in CI)
7. NVIDIA PGI (20.9 tested in CI)

1.4 □□

This project was created by Wenzel Jakob. Significant features and/or improvements to the code were contributed by Jonas Adler, Lori A. Burns, Sylvain Corlay, Eric Cousineau, Aaron Gokaslan, Ralf Grosse-Kunstleve, Trent Houliston, Axel Huebl, @hulucc, Yannick Jadoul, Sergey Lyskov Johan Mabille, Tomasz Miąsko, Dean Moldovan, Ben Pritchard, Jason Rhinelander, Boris Schäling, Pim Schellart, Henry Schreiner, Ivan Smirnov, Boris Staletic, and Patrick Stewart.

We thank Google for a generous financial contribution to the continuous integration infrastructure used by this project.

1.5 □□

See the contributing guide for information on building and contributing to pybind11.

1.6 License

pybind11 is provided under a BSD-style license that can be found in the LICENSE file. By using, distributing, or contributing to this project, you agree to the terms and conditions of this license.

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□□□□

3. □□□□

□□□□□pybind/pybind11 on GitHub□□□pybind11□□□□□□pybind11□□□□□□□□□□□□□□□□ □□□□□pybind11□

3.1 □□□□□□□□□□

□□□□□□□Git□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□git□□□□□□□□□□□□□pybind11□

```
git submodule add -b stable ../../pybind/pybind11 extern/pybind11
git submodule update --init
```

□□□□□□□□□□□□□□`extern`□□□□□□□□GitHub□□□□□□□□GitHub□□□□□□□□https□ssh URL □□□□□□□□URL`../../pybind/pybind11`□□□□□□□□□□`.git`□□□GitHub□□□□

□□□□□□□□□□□include `extern/pybind11/include`□□□□□□□□□□□□□□□□□□□□□Build System□□)□□□pybind11□

3.2 □□PyPI□□□

□□□□□pip□□□PyPI□□□Pybind11□Python□□□□□□□□□□□CMake□□□□□□□

```
pip install pybind11
```

□□pybind11□□□□□Python□□□□□□□□□□□□root□□□□□□□□pybind11□□□□□□□

```
pip install "pybind11[global]"
```

□□□□□□□□□□Python□□□□□□□□□root□□□□□□□□□□□`/usr/local/include/pybind11`□ `/usr/local/share/cmake/pybind11`□□□□□□□□□□□□□□□□□□□□□□□□□□

`pyproject.toml` □□□□

3.3 □□conda-forge□□

You can use pybind11 with conda packaging via conda-forge:

```
conda install -c conda-forge pybind11
```

3.4 □□vcpkg□□

□□□□□Microsoft vcpkg□□□□□□□□□□□□pybind11□

```
git clone https://github.com/Microsoft/vcpkg.git
cd vcpkg
./bootstrap-vcpkg.sh
./vcpkg integrate install
vcpkg install pybind11
```

3.5 □□brew□□□□

brew□□□□Homebrew on macOS, or Linuxbrew on Linux□□pybind11□□□□□□

```
brew install pybind11
```

3.6 □□□□

Other locations you can find pybind11 are listed here; these are maintained by various packagers and the community.

4. □□□□□First steps□

□□□□pybind11□□□□□□□□□□□□□□□□□pybind11□□□□□□□□

4.1 □□□□□

Linux/macOS

□Linux□□□□□□python-dev□python3-dev□□cmake□□macOS□□□□□□□□python□□□□□□□cmake□

□□□□□□□□□□□□□□

```
mkdir build
cd build
cmake ..
make check -j 4
```

□□□□□□□□□□□□□□

Windows

□Windows□□□□□C++11□Visual Studio□□□15□□□□

> Note□□Visual Studio 2017(MSVC 14.1)□□□C++17□□pybind11□□□□□ `/permissive-` □□□□□□□□□□Visual Studio 2019□□□□□□□□□□□□□

□□□□□□□□□□□□

```
mkdir build
cd build
cmake ..
cmake --build . --config Release --target check
```

□□□□□□□□□Visual Studio□□□□□□□□□□□

> Note□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□i386□x86_64□□□□□□□□□□x86_64□□□□□□□vs□□□□□□□□`cmake -A x64 ..`□

4.2 □□□□□□□□□□

□□□□□□□□□□□□□□□□□□□□□

```
#include <pybind11/pybind11.h>
namespace py = pybind11;
```

□□□□□□□□□□□□□□□□□□□□□□

4.3 □□□□□□□□□

□□□□□□□□□□□□□□□□□pybind11□□□□

```
int add(int i, int j) {
    return i + j;
}
```

□□□□□□□□□□□□□□□□□□□`example.cpp`□□□□□□□□

```cpp
#include <pybind11/pybind11.h>

int add(int i, int j) {
    return i + j;
}

PYBIND11_MODULE(example, m) {
    m.doc() = "pybind11 example plugin"; // optional module docstring
    m.def("add", &add, "A function which adds two numbers");
}
```

`PYBIND11_MODULE`□□□□□□□□□□Python□□□`import`□□□□□□□□□□□□□□□□□□□□□example□□□□□□□□□□□□□□□□□□□`py::module_`□□□□m□□□□□□□□□□□□□□□`module_::def()`□□□□□□add□□□Python□□□□□

> Note□□□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Boost.Python□□□□□□□□□□□□□□□

pybind11□□□head-only□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Linux□□□□□□□□□□□□□□□□□□□

```
c++ -O3 -Wall -shared -std=c++11 -fPIC $(python3 -m pybind11 --includes) example.cpp -o example$(python3-config --extension-suffix)
```

> Note□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□`$(python3-config --includes) -Iextern/pybind11/include`□□`$(python3 -m pybind11 --includes)`□□□□□□□□□□□□

□□□□□□□□□□Linux□MacOS□□□

□□□□□C++□□□□□□□□□□□□□□□□□□□□□□□□□□`import`□□□□□Python□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□

```
>>> import example
>>> example.add(1, 2)
3L
>>>
```

4.4 □□□□□

□□□□□□□□□C++□□□□□□□□□□□□□Python□□□□□□□□□□□□□“i”□“j”□□

```
m.def("add", &add, "A function which adds two numbers",
      py::arg("i"), py::arg("j"));
```

arg□□□□□□□□□□□module::def()□□

```
import example
example.add(i=1, j=2)  #3L
```

□□□□□□□□□□□□□□□□□□□

```
>>> help(example)

....

FUNCTIONS
    add(...)
        Signature : (i: int, j: int) -> int

        A function which adds two numbers
```

□□□□□□□□□□□□□□□□□□

```
// regular notation
m.def("add1", &add, py::arg("i"), py::arg("j"));
// shorthand
using namespace pybind11::literals;
m.def("add2", &add, "i"_a, "j"_a);
```

□□ `_a` □□□□□□ `arg` □□□□□□□□□□□□□□ `using namespace pybind11::literals` □
□□□□□□□□□□□□ `literals` □□□□pybind11□□□□□□□□□□□

4.5 □□□□

□□□□□□□□□□□□□□

```cpp
int add(int i = 1, int j = 2) {
    return i + j;
}
```

pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□ `arg` □□□□□□

```cpp
m.def("add", &add, "A function which adds two numbers",
      py::arg("i") = 1, py::arg("j") = 2);
```

□□□□□□□□□□

```
>>> help(example)

....

FUNCTIONS
    add(...)
        Signature : (i: int = 1, j: int = 2) -> int

        A function which adds two numbers
```

□□□□□□□

```cpp
// regular notation
m.def("add1", &add, py::arg("i") = 1, py::arg("j") = 2);
// shorthand
m.def("add2", &add, "i"_a=1, "j"_a=2);
```

4.6 □□□□

□□□□□□`attr`□□□□□□□□□□Python□□□□C++□□□□□□□□□□□□□□□□□□□□□□□□attriutes□□□□
□□□□□□□`py::cast`□□□□□□

```
PYBIND11_MODULE(example, m) {
    m.attr("the_answer") = 42;
    py::object world = py::cast("World");
    m.attr("what") = world;
}
``

Python□□□□□
```pyhton
>>> import example
>>> example.the_answer
42
>>> example.what
'World'
```

4.7 □□□□□□□□

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□py::cast□□□□□□□□□□□□□□□□□□□□□□□(A large number of data types are supported out of the box and can be used seamlessly as functions arguments, return values or with py::cast in general. For a full overview, see the Type conversions section.)
```

5. □□□□□□

5.1 □□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□C++□□□□□□□`Pet`□□□□□□

```
struct Pet {
    Pet(const std::string &name) : name(name) { }
    void setName(const std::string &name_) { name = name_; }
    const std::string &getName() const { return name; }

    std::string name;
};
```

□□□□□□□□□

```
#include <pybind11/pybind11.h>
namespace py = pybind11;

PYBIND11_MODULE(example, m) {
    py::class_<Pet>(m, "Pet")
        .def(py::init<const std::string &>())
        .def("setName", &Pet::setName)
        .def("getName", &Pet::getName);
}
```

`class_`□□□C++ class□ struct□□□□`init()`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
□□□□□□□□□Python□□□□□□□

```
>>> import example
>>> p = example.Pet("Molly")
>>> print(p)
<example.Pet object at 0x10cd98060>
>>> p.getName()
u'Molly'
>>> p.setName("Charly")
>>> p.getName()
u'Charly'
```

See also□□□□□□□□□□□□ `class_::def_static` □□□□

5.2 □□□□□□□□□□□□

□□□□□4□□□□□□□□□□□□□□□□□□□□□□4□□□□□□

5.3 □□□□□□□

□□`print(p)`□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□ `__repr__` □□□□□□□□□□□□□□□□□□□□□Pet□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
py::class_<Pet>(m, "Pet")
    .def(py::init<const std::string &>())
    .def("setName", &Pet::setName)
    .def("getName", &Pet::getName)
    .def("__repr__",
        [](const Pet &a) {
            return "<example.Pet named '" + a.name + "'>";
        });
```

□□□□□□□□Python□□□□□□□

```
>>> print(p)
<example.Pet named 'Molly'>
```

pybind11□□□□□□□□□□lambda□□□□lambda□□□□`[]`□□□□□□□□

5.4 □□□□

□□`class_::def_readwrite`□□□□□□□□□□□□□□□`class_::def_readonly`□□□□□□□□□□□□

```
py::class_<Pet>(m, "Pet")
    .def(py::init<const std::string &>())
    .def_readwrite("name", &Pet::name)
    // ... remainder ...
```

Python□□□□□□□□

```
>>> p = example.Pet("Molly")
>>> p.name
u'Molly'
>>> p.name = "Charly"
>>> p.name
u'Charly'
```

□□`Pet::name`□□□□□□□□□□□□□□setter□getters□□□

```
class Pet {
public:
    Pet(const std::string &name) : name(name) { }
    void setName(const std::string &name_) { name = name_; }
    const std::string &getName() const { return name; }
private:
    std::string name;
};
```

□□□□ `class_::def_property()` (□□□□□□ `class_::def_property_readonly()`)□□□□□□□□□□□□□□□setter□geter□□□

```
py::class_<Pet>(m, "Pet")
    .def(py::init<const std::string &>())
    .def_property("name", &Pet::getName, &Pet::setName)
    // ... remainder ...
```

□□□□□□□read□□□□□nullptr□□□□

> **see also**: □□□□□ `class_::def_readwrite_static()` , `class_::def_readonly_static()` `class_::def_property_static()` , `class_::def_property_readonly_static()` □□□□□□□□□□□□

5.5 □□□□

□□□Pyhton□□□□□□□□□□□□

```
>>> class Pet:
...     name = "Molly"
...
>>> p = Pet()
>>> p.name = "Charly"  # overwrite existing
>>> p.age = 2  # dynamically add a new attribute
```

□□□□□□□C++□□□□□□□□□□□□□□□□□□□□□□ `class_::def_readwrite` □ `class_::def_property` □□□□□□□□□□□□□□□□□□

```
>>> p = example.Pet()
>>> p.name = "Charly"  # OK, attribute defined in C++
>>> p.age = 2  # fail
AttributeError: 'Pet' object has no attribute 'age'
```

□□C++□□□□□□□□□□□□□□ `py::class_` □□□□□□□ `py::dynamic_attr` □□□

```
py::class_<Pet>(m, "Pet", py::dynamic_attr())
    .def(py::init<>())
    .def_readwrite("name", &Pet::name);
```

[illegible]

```
>>> p = example.Pet()
>>> p.name = "Charly"  # OK, overwrite value in C++
>>> p.age = 2  # OK, dynamically add a new attribute
>>> p.__dict__  # just like a native Python class
{'age': 2}
```

[illegible] `__dict__` [illegible]Python[illegible]pybind11[illegible]Python[illegible]

5.6 [illegible]

[illegible]

```
struct Pet {
    Pet(const std::string &name) : name(name) { }
    std::string name;
};

struct Dog : Pet {
    Dog(const std::string &name) : Pet(name) { }
    std::string bark() const { return "woof!"; }
};
```

pybind11[illegible]1[illegible]C++[illegible] `class_` [illegible]2[illegible] `class_` [illegible]

```
py::class_<Pet>(m, "Pet")
   .def(py::init<const std::string &>())
   .def_readwrite("name", &Pet::name);

// Method 1: template parameter:
py::class_<Dog, Pet /* <- specify C++ parent type */>(m, "Dog")
    .def(py::init<const std::string &>())
    .def("bark", &Dog::bark);

// Method 2: pass parent class_ object:
py::class_<Dog>(m, "Dog", pet /* <- specify Python parent type */)
    .def(py::init<const std::string &>())
    .def("bark", &Dog::bark);
```

□□□□□□□□□□□□□□□□□□□□□□□□□□

```
>>> p = example.Dog("Molly")
>>> p.name
u'Molly'
>>> p.bark()
u'woof!'
```

□□□□□□□□□□□□□□□□□□□□□□Python□□□

```
// □□□□□□□□□□□□□□
m.def("pet_store", []() { return std::unique_ptr<Pet>(new Dog("Molly"));
});
```

```
>>> p = example.pet_store()
>>> type(p)  # `Dog` instance behind `Pet` pointer
Pet          # no pointer downcasting for regular non-polymorphic types
>>> p.bark()
AttributeError: 'Pet' object has no attribute 'bark'
```

`pet_store`□□□□□□□Dog□□□□□□□□□□□□□□□Python□□□□□Pet□□C++□□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□

```cpp
struct PolymorphicPet {
    virtual ~PolymorphicPet() = default;
};

struct PolymorphicDog : PolymorphicPet {
    std::string bark() const { return "woof!"; }
};

// Same binding code
py::class_<PolymorphicPet>(m, "PolymorphicPet");
py::class_<PolymorphicDog, PolymorphicPet>(m, "PolymorphicDog")
    .def(py::init<>())
    .def("bark", &PolymorphicDog::bark);

// Again, return a base pointer to a derived instance
m.def("pet_store2", []() { return std::unique_ptr<PolymorphicPet>(new
PolymorphicDog); });
```

```python
>>> p = example.pet_store2()
>>> type(p)
PolymorphicDog  # automatically downcast
>>> p.bark()
u'woof!'
```

pybind11[illegible]C++[illegible]

5.7 [illegible]

[illegible]

```cpp
struct Pet {
    Pet(const std::string &name, int age) : name(name), age(age) { }

    void set(int age_) { age = age_; }
    void set(const std::string &name_) { name = name_; }

    std::string name;
    int age;
};
```

□□□□□`Pet::set`□□
□□Python□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□

```cpp
py::class_<Pet>(m, "Pet")
   .def(py::init<const std::string &, int>())
   .def("set", static_cast<void (Pet::*)(int)>(&Pet::set), "Set the pet's
age")
   .def("set", static_cast<void (Pet::*)(const std::string &)>(&Pet::set),
"Set the pet's name");
```

□□□□□□□□□□□□□□□□□□□□□□□□

```python
>>> help(example.Pet)

class Pet(__builtin__.object)
 |  Methods defined here:
 |
 |  __init__(...)
 |      Signature : (Pet, str, int) -> NoneType
 |
 |  set(...)
 |      1. Signature : (Pet, int) -> NoneType
 |
 |      Set the pet's age
 |
 |      2. Signature : (Pet, str) -> NoneType
 |
 |      Set the pet's name
```

□□□□□□□□□C++14□□□□□□□□□□□□□□□□□□□

```
py::class_<Pet>(m, "Pet")
    .def("set", py::overload_cast<int>(&Pet::set), "Set the pet's age")
    .def("set", py::overload_cast<const std::string &>(&Pet::set), "Set
the pet's name");
```

□□□`py::overload_cast`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□(`void (Pet::*)`)□□□□□□const□□□□□□□□`py::const`□□□

```
struct Widget {
    int foo(int x, float y);
    int foo(int x, float y) const;
};

py::class_<Widget>(m, "Widget")
   .def("foo_mutable", py::overload_cast<int, float>(&Widget::foo))
   .def("foo_const",   py::overload_cast<int, float>(&Widget::foo,
py::const_));
```

□□□□□□□□c++11□□□□□□□`py::overload_cast`□□□□□□□`py::detail::overload_cast_impl`□□□□

```
template <typename... Args>
using overload_cast_ = pybind11::detail::overload_cast_impl<Args...>;

py::class_<Pet>(m, "Pet")
    .def("set", overload_cast_<int>()(&Pet::set), "Set the pet's age")
    .def("set", overload_cast_<const std::string &>()(&Pet::set), "Set the
pet's name");
```

> Note: □□□□□□□□□□□□□□□□□ `.def(py::init<...>())` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□

5.8 □□□□□□□

□□□□□□□□□□□□□□□□□

```
struct Pet {
    enum Kind {
        Dog = 0,
        Cat
    };

    struct Attributes {
        float age = 0;
    };

    Pet(const std::string &name, Kind type) : name(name), type(type) { }

    std::string name;
    Kind type;
    Attributes attr;
};
```

□□□□□□□□□□

```
py::class_<Pet> pet(m, "Pet");

pet.def(py::init<const std::string &, Pet::Kind>())
    .def_readwrite("name", &Pet::name)
    .def_readwrite("type", &Pet::type)
    .def_readwrite("attr", &Pet::attr);

py::enum_<Pet::Kind>(pet, "Kind")
    .value("Dog", Pet::Kind::Dog)
    .value("Cat", Pet::Kind::Cat)
    .export_values();

py::class_<Pet::Attributes> attributes(pet, "Attributes")
    .def(py::init<>())
    .def_readwrite("age", &Pet::Attributes::age);
```

□□□□□□□□ `Kind` □ `Attributes` □ `Pet` □□□□□□□□□□□□□□ `enum_` □ `class_` □□□□□□□□ `Pet` `class_` □□□ `enum_::export_values()` □□□□□□□□□□□□□□C++11□□□□□□□□□□□□□□

```
>>> p = Pet("Lucy", Pet.Cat)
>>> p.type
Kind.Cat
>>> int(p.type)
1L
```

□□□□□□□□□□□□□□`__members__`□□□□

```
>>> Pet.Kind.__members__
{'Dog': Kind.Dog, 'Cat': Kind.Cat}
```

`name`□□□□□□□□□□□□□unicode□□□□`str(enum)`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
>>> p = Pet("Lucy", Pet.Cat)
>>> pet_type = p.type
>>> pet_type
Pet.Cat
>>> str(pet_type)
'Pet.Cat'
>>> pet_type.name
'Cat'
```

> Note: □□□□`enum_`□□□□□□□`py::arithmetic()`□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
>
> ```
> py::enum_<Pet::Kind>(pet, "Kind", py::arithmetic())
>    ...
> ```
>
> □□□□□□□□□□□□□□□□□□□

6. □□□□

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7. □□

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7.1 □□□□□

Python□C++□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□no-trivial□□□□□□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□C++□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□ `model::def()` □ `class_def()` □□□□□□□□□ `return_value_policy::automatic` □

□□

```
/* Function declaration */
Data *get_data() { return _data; /* (pointer to a static data structure)
*/ }
...

/* Binding code */
m.def("get_data", &get_data); // <-- KABOOM, will cause crash when called
from Python
```

□Python□□□ `get_data()` □□□□□□□□□□C++□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□ `return_value_policy::automatic` □□□pybind11□□□□□□□□ `_data` □□□□□

□Python□□□□□□□□□ `_data` □Python□□□□pybind11□□□□□C++□□□□□operator delete()□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□□ `return_value_policy::reference` □□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
m.def("get_data", &get_data, py::return_value_policy::reference);
```

[illegible]pybind11[illegible]

[illegible]	[illegible]
`return_value_policy::take_ownership`	[illegible]Pyhton[illegible]delete[illegible]
`return_value_policy::copy`	[illegible]Python[illegible]
`return_value_policy::move`	[illegible]`std::move`[illegible]Python[illegible]
`return_value_policy::reference`	[illegible]C++[illegible]Pytho[illegible]C++[illegible]
`return_value_policy::reference_internal`	[illegible]`this`[illegible]`self`[illegible]referenc[illegible]`keep_alive<0, 1>`[illegible]Python[illegible]`def_property`[illegible]`def_readwrite`[illegible]getter[illegible]
`return_value_policy::automatic`	[illegible]`return_value_policy::take_ow`[illegible]`return_value_policy::copy`[illegible]`py::cl`[illegible]
`return_value_policy::automatic_reference`	[illegible]`return_value_policy::referen`[illegible]C++[illegible]Python[illegible]`pybind11/stl.h`[illegible]casters[illegible]

[illegible]

```
class_<MyClass>(m, "MyClass")
    .def_property("data", &MyClass::getData, &MyClass::setData,
                 py::return_value_policy::copy);
```

□□□□□□□□□□□□□□□□□□□getter□setter□□□□□setter□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`cpp_function`□□□□□□□□□□□□

```
class_<MyClass>(m, "MyClass")
    .def_property("data"
        py::cpp_function(&MyClass::getData,
py::return_value_policy::copy),
        py::cpp_function(&MyClass::setData)
    );
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□free□□

□□□

1. □□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□
2. □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
3. □□C++□Python□□□□□□□□□□□□□□□□crash□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

7.2 □□□□□□□□

□□□

□□□keep alive□

□□□C++□□□□□□□□□C++□□□□□□□□□□□□□□`keep_alive<Nurse, Patient>`□□□□□□□Nurse□□□□□□□Patient□□□□□□0□□□□□□1□□□□□□□□□□1□□□□□□□this□□□□□□□□□□□□□□2□□□□Nurse□□□□□□□□□□□None□□□□□□□□□□□□□

□nurse□□□□pybind11□□□□□□□□□□□□□□□nurse□□□□□□□□□□□□nurse□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□□□□“Could not cativate keep_alive!“□□□□□□□□□□□□□□□□review□□□□□□□□□□□

□□□□□□□□□□□list append□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
py::class_<List>(m, "List").def("append", &List::append, py::keep_alive<1,
2>());
```

□□□□□□□□□□□□□□□□□□□□□□□□□1□□this□□□□□0□□□□□□□□□□□□□□□□□□□void□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
py::class_<Nurse>(m, "Nurse").def(py::init<Patient &>(), py::keep_alive<1,
2>());
```

> Note: `keep_alive` □Boost.Python□□ `with_custodian_and_ward` □ `with_custodian_and_ward_postcall` □□□

Call guard

`call_guard<T>` □□□□□□T□□□scope guard□□□□□□□□□□□□□□□□

```
m.def("foo", foo, py::call_guard<T>());
```

□□□□□□□□□□

```
m.def("foo", [](args...) {
    T scope_guard;
    return foo(args...); // forwarded arguments
});
```

□□□□□□□□T□□□□□□□`gil_scoped_release`□□□□□□□□□□□□□

`call_guard`□□□□□□□□□□□□□□`call_guard<T1, T2, T3 ...>`□□□□□□□□□□□□□□□□□□□□

> See also: `test/test_call_policies.cpp`□□□□□□□□□□□□`keep_alive`□`call_guard`□□□□

7.3 □Python□□□□□

pybind11□□□□C++□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□□□C++□□□□□python□□□□□□Python dict□□□

```
void print_dict(const py::dict& dict) {
    /* Easily interact with Python types */
    for (auto item : dict)
        std::cout << "key=" << std::string(py::str(item.first)) << ", "
                  << "value=" << std::string(py::str(item.second)) <<
std::endl;
}

// it can be exported as follow:
m.def("print_dict", &print_dict);
```

□Python□□□□

```
>>> print_dict({"foo": 123, "bar": "hello"})
key=foo, value=123
key=bar, value=hello
```

7.4 □□*args□**kwatgs□□

Python□□□□□□□□□□□□□□□□□

```
def generic(*args, **kwargs):
    ...  # do something with args and kwargs
```

□□□□□□pybind11□□□□□□□□

```
void generic(py::args args, const py::kwargs& kwargs) {
    /// .. do something with args
    if (kwargs)
        /// .. do something with kwargs
}

/// Binding code
m.def("generic", &generic);
```

`py::args`□□□`py::tuple`□`py::kwargs`□□□`py::dict`□

□□□□□`test/test_kwargs_and_defualts.cpp`□

7.5 □□□□□□

□□Python□□□□□□□□□□□

```
py::class_<MyClass>("MyClass").def("myFunction", py::arg("arg") =
SomeType(123));
```

□□□□□□□□□SomeType□□□□□binding□□□□py::class_□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□□□□□`__repr__`□□□□□□□□□□□□□□□□□□□□□□□□□□□□
□□□□□□□□□□

```
FUNCTIONS

|  myFunction(...)
|      Signature : (MyClass, arg : SomeType = <SomeType object at
0x101b7b080>) -> NoneType
```

□□□□□□□□□□□□`SomeType.__repr__`□□□□□□`arg_v`□□□□□□□□□□□□□□□

````
py::class_<MyClass>("MyClass")
    .def("myFunction", py::arg_v("arg", SomeType(123), "SomeType(123)"));
``

□□□□□□□□□□□□□□□□□□□□
```c++
py::class_<MyClass>("MyClass")
    .def("myFunction", py::arg("arg") = static_cast<SomeType *>(nullptr));
````

7.6 Keyword-only□□

Python3□□□keyword-only□□□□□□□□`*`□□□□□□

```
def f(a, *, b):  # a can be positional or via keyword; b must be via keyword
    pass

f(a=1, b=2)  # good
f(b=2, a=1)  # good
f(1, b=2)  # good
f(1, 2)  # TypeError: f() takes 1 positional argument but 2 were given
```

pybind11□□□`py::kw_only`□□□□□□□□

```
m.def("f", [](int a, int b) { /* ... */ },
      py::arg("a"), py::kw_only(), py::arg("b"));
```

□□□□□□□`py::args`□□□□

7.7 Positional-only□□

python3.8□□□Positional-only□□□□pybind11□□`py::pos_only()`□□□□□□□

```
m.def("f", [](int a, int b) { /* ... */ },
       py::arg("a"), py::pos_only(), py::arg("b"));
```
```

□□□□□□□□□□□□□□`a`□□□□□□□□□keyword-only□□□□□□□

7.8 Non-converting□□

□□□□□□□□□□□□□□□

- □□`py::implicitly_convertible<A,B>()`□□□□□□
- □□□□□□□□□□□□□□□□□
- □□□□□□□□float□□□□□□`std::complex<float>`□□□□□
- Calling a function taking an Eigen matrix reference with a numpy array of the wrong type or of an incompatible data layout.

□□`py::arg`□□□`.noconvert()`□□□□□□□□□□□

```
m.def("floats_only", [](double f) { return 0.5 * f; },
py::arg("f").noconvert());
m.def("floats_preferred", [](double f) { return 0.5 * f; }, py::arg("f"));
```

□□□□□□□□□□□`TypeError`□□□

```
>>> floats_preferred(4)
2.0
>>> floats_only(4)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: floats_only(): incompatible function arguments. The following
argument types are supported:
    1. (f: float) -> float

Invoked with: 4
```

□□□□□□□□□□`_a`□□□□□□□□□□□□□`py::arg().noconvert()`□

7.9 □□/□□□□□

□□□□□□`py::class_`□□□C++□□□□□□shared holder(□□□□□□)□pybind11□□□Python□None□□□□□□□□C++□□□nullptr□□□□

□□□□□□`py::arg`□□□`.none`□□□□□□□□□□□□□□□

```
py::class_<Dog>(m, "Dog").def(py::init<>());
py::class_<Cat>(m, "Cat").def(py::init<>());
m.def("bark", [](Dog *dog) -> std::string {
    if (dog) return "woof!"; /* Called with a Dog instance */
    else return "(no dog)"; /* Called with None, dog == nullptr */
}, py::arg("dog").none(true));
m.def("meow", [](Cat *cat) -> std::string {
    // Can't be called with None argument
    return "meow";
}, py::arg("cat").none(false));
```

□□□Python□□`bark(None)`□□□`"(no dog)"`□□□`meow(None)`□□□□□`TypeError`□

```
>>> from animals import Dog, Cat, bark, meow
>>> bark(Dog())
'woof!'
>>> meow(Cat())
'meow'
>>> bark(None)
'(no dog)'
>>> meow(None)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: meow(): incompatible function arguments. The following argument
types are supported:
    1. (cat: animals.Cat) -> str

Invoked with: None
```

□□□□□□□□□□□□□□□□□`None`□

> Note: Even when `.none(true)` is specified for an argument, `None` will be converted to a `nullptr` *only* for custom and opaque types. Pointers to built-in types (`double *`, `int *`, ...) and STL types (`std::vector<T> *`, ...; if `pybind11/stl.h` is included) are copied when converted to C++ (see Overview) and will not allow `None` as argument. To pass optional argument of these copied types consider using `std::optional<T>`

7.10 [illegible]

[illegible]pybind11[illegible]`py::arg().noconvert()`[illegible]

[illegible]`TypeError`[illegible]

[illegible]pybind11[illegible]`py::prepend()`[illegible]

> Note: pybind11[illegible]pybind11[illegible]

8. □

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8.1 □Python□□□□□

□□□□□□□□□□□C++□□□□□□□□□Python□□□□□□□

```
class Animal {
public:
    virtual ~Animal() { }
    virtual std::string go(int n_times) = 0;
};

class Dog : public Animal {
public:
    std::string go(int n_times) override {
        std::string result;
        for (int i=0; i<n_times; ++i)
            result += "woof! ";
        return result;
    }
};
```

□□□□□□□□□□□□□□□Animal□□□`go()`□□□

```
std::string call_go(Animal *animal) {
    return animal->go(3);
}
```

pybind11□□□□□□□

```
PYBIND11_MODULE(example, m) {
    py::class_<Animal>(m, "Animal")
        .def("go", &Animal::go);

    py::class_<Dog, Animal>(m, "Dog")
        .def(py::init<>());

    m.def("call_go", &call_go);
}
```

□□□□□□□□□□□□□□□□□□□□□Animal□□□□□□“No constructor defined!“□□□Animal□□□□□□□□□□□□□□□□□“□□(trampoline)“□□□□□□□□□□□□□□□□□□□□Python□□

□□□□□Python□□□□□□□□Animal□□□□□□□□□

```
class PyAnimal : public Animal {
public:
    /* Inherit the constructors */
    using Animal::Animal;

    /* Trampoline (need one for each virtual function) */
    std::string go(int n_times) override {
        PYBIND11_OVERRIDE_PURE(
            std::string, /* Return type */
            Animal,      /* Parent class */
            go,          /* Name of function in C++ (must match Python
name) */
            n_times      /* Argument(s) */
        );
    }
};
```

□□□□□□□□□□□□ `PYBIND11_OVERRIDE_PURE` □□□□□□□□□□□□□□□□□ `PYBIND11_OVERRIDE` □ `PYBIND11_OVERRIDE_PURE_NAME` □ `PYBIND11_OVERRIDE_NAME` □□□□□□□□□□□□□C□□□□ Python□□□□□□□□□□□□ `__str__` □□□

```
std::string toString() override {
  PYBIND11_OVERRIDE_NAME(
      std::string, // Return type (ret_type)
      Animal,      // Parent class (cname)
      "__str__",   // Name of method in Python (name)
      toString,    // Name of function in C++ (fn)
  );
}
```

Animal□□□□□□□□□□□□□□□□

```
PYBIND11_MODULE(example, m) {
    py::class_<Animal, PyAnimal /* <--- trampoline*/>(m, "Animal")
        .def(py::init<>())
        .def("go", &Animal::go);

    py::class_<Dog, Animal>(m, "Dog")
        .def(py::init<>());

    m.def("call_go", &call_go);
}
```

pybind11□□□`class_`□□□□□□□□□□PyAnimal□□□□□□□□Python□□□Animal□□

□□□

```
py::class_<Animal, PyAnimal /* <--- trampoline*/>(m, "Animal");
    .def(py::init<>())
    .def("go", &PyAnimal::go); /* <--- THIS IS WRONG, use &Animal::go */
```

□□□□□□□□□□□□□□□□Python□□□Animal□□□□□□□□Dog□□□□□□□□□□□□□□□□□□□□□□

□□□Python□□□□□□□□□□□□□□□`Animal::go`□□□□□□□□□□□□□□□□

```python
from example import *
d = Dog()
call_go(d)     # u'woof! woof! woof! '
class Cat(Animal):
    def go(self, n_times):
        return "meow! " * n_times

c = Cat()
call_go(c)   # u'meow! meow! meow! '
```

□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□C++□□□□(□□ `__init__`)□□□□□□□□□□□□□□□□□□□□□□□C++□□□□□□□□□□□□□□□□□□□□□□□□pybind11 2.6□□□□□□□□□□□□ `TypeError` □□□

```python
class Dachshund(Dog):
    def __init__(self, name):
        Dog.__init__(self)  # Without this, a TypeError is raised.
        self.name = name

    def bark(self):
        return "yap!"
```

□□□□□□□□□ `__init__` □□□□□□□ `supper()` □□□□□□□□□□□□□ `supper()` □□□□□□□□□□□□□□□Python□C++□□□□□□□□□□Python MRO□C++□□□□□□□□□□□

> Note□
>
> □□□□□□□□□pybind11□Python□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
>
> - because in these cases there is no C++ variable to reference (the value is stored in the referenced Python variable), pybind11 provides one in the PYBIND11_OVERRIDE macros (when needed) with static storage duration. Note that this means that invoking the overridden method on *any* instance will change the referenced value stored in *all* instances of that type.
> - Attempts to modify a non-const reference will not have the desired effect: it will change only the static cache variable, but this change will not propagate to underlying Python instance, and the change will be replaced the next time the override is invoked.

8.2 □□□□□□

□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□Animal□Dog□□□□

```cpp
class Animal {
public:
    virtual std::string go(int n_times) = 0;
    virtual std::string name() { return "unknown"; }
};
class Dog : public Animal {
public:
    std::string go(int n_times) override {
        std::string result;
        for (int i=0; i<n_times; ++i)
            result += bark() + " ";
        return result;
    }
    virtual std::string bark() { return "woof!"; }
};
```

□□□□□□Animal□□□□□□□□□□□□Python□□□□□□`Dog`□□□□□□□□`Dog`□□□□□□□□□□□□
`bark()`□□□□Animal□`go()`□`name()`□□□□□□□□Dog□□□□□□□name□□□□

```cpp
class PyAnimal : public Animal {
public:
    using Animal::Animal; // Inherit constructors
    std::string go(int n_times) override {
PYBIND11_OVERRIDE_PURE(std::string, Animal, go, n_times); }
    std::string name() override { PYBIND11_OVERRIDE(std::string, Animal,
name, ); }
};
class PyDog : public Dog {
public:
    using Dog::Dog; // Inherit constructors
    std::string go(int n_times) override { PYBIND11_OVERRIDE(std::string,
Dog, go, n_times); }
    std::string name() override { PYBIND11_OVERRIDE(std::string, Dog,
name, ); }
    std::string bark() override { PYBIND11_OVERRIDE(std::string, Dog,
bark, ); }
};
```

□□□ `name()` □ `bark()` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
class Husky : public Dog {};
class PyHusky : public Husky {
public:
    using Husky::Husky; // Inherit constructors
    std::string go(int n_times) override {
PYBIND11_OVERRIDE_PURE(std::string, Husky, go, n_times); }
    std::string name() override { PYBIND11_OVERRIDE(std::string, Husky,
name, ); }
    std::string bark() override { PYBIND11_OVERRIDE(std::string, Husky,
bark, ); }
};
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
template <class AnimalBase = Animal> class PyAnimal : public AnimalBase {
public:
    using AnimalBase::AnimalBase; // Inherit constructors
    std::string go(int n_times) override {
PYBIND11_OVERRIDE_PURE(std::string, AnimalBase, go, n_times); }
    std::string name() override { PYBIND11_OVERRIDE(std::string,
AnimalBase, name, ); }
};
template <class DogBase = Dog> class PyDog : public PyAnimal<DogBase> {
public:
    using PyAnimal<DogBase>::PyAnimal; // Inherit constructors
    // Override PyAnimal's pure virtual go() with a non-pure one:
    std::string go(int n_times) override { PYBIND11_OVERRIDE(std::string,
DogBase, go, n_times); }
    std::string bark() override { PYBIND11_OVERRIDE(std::string, DogBase,
bark, ); }
};
```

□□□

□□□□pybind11□□□□□□

```cpp
py::class_<Animal, PyAnimal<>> animal(m, "Animal");
py::class_<Dog, Animal, PyDog<>> dog(m, "Dog");
py::class_<Husky, Dog, PyDog<Husky>> husky(m, "Husky");
// ... add animal, dog, husky definitions
```

□□□Husky□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

Python□□□□□□□

```python
class ShihTzu(Dog):
    def bark(self):
        return "yip!"
```

8.3 □□□□□□□□

8.3.1 □□□□□□□

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□□Python□□□□□□

□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□`py::init_alias<Args, ...>()`□□□`py::init<Args, ...>()`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

> **See also**□See the file `tests/test_virtual_functions.cpp` for complete examples showing both normal and forced trampoline instantiation.

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□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□ [Limitations involving reference arguments]□□□□□□□

`get_override()`□□□□Python□□□□□□□□□□□□□□□Consider for example a C++ method which has the signature `bool myMethod(int32_t& value)`, where the return indicates whether something should be done with the `value`. This can be made convenient on the Python side by allowing the Python function to return `None` or an `int`:

```
bool MyClass::myMethod(int32_t& value)
{
    pybind11::gil_scoped_acquire gil;  // Acquire the GIL while in this scope.
    // Try to look up the overridden method on the Python side.
    pybind11::function override = pybind11::get_override(this, "myMethod");
    if (override) {  // method is found
        auto obj = override(value);  // Call the Python function.
        if (py::isinstance<py::int_>(obj)) {  // check if it returned a Python integer type
            value = obj.cast<int32_t>();  // Cast it and assign it to the value.
            return true;  // Return true; value should be used.
        } else {
            return false;  // Python returned none, return false.
        }
    }
    return false;  // Alternatively return MyClass::myMethod(value);
}
```

8.4 □□□□□□

□□□□□□□□□□□□□□□□□□□□□□C++□□□□□□□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□□□
□□□□□□□□□□□□□□□

```
class Example {
private:
    Example(int); // private constructor
public:
    // Factory function:
    static Example create(int a) { return Example(a); }
};

py::class_<Example>(m, "Example")
    .def(py::init(&Example::create));
```

□□□□□□□□`create`□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□`.def(py::init(...))`□□□□□□□□□□□□□□□□□□□□□□create□□□□□□□`py::init()`□□□``std::unique_ptr`□□□□□□□

```
class Example {
private:
    Example(int); // private constructor
public:
    // Factory function - returned by value:
    static Example create(int a) { return Example(a); }

    // These constructors are publicly callable:
    Example(double);
    Example(int, int);
    Example(std::string);
};

py::class_<Example>(m, "Example")
    // Bind the factory function as a constructor:
    .def(py::init(&Example::create))
    // Bind a lambda function returning a pointer wrapped in a holder:
    .def(py::init([](std::string arg) {
        return std::unique_ptr<Example>(new Example(arg));
    }))
    // Return a raw pointer:
    .def(py::init([](int a, int b) { return new Example(a, b); }))
    // You can mix the above with regular C++ constructor bindings as
well:
    .def(py::init<double>())
    ;
```

□Python□□□□□□□□□□□pybind11□□□□□□□□□□□□□C++□□□□□Python□□□□

□□`py::init()`□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□□□□□□□□□`py::init_alias<...>`□□□□□□

□□□□□□□□□□□□□□

```
#include <pybind11/factory.h>
class Example {
public:
    // ...
    virtual ~Example() = default;
};
class PyExample : public Example {
public:
    using Example::Example;
    PyExample(Example &&base) : Example(std::move(base)) {}
};
py::class_<Example, PyExample>(m, "Example")
    // Returns an Example pointer.  If a PyExample is needed, the Example
    // instance will be moved via the extra constructor in PyExample,
above.
    .def(py::init([]() { return new Example(); }))
    // Two callbacks:
    .def(py::init([]() { return new Example(); } /* no alias needed */,
                  []() { return new PyExample(); } /* alias needed */))
    // *Always* returns an alias instance (like py::init_alias<>())
    .def(py::init([]() { return new PyExample(); }))
    ;
```

□□□□□□

`pybind11`□□□□□C++11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```cpp
struct Aggregate {
    int a;
    std::string b;
};

py::class_<Aggregate>(m, "Aggregate")
    .def(py::init<int, const std::string &>());
```

> Note: □□`py::init(...)`□□□□□
> □□□□□□□□□□□□□□□□□□□

8.5 □□□□□□□

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□`std::unique_ptr`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Pybind11□□□□□□□`py::nodelete`□□□□□□□□□□□□□□□□□□□C++□□□□□□□□□□□□□□□□□□□□□

```cpp
/* ... definition ... */

class MyClass {
private:
    ~MyClass() { }
};

/* ... binding code ... */

py::class_<MyClass, std::unique_ptr<MyClass, py::nodelete>>(m, "MyClass")
    .def(py::init<>())
```

8.6 □□□□□□□□Python

□□□□□□□□□Python□□□□□□□□□□□□`error_already_set`□□□□□□□□□□□□□□□□□□□□`std::terminate()`□□□□□□□□□□□□□□□□□□□□□□`error_already_set`□□□□□□□□□□`error_already_set::discard_as_unraisable()`□□□Python□□□

□□Python□□□□□□□□□□□□□□Python□□□□□□□□□□□Pyhton□□□ `StopIteration` □□□□□□□□□□□□□C++□□□□□□□□□□□□□□□□□□□C++□□□□□

```
class MyClass {
public:
    ~MyClass() {
        try {
            py::print("Even printing is dangerous in a destructor");
            py::exec("raise ValueError('This is an unraisable
exception')");
        } catch (py::error_already_set &e) {
            // error_context should be information about where/why the
occurred,
            // e.g. use __func__ to get the name of the current function
            e.discard_as_unraisable(__func__);
        }
    }
};
```

> Note: pybind11□□□□C++□□□□□□□ `noexcept(false)` □

8.7 □□□□

□□□A□B□□□A□□□□□□□B□

```
py::class_<A>(m, "A")
    /// ... members ...

py::class_<B>(m, "B")
    .def(py::init<A>())
    /// ... members ...

m.def("func",
    [](const B &) { /* .... */ }
);
```

□□□func□□□□A□□□□□a□Pyhton□□□□□□ `func(B(a))` □□C++□□□□□□□ `func(a)` □□□□A□□□□□B□□□

□□□□□□B□□□□□A□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□

```
py::implicitly_convertible<A, B>();
```

> Note: A□B□□□□□□□□□pybind11□□□B□□□□□□□□□
>
> □□□□□□□□□□□□□□□□□□□□□□□an implicit conversion invoked as part of another implicit conversion of the same type (i.e. from `A` to `B`) will fail.

8.8 □□□□

□□□□□□□□□□□□□□□□getter□setter□□□□□□self□□□□□□□□□Python□□□□□Python `type` □□□□□□□□□□C++□□□□□□□□□□□□□□□□□□□□lambda□□□□□getter□□□□□□self□□□

```
py::class_<Foo>(m, "Foo")
    .def_property_readonly_static("foo", [](py::object /* self */) {
return Foo(); });
```

8.9 □□□□□

□□□□□□□□□ `Vector2` □□□□□□□□□□□□□□□□□□□□□□□□□

```cpp
class Vector2 {
public:
    Vector2(float x, float y) : x(x), y(y) { }

    Vector2 operator+(const Vector2 &v) const { return Vector2(x + v.x, y + v.y); }
    Vector2 operator*(float value) const { return Vector2(x * value, y * value); }
    Vector2& operator+=(const Vector2 &v) { x += v.x; y += v.y; return *this; }
    Vector2& operator*=(float v) { x *= v; y *= v; return *this; }

    friend Vector2 operator*(float f, const Vector2 &v) {
        return Vector2(f * v.x, f * v.y);
    }

    std::string toString() const {
        return "[" + std::to_string(x) + ", " + std::to_string(y) + "]";
    }
private:
    float x, y;
};
```

□□□□□□□□□□

```cpp
#include <pybind11/operators.h>

PYBIND11_MODULE(example, m) {
    py::class_<Vector2>(m, "Vector2")
        .def(py::init<float, float>())
        .def(py::self + py::self)
        .def(py::self += py::self)
        .def(py::self *= float())
        .def(float() * py::self)
        .def(py::self * float())
        .def(-py::self)
        .def("__repr__", &Vector2::toString);
}
```

`.def(py::self * float())` □□□□□□□□□□□

```
.def("__mul__", [](const Vector2 &a, float b) {
    return a * b;
}, py::is_operator())
```

8.10 □□pickle

Python□ `pickle` □□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□□ `py::pickle()` □□□□□pickle□unpickle C++□□□□□□□□□□□

```
class Pickleable {
public:
    Pickleable(const std::string &value) : m_value(value) { }
    const std::string &value() const { return m_value; }

    void setExtra(int extra) { m_extra = extra; }
    int extra() const { return m_extra; }
private:
    std::string m_value;
    int m_extra = 0;
};
```

Python□□□□□ `__setstate__` □ `__getstate__` □□pciking□□□□□pybind11□□□□□□ `py::pickle()` □□□□□□□□□

```
py::class_<Pickleable>(m, "Pickleable")
    .def(py::init<std::string>())
    .def("value", &Pickleable::value)
    .def("extra", &Pickleable::extra)
    .def("setExtra", &Pickleable::setExtra)
    .def(py::pickle(
        [](const Pickleable &p) { // __getstate__
            /* Return a tuple that fully encodes the state of the object */
            return py::make_tuple(p.value(), p.extra());
        },
        [](py::tuple t) { // __setstate__
            if (t.size() != 2)
                throw std::runtime_error("Invalid state!");

            /* Create a new C++ instance */
            Pickleable p(t[0].cast<std::string>());

            /* Assign any additional state */
            p.setExtra(t[1].cast<int>());

            return p;
        }
    ));
```

`py::pickle()`□□`__setstate__`□□□□`py::init()`□□□□□□□□□□□□□□□□□□holder type□

Python□□□□□□□□

```python
try:
    import cPickle as pickle  # Use cPickle on Python 2.7
except ImportError:
    import pickle

p = Pickleable("test_value")
p.setExtra(15)
data = pickle.dumps(p, 2)
```

> Note: Note that only the cPickle module is supported on Python 2.7.

> The second argument to `dumps` is also crucial: it selects the pickle protocol version 2, since the older version 1 is not supported. Newer versions are also fine—for instance, specify `-1` to always use the latest available version. Beware: failure to follow these instructions will cause important pybind11 memory allocation routines to be skipped during unpickling, which will likely lead to memory corruption and/or segmentation faults.

8.11 □□□□□

Python□□□□□□□□□□□□□□□□□□□□□□□□□□□Python□`copy`□□□□□□□□□□

□Python3□□□pickle□□□□□□□□□□□□□□`__copy__`□`__deepcopy__`□□□□□□□□□□ Python2.7□□□□pybind11□□□cPickle□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□□□□□□

```
py::class_<Copyable>(m, "Copyable")
    .def("__copy__",  [](const Copyable &self) {
        return Copyable(self);
    })
    .def("__deepcopy__", [](const Copyable &self, py::dict) {
        return Copyable(self);
    }, "memo"_a);
```

> Note: □□□□□□□□□

8.12 □□□□

pybind11□□□□□□□□□□□□□□□□`class_`□□□□□□

```
py::class_<MyType, BaseType1, BaseType2, BaseType3>(m, "MyType")
   ...
```

□□□□□□□□□□□□□□□□□□□□holder□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□
□□

□□Python□□□□□□□□□C++□□□□□□□□□C++□□Python□□

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□
□□□□□□□□□□□□□□□□□`multiple_inheritance`□□□□

```
py::class_<MyType, BaseType2>(m, "MyType", py::multiple_inheritance());
```

□□□□□□□□□□□□□□□□□□□□□

8.13 □□Module-local□

pybind11□□□

```
// In the module1.cpp binding code for module1:
py::class_<Pet>(m, "Pet")
    .def(py::init<std::string>())
    .def_readonly("name", &Pet::name);

// In the module2.cpp binding code for module2:
m.def("create_pet", [](std::string name) { return new Pet(name); });
```

```
>>> from module1 import Pet
>>> from module2 import create_pet
>>> pet1 = Pet("Kitty")
>>> pet2 = create_pet("Doggy")
>>> pet2.name()
'Doggy'
```

□□□□□□□□□□□□□□□□□□Python□□□□

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□C++□□□□□□□□□□□□□□□□□□□□□□□Python□
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
// dogs.cpp

// Binding for external library class:
py::class<pets::Pet>(m, "Pet")
    .def("name", &pets::Pet::name);

// Binding for local extension class:
py::class<Dog, pets::Pet>(m, "Dog")
    .def(py::init<std::string>());
```

```
// cats.cpp, in a completely separate project from the above dogs.cpp.

// Binding for external library class:
py::class<pets::Pet>(m, "Pet")
    .def("get_name", &pets::Pet::name);

// Binding for local extending class:
py::class<Cat, pets::Pet>(m, "Cat")
    .def(py::init<std::string>());
```

```
>>> import cats
>>> import dogs
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ImportError: generic_type: type "Pet" is already registered!
```

□□□□□□□□□□`py::class_`□□`py::module_local()`□□□□□□□□□□□□□□□

```
// Pet binding in dogs.cpp:
py::class<pets::Pet>(m, "Pet", py::module_local())
    .def("name", &pets::Pet::name);
```

```
// Pet binding in cats.cpp:
py::class<pets::Pet>(m, "Pet", py::module_local())
    .def("get_name", &pets::Pet::name);
```

□□□Python□□`dogs.Pet`□`cats.Pet`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□1□□□□□□□□□□□□`Pet`□□□Python□□□□□□□□□□□□□□□□2□□Python□□□□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□C++□Python□□□□□□□ `py::module_local` □□□C++□□□□module-local□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□cats□dogs□□□□□□□□□□□□ `dogs.Pet` □ `cats.Pet` □□□□□□

```
m.def("pet_name", [](const pets::Pet &pet) { return pet.name(); });
```

□□□□□□□□□□□□□□□ `cats.cpp` □ `dogs.cpp` □ `frogs.cpp` □ `frogs.cpp` □□□□ `Pets` □□□

```
>>> import cats, dogs, frogs  # No error because of the added
py::module_local()
>>> mycat, mydog = cats.Cat("Fluffy"), dogs.Dog("Rover")
>>> (cats.pet_name(mycat), dogs.pet_name(mydog))
('Fluffy', 'Rover')
>>> (cats.pet_name(mydog), dogs.pet_name(mycat), frogs.pet_name(mycat))
('Rover', 'Fluffy', 'Fluffy')
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `py::module_local()` □□□□□□□□□□□module-local□□□□□□□C++□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□Python□□□

Note: STL bindings (as provided via the optional `pybind11/stl_bind.h` header) apply `py::module_local` by default when the bound type might conflict with other modules; see Binding STL containers for details.

The localization of the bound types is actually tied to the shared object or binary generated by the compiler/linker. For typical modules created with `PYBIND11_MODULE()`, this distinction is not significant. It is possible, however, when Embedding the interpreter to embed multiple modules in the same binary (see Adding embedded modules). In such a case, the localization will apply across all embedded modules within the same binary.

8. 14 □□protected□□□□

□□□□□□Python□□protected □□□□□

```cpp
class A {
protected:
    int foo() const { return 42; }
};

py::class_<A>(m, "A")
    .def("foo", &A::foo); // error: 'foo' is a protected member of 'A'
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□protected □□□□□□□□□□□□□□□□□□□

```cpp
class A {
protected:
    int foo() const { return 42; }
};

class Publicist : public A { // helper type for exposing protected functions
public:
    using A::foo; // inherited with different access modifier
};

py::class_<A>(m, "A") // bind the primary class
    .def("foo", &Publicist::foo); // expose protected methods via the publicist
```

□□ `&Publicist::foo` □`&A::foo` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `Publicist` □□□□□□□□□□□□□□□□□□`public`□

□□□□□□□□Python□□□□ `protected` □□□□□□□publicist pattern□□□□□□trampoline□□□□

```
class A {
public:
    virtual ~A() = default;

protected:
    virtual int foo() const { return 42; }
};

class Trampoline : public A {
public:
    int foo() const override { PYBIND11_OVERRIDE(int, A, foo, ); }
};

class Publicist : public A {
public:
    using A::foo;
};

py::class_<A, Trampoline>(m, "A") // <-- `Trampoline` here
    .def("foo", &Publicist::foo); // <-- `Publicist` here, not
`Trampoline`!
```

8.15 □□final□

□C++11□□□□□□□□□ `findal` □□□□□□□□□□□□□□□ `py::is_final` □□□□□□□□□□□□□□Python□□□□□□□□□C++□□□□□□□□final□

```
class IsFinal final {};

py::class_<IsFinal>(m, "IsFinal", py::is_final());
```

□Python□□□□□□□□□□□□□□□□□

```
class PyFinalChild(IsFinal):
    pass

TypeError: type 'IsFinal' is not an acceptable base type
```

8.16 □□□□□□□□

□□□“□□□□□□□□”□□□□□□□pybind11□□□□□C++□□□□□□□□□□□□Sometimes, you might want to provide this automatic downcasting behavior when creating bindings for a class hierarchy that does not use standard C++ polymorphism, such as LLVM. As long as there’s some way to determine at runtime whether a downcast is safe, you can proceed by specializing the `pybind11::polymorphic_type_hook` template:

```cpp
enum class PetKind { Cat, Dog, Zebra };
struct Pet {   // Not polymorphic: has no virtual methods
    const PetKind kind;
    int age = 0;
  protected:
    Pet(PetKind _kind) : kind(_kind) {}
};
struct Dog : Pet {
    Dog() : Pet(PetKind::Dog) {}
    std::string sound = "woof!";
    std::string bark() const { return sound; }
};

namespace pybind11 {
    template<> struct polymorphic_type_hook<Pet> {
        static const void *get(const Pet *src, const std::type_info*&
type) {
            // note that src may be nullptr
            if (src && src->kind == PetKind::Dog) {
                type = &typeid(Dog);
                return static_cast<const Dog*>(src);
            }
            return src;
        }
    };
} // namespace pybind11
```

When pybind11 wants to convert a C++ pointer of type `Base*` to a Python object, it calls `polymorphic_type_hook<Base>::get()` to determine if a downcast is possible. The `get()` function should use whatever runtime information is available to determine if its `src` parameter is in fact an instance of some class `Derived` that inherits from `Base`. If it finds such a `Derived`, it sets `type = &typeid(Derived)` and returns a pointer to the `Derived` object that contains `src`. Otherwise, it just returns `src`, leaving `type` at its default value of nullptr. If you set `type` to a type that pybind11 doesn't know about, no downcasting will occur, and the original `src` pointer will be used with its static type `Base*`.

It is critical that the returned pointer and `type` argument of `get()` agree with each other: if `type` is set to something non-null, the returned pointer must point to the start of an object whose type is `type`. If the hierarchy being exposed uses only single inheritance, a simple `return src;` will achieve this just fine, but in the general case, you must cast `src` to the appropriate derived-class pointer (e.g. using `static_cast<Derived>(src)`) before allowing it to be returned as a `void*`.

8.17 □□□□□□

□□□□□□□□□C++□□□□□□□□□□

```
py::type T_py = py::type::of<T>();
```

□□□□□□□`py::type::of(ob)`□□□□□Python□□□□□□□Python□□`type(ob)`□□□

9. □□

9.1 C++□□□□□Python□□□□□

□Python□□pybind11□□C++□□□□pybind11□□□C++□□□□□□□□□□Python□□□□□□□
Python□□□□□□□□

pybind11□□□`std::exception`□□□□□□□□□□□□□Python□□□□□□□□□□□□□Python□
□□□□□□□Python C API□□□□□□□□□□C++□□□□□□□□□□□□□pybind11□□□□□□□
Python□□□

Exception thrown by C++	Translated to Python exception type
`std::exception`	`RuntimeError`
`std::bad_alloc`	`MemoryError`
`std::domain_error`	`ValueError`
`std::invalid_argument`	`ValueError`
`std::length_error`	`ValueError`
`std::out_of_range`	`IndexError`
`std::range_error`	`ValueError`
`std::overflow_error`	`OverflowError`
`pybind11::stop_iteration`	`StopIteration` (used to implement custom iterators)
`pybind11::index_error`	`IndexError` (used to indicate out of bounds access in `__getitem__`, `__setitem__`, etc.)
`pybind11::key_error`	`KeyError` (used to indicate out of bounds access in `__getitem__`, `__setitem__` in dict-like objects, etc.)

Exception thrown by C++	Translated to Python exception type
`pybind11::value_error`	`ValueError` (used to indicate wrong value passed in `container.remove(...)`)
`pybind11::type_error`	`TypeError`
`pybind11::buffer_error`	`BufferError`
`pybind11::import_error`	`ImportError`
`pybind11::attribute_error`	`AttributeError`
Any other exception	`RuntimeError`

□□□□□□□□□□□□□□□□□□□□□Python□□□□Python□□□□□□□□ `pybind11::error_already_set`□

□□□□□□□□□□□□□□□□□□Python□□□□`handle::call()`□□□`cast_error`□□□

9.2 □□□□□□□□□

□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□pybind11 class□□□□□□□□□□□□□□□global□□□□□□□□C++□□□`what()`□□□C++□Python□□□□□□□□□□□□□□□□

```
py::register_exception<CppExp>(module, "PyExp");
```

□□□□□□□□□□□□□□□□□□□PyExp□Python□□□□□□□□CppExp□□□□□□□□□PyExp□□□

□□□□□□□□□□□□□□□□□□□□

```
py::register_local_exception<CppExp>(module, "PyExp");
```

□□□□□□□□handle□□□□□□□□□□

```
py::register_exception<CppExp>(module, "PyExp", PyExc_RuntimeError);
py::register_local_exception<CppExp>(module, "PyExp", PyExc_RuntimeError);
```

□□□PyExp□□□□□□PyExp□RuntimeError□

Python□□□□□□□□□□□□Python□□Standard Exceptions□□□□□□□ `PyExc_Exception` □

`py::register_exception_translator(translator)` □ `py::register_local_exception_translator(translator)` □□□□□□□□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□ `void(std::exception_ptr)` □

C++□□

Inside the translator, `std::rethrow_exception` should be used within a try block to re-throw the exception. One or more catch clauses to catch the appropriate exceptions should then be used with each clause using `PyErr_SetString` to set a Python exception or `ex(string)` to set the python exception to a custom exception type (see below).

To declare a custom Python exception type, declare a `py::exception` variable and use this in the associated exception translator (note: it is often useful to make this a static declaration when using it inside a lambda expression without requiring capturing).

The following example demonstrates this for a hypothetical exception classes `MyCustomException` and `OtherException`: the first is translated to a custom python exception `MyCustomError`, while the second is translated to a standard python RuntimeError:

```
static py::exception<MyCustomException> exc(m, "MyCustomError");
py::register_exception_translator([](std::exception_ptr p) {
    try {
        if (p) std::rethrow_exception(p);
    } catch (const MyCustomException &e) {
        exc(e.what());
    } catch (const OtherException &e) {
        PyErr_SetString(PyExc_RuntimeError, e.what());
    }
});
```

Multiple exceptions can be handled by a single translator, as shown in the example above. If the exception is not caught by the current translator, the previously registered one gets a chance.

If none of the registered exception translators is able to handle the exception, it is handled by the default converter as described in the previous section.

9.3 Local vs Global Exception Translators

When a global exception translator is registered, it will be applied across all modules in the reverse order of registration. This can create behavior where the order of module import influences how exceptions are translated.

If module1 has the following translator:

```
py::register_exception_translator([](std::exception_ptr p) {
  try {
      if (p) std::rethrow_exception(p);
  } catch (const std::invalid_argument &e) {
      PyErr_SetString("module1 handled this")
  }
}
```

and module2 has the following similar translator:

```
py::register_exception_translator([](std::exception_ptr p) {
  try {
      if (p) std::rethrow_exception(p);
  } catch (const std::invalid_argument &e) {
      PyErr_SetString("module2 handled this")
  }
}
```

then which translator handles the invalid_argument will be determined by the order that module1 and module2 are imported. Since exception translators are applied in the reverse order of registration, which ever module was imported last will “win” and that translator will be applied.

If there are multiple pybind11 modules that share exception types (either standard built-in or custom) loaded into a single python instance and consistent error handling behavior is needed, then local translators should be used.

Changing the previous example to use `register_local_exception_translator` would mean that when invalid_argument is thrown in the module2 code, the module2 translator will always handle it, while in module1, the module1 translator will do the same.

9.4 □C++□□□Python□□

□C++□□Python□□□□□□□□□□□□□□Python□□□□□□Python□□□□□□□pybind11□□Python□□□□□□ `pybind11::error_already_set` □□□□□□□□□□□□□□C++□□□□□□□□□□□Python□□□ `error_already_set` □□□Python□□□□Python□□□□C++□□□□□

Exception raised in Python	Thrown as C++ exception type
Any Python `Exception`	`pybind11::error_already_set`

□□□□□

```
try {
    // open("missing.txt", "r")
    auto file = py::module_::import("io").attr("open")("missing.txt",
"r");
    auto text = file.attr("read")();
    file.attr("close")();
} catch (py::error_already_set &e) {
    if (e.matches(PyExc_FileNotFoundError)) {
        py::print("missing.txt not found");
    } else if (e.matches(PyExc_PermissionError)) {
        py::print("missing.txt found but not accessible");
    } else {
        throw;
    }
}
```

□□□□□□□C++□Python□□□□Python□□□□□□□□□□□ `error_already_set`.

```cpp
try {
    py::eval("raise ValueError('The Ring')");
} catch (py::value_error &boromir) {
    // Boromir never gets the ring
    assert(false);
} catch (py::error_already_set &frodo) {
    // Frodo gets the ring
    py::print("I will take the ring");
}

try {
    // py::value_error is a request for pybind11 to raise a Python
exception
    throw py::value_error("The ball");
} catch (py::error_already_set &cat) {
    // cat won't catch the ball since
    // py::value_error is not a Python exception
    assert(false);
} catch (py::value_error &dog) {
    // dog will catch the ball
    py::print("Run Spot run");
    throw;  // Throw it again (pybind11 will raise ValueError)
}
```

9.5 □□Python C API□□□

□□□□□□pybind11 wrappers□□□□□□Python C API□□□□□□□□□□□Python C API□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□

□□□Python C API□□□□Python□□□□□□□□□`throw py::error_already_set();`□□□□pybind11□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□`PyErr_SetString`□

```cpp
PyErr_SetString(PyExc_TypeError, "C API type error demo");
throw py::error_already_set();

// But it would be easier to simply...
throw py::type_error("pybind11 wrapper type error");
```

□□□□□`PyErr_Clear`□□□□□□

□□Python□□□□□□□□□□□□□□Python/pybind11□□□□□□□□□

9.6 □□□□raise from□

□Python 3.3□□□□□□□□□□□□□□□□□□□□□□□

```
try:
    print(1 / 0)
except Exception as exc:
    raise RuntimeError("could not divide by zero") from exc
```

pybind11 2.8□□□□□□□□`py::raise_from`□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□`throw py::error_already_set()`□Python 3 only□□

```
try {
    py::eval("print(1 / 0"));
} catch (py::error_already_set &e) {
    py::raise_from(e, PyExc_RuntimeError, "could not divide by zero");
    throw py::error_already_set();
}
```

9.7 □□unraiseable□□

□□Python□□□C++□□□□□□□□□□`noexcept(true)`□□c++□□□□□□std::terminate()□□□□□□□

□□□□□□`__del__`□□□□□Python□□□□□□□□□□□Python□□unraisable□□□□□□□□Python 3.8+□□□□□system hook□□□□auditing event□□□

□□noexcept□□□□□□try-catch□□□□□□`error_already_set`□□□□□□□□□□□□□□pybind11□□□Python□□□□□□□Python□□□□□pybind11□□□□□□C++□□□noexcept□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□`discard_as_unraisable`□□□□□□

```cpp
void nonthrowing_func() noexcept(true) {
    try {
        // ...
    } catch (py::error_already_set &eas) {
        // Discard the Python error using Python APIs, using the C++ magic
        // variable __func__. Python already knows the type and value and
of the
        // exception object.
        eas.discard_as_unraisable(__func__);
    } catch (const std::exception &e) {
        // Log and discard C++ exceptions.
        third_party::log(e);
    }
}
```

10. □□□□

10.1 std::unique_ptr

□□□□□Python□□□□`Example`□□□□□□□□□□□□□□unique pointer□□□□□□□

```
std::unique_ptr<Example> create_example() { return
std::unique_ptr<Example>(new Example()); }

m.def("create_example", &create_example);
```

□□□□□□□□□□□□□□□□□□□□□□□□□□unique_ptr□□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□

```
void do_something_with_example(std::unique_ptr<Example> ex) { ... }
```

□□□□□□□□Python□□□

10.2 std::shared_ptr

`class_`□□□ `std::unique_ptr<Type>`□□□□□□□□Python□□□□□□0□□□`std::shared_ptr`□

```
py::class_<Example, std::shared_ptr<Example> /* <- holder type */> obj(m,
"Example");
```

□□□□□□□□□□□□□□□□□□□

□□□

```cpp
class Child { };

class Parent {
public:
   Parent() : child(std::make_shared<Child>()) { }
   Child *get_child() { return child.get(); }  /* Hint: ** DON'T DO THIS
** */
private:
    std::shared_ptr<Child> child;
};

PYBIND11_MODULE(example, m) {
    py::class_<Child, std::shared_ptr<Child>>(m, "Child");

    py::class_<Parent, std::shared_ptr<Parent>>(m, "Parent")
       .def(py::init<>())
       .def("get_child", &Parent::get_child);
}
```

□□□Python□□□□□□□□□□□□□□□□□□□□

```python
from example import Parent
print(Parent().get_child())
```

□□□□`Parent::get_child()`□□□`Child`□□□□□□□□□□□□□□□`std::shared_ptr<...>`□□□□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□`std::shared_ptr<...>`□□□□□□□□□□□□□□□□□free□□□□□□shared□□□□□□□□□□□□□

□□□□□□□□□□□□□

1. □□□`get_child()`□□□□□□□

   ```cpp
   std::shared_ptr<Child> get_child() { return child; }
   ```

2. □□`Child`□□□`std::enable_shared_from_this<T>`□□□□□□□□`Child`□□□□□□□□□□□□□pybind11□□□□□□□□□□□□`std::shared_ptr<...>`□□□□□□□□□□□□□□□

```
class Child : public std::enable_shared_from_this<Child> { };
```

10.3 □□□□□□□

pybind11□□□□□□□ `std::unique_ptr` □ `std::shared_ptr` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□transparent conversions□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
PYBIND11_DECLARE_HOLDER_TYPE(T, SmartPtr<T>);
```

□□□

□□□□□□□□□□□□bool□□□□□□□□false□

```
PYBIND11_DECLARE_HOLDER_TYPE(T, SmartPtr<T>, true);
```

□□ `SmartPtr<T>` □□□ `T*` □□□□□□□□□□□□□□□□□□□□□□□ `SmartPtr<T>` □□□□□ `T*` □□□□□□□□□□□ `T` □□□□□□□□□□□□□□□□□□ `true` □

□□□□□□□□□□□□ General notes regarding convenience macros□

□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□ `.get()` □□□□□□□□□□□□□□□□□□□□□□□□□□ `holder_helper` □

```
// Always needed for custom holder types
PYBIND11_DECLARE_HOLDER_TYPE(T, SmartPtr<T>);

// Only needed if the type's `.get()` goes by another name
namespace pybind11 { namespace detail {
    template <typename T>
    struct holder_helper<SmartPtr<T>> { // <-- specialization
        static const T *get(const SmartPtr<T> &p) { return p.getPointer();
}
    };
}}
```

□□□□□□pybind11□□□□`SmartPtr`□□`.getPointer()`□□`.get()`□□□

> see also: □□`tests/test_smart_ptr.cpp`□□□□□□□□□□□□□□□□□□holder□□□□□□□□

11. [illegible]

[illegible]pybind11[illegible]C++[illegible]Python[illegible]

1. [illegible]C++[illegible]pybind11[illegible]Python[illegible]
2. [illegible]Python[illegible]C++[illegible]
3. C++[illegible]C++[illegible]Python[illegible]Python[illegible]pybind11[illegible] [illegible]Python[illegible]C++[illegible]C++[illegible]Python[illegible] pybind11[illegible]

[illegible]

11.1 [illegible]

1. Native type in C++, wrapper in Python

[illegible]“[illegible]”[illegible]`py::class_`[illegible]C++[illegible]C++[illegible]`py::class_`[illegible]Python[illegible]C++[illegible]Python[illegible]pybind11[illegible]C++[illegible]Python[illegible]

2. Wrapper in C++, native type in Python

[illegible]Python[illegible]tuple[illegible]list[illegible]C++[illegible]`py::object`[illegible]

```cpp
void print_list(py::list my_list) {
    for (auto item : my_list)
        std::cout << item << " ";
}
```

```python
>>> print_list([1, 2, 3])
1 2 3
```

Python□list□□□□□□□C++ `py::list` □□□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□ `py::list` □□Python□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□

3. Converting between native C++ and Python types

□□

```cpp
void print_vector(const std::vector<int> &v) {
    for (auto item : v)
        std::cout << item << "\n";
}
```

```python
>>> print_vector([1, 2, 3])
1 2 3
```

□□□□□□□pybind11□□□□□□ `std::vector<int>` □□□□□□Python list□□□□□□□□□□□□□□□□□□□□□□□□ `print_vector` □□□□□□□□□□□□□□□□□□□□□□□□list□□□□C++□vector□□□□□□□□□

□□1□□This requires some manual effort and more details are available in the Making opaque types section.

□□□□□□□□

□□□□□□□□□□□□□□□□□□□□□□□□□□include□□□□□□□□□

Data type	Description	Header file
`int8_t`, `uint8_t`	8-bit integers	`pybind11/pybind11.h`
`int16_t`, `uint16_t`	16-bit integers	`pybind11/pybind11.h`
`int32_t`, `uint32_t`	32-bit integers	`pybind11/pybind11.h`
`int64_t`, `uint64_t`	64-bit integers	`pybind11/pybind11.h`

Data type	Description	Header file
`ssize_t`, `size_t`	Platform-dependent size	`pybind11/pybind11.h`
`float`, `double`	Floating point types	`pybind11/pybind11.h`
`bool`	Two-state Boolean type	`pybind11/pybind11.h`
`char`	Character literal	`pybind11/pybind11.h`
`char16_t`	UTF-16 character literal	`pybind11/pybind11.h`
`char32_t`	UTF-32 character literal	`pybind11/pybind11.h`
`wchar_t`	Wide character literal	`pybind11/pybind11.h`
`const char *`	UTF-8 string literal	`pybind11/pybind11.h`
`const char16_t *`	UTF-16 string literal	`pybind11/pybind11.h`
`const char32_t *`	UTF-32 string literal	`pybind11/pybind11.h`
`const wchar_t *`	Wide string literal	`pybind11/pybind11.h`
`std::string`	STL dynamic UTF-8 string	`pybind11/pybind11.h`
`std::u16string`	STL dynamic UTF-16	`pybind11/pybind11.h`

Data type	Description	Header file
	string	
`std::u32string`	STL dynamic UTF-32 string	`pybind11/pybind11.h`
`std::wstring`	STL dynamic wide string	`pybind11/pybind11.h`
`std::string_view`, `std::u16string_view`, etc.	STL C++17 string views	`pybind11/pybind11.h`
`std::pair<T1, T2>`	Pair of two custom types	`pybind11/pybind11.h`
`std::tuple<...>`	Arbitrary tuple of types	`pybind11/pybind11.h`
`std::reference_wrapper<...>`	Reference type wrapper	`pybind11/pybind11.h`
`std::complex<T>`	Complex numbers	`pybind11/complex.h`
`std::array<T, Size>`	STL static array	`pybind11/stl.h`
`std::vector<T>`	STL dynamic array	`pybind11/stl.h`
`std::deque<T>`	STL double-ended queue	`pybind11/stl.h`
`std::valarray<T>`	STL value array	`pybind11/stl.h`
`std::list<T>`	STL linked list	`pybind11/stl.h`

Data type	Description	Header file
`std::map<T1, T2>`	STL ordered map	`pybind11/stl.h`
`std::unordered_map<T1, T2>`	STL unordered map	`pybind11/stl.h`
`std::set<T>`	STL ordered set	`pybind11/stl.h`
`std::unordered_set<T>`	STL unordered set	`pybind11/stl.h`
`std::optional<T>`	STL optional type (C++17)	`pybind11/stl.h`
`std::experimental::optional<T>`	STL optional type (exp.)	`pybind11/stl.h`
`std::variant<...>`	Type-safe union (C++17)	`pybind11/stl.h`
`std::filesystem::path<T>`	STL path (C++17) [1]	`pybind11/stl.h`
`std::function<...>`	STL polymorphic function	`pybind11/functional.h`
`std::chrono::duration<...>`	STL time duration	`pybind11/chrono.h`
`std::chrono::time_point<...>`	STL date/time	`pybind11/chrono.h`
`Eigen::Matrix<...>`	Eigen: dense matrix	`pybind11/eigen.h`
`Eigen::Map<...>`	Eigen: mapped	`pybind11/eigen.h`

Data type	Description	Header file
	memory	
`Eigen::SparseMatrix<...>`	Eigen: sparse matrix	`pybind11/eigen.h`

11.2 Strings, bytes and Unicode conversions

> Note: □□□□□string□□□□Python3 strings□□□python2.7□□□ `unicode` □□ `str` □ `str` □□ `bytes` □Python2.7□□□□□□ `from __future__ import unicode_literals` □□□□□□□ `str` □□ `unicode` □

11.2.1 □□Python strings□C++

□□□□□□ `std::string` □ `char *` □□□□□□Python□ `str` □□pybind11□□Python□□□□□□ UTF-8□□□□Python `str` □□□□UTF-8□□□□□□□□□□□□□□□

C++□□□encoding agnostic□□□□□□□□□□□□□□□□□□□□□□□□□□□□UTF-8□

```
m.def("utf8_test",
    [](const std::string &s) {
        cout << "utf-8 is icing on the cake.\n";
        cout << s;
    }
);
m.def("utf8_charptr",
    [](const char *s) {
        cout << "My favorite food is\n";
        cout << s;
    }
);
```

```
>>> utf8_test("🎂")
utf-8 is icing on the cake.
🎂

>>> utf8_charptr("🍕")
My favorite food is
🍕
```

> Note: □□□□□□□□□□UTF-8□emoji□□□□□□□□□□□□□□□

□□C++□□□□□□□□□□□□□□□const□□□□□□□□□

□C++□□bytes□□

□□□ `std::string` □ `char *` □□□□□C++□□□□Python bytes□□□□□□□□Python3□□□□□□□□□□□bytes□□□□str□□□□□□□□□□ `py::bytes` □

11.2.2 □Python□□C++ □□□

□C++□□□□ `std::string` □ `char*` □□□Python□□□□□pybind11□□□□□□UTF-8□□□□□□□Python str□□□□Python□□ `bytes.decode('utf-8')` □□□□□□□□□□pybind11□□□□□□ `UnicodeDecodeError` □

```
m.def("std_string_return",
    []() {
        return std::string("This string needs to be UTF-8 encoded");
    }
);
```

```
>>> isinstance(example.std_string_return(), str)
True
```

□□UTF-8□□□ASCII□□□□□ASCII□□□□Python□□□□□□□□□□□□□□□□□□□□□□□UTF-8□

> Warning: □□□□□□□ `char *` □□□□null□□□□□□□□□□□□□□□□□□□□

□□□□

□□C++□□□□□□□□□□UTF-8□string□□□□□□□□□□□□□□□□□□□ `py::str` □□□□□□□□□□□□□□□□□□□□□□

```
// This uses the Python C API to convert Latin-1 to Unicode
m.def("str_output",
    []() {
        std::string s = "Send your r\xe9sum\xe9 to Alice in HR"; // Latin-1
        py::str py_s = PyUnicode_DecodeLatin1(s.data(), s.length());
        return py_s;
    }
);
```

```
>>> str_output()
'Send your résumé to Alice in HR'
```

Python C API□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□libiconv □□□UTF-8□

□□□□□□□□□□□**C++**□□□

□□C++ `std::string` □□□□□□□□□□□□□□□□□□ `bytes` □□□□□□Python□□□□□□□□□□□□□□ `py::btyes` □□□

```
m.def("return_bytes",
    []() {
        std::string s("\xba\xd0\xba\xd0");  // Not valid UTF-8
        return py::bytes(s);  // Return the data without transcoding
    }
);
```

```
>>> example.return_bytes()
b'\xba\xd0\xba\xd0'
```

□□□pybind11□□□bytes□□□□□□□□□ `std::string` □□□□□□□□□□□□□□□□ `std::string` □bytes□

```
m.def("asymmetry",
    [](std::string s) {  // Accepts str or bytes from Python
        return s;  // Looks harmless, but implicitly converts to str
    }
);
```

```
>>> isinstance(example.asymmetry(b"have some bytes"), str)
True

>>> example.asymmetry(b"\xba\xd0\xba\xd0")  # invalid utf-8 as bytes
UnicodeDecodeError: 'utf-8' codec can't decode byte 0xba in position 0:
invalid start byte
```

11.2.3 □□□□

□□□□`std::wstring`□`wchar_t*`□`std::u16string`□`std::u32string`□C++□□□□Python str□□□str□□□□□UTF-16□UTF-32□□□□□□□□C++□□□□□□□□□C++□□□□□□□□□□□□□Python str□□□□□□□□□□□□□UTF-16□UTF-32□

```
#define UNICODE
#include <windows.h>

m.def("set_window_text",
    [](HWND hwnd, std::wstring s) {
        // Call SetWindowText with null-terminated UTF-16 string
        ::SetWindowText(hwnd, s.c_str());
    }
);
m.def("get_window_text",
    [](HWND hwnd) {
        const int buffer_size = ::GetWindowTextLength(hwnd) + 1;
        auto buffer = std::make_unique< wchar_t[] >(buffer_size);

        ::GetWindowText(hwnd, buffer.data(), buffer_size);

        std::wstring text(buffer.get());

        // wstring will be converted to Python str
        return text;
    }
);
```

> □□□□ `--enable-unicode=ucs2` □□□□□Python 2.7□3.3□□□□□□□□□□□□□□□□

□□□□□□□□□□□□Shift-JIS□□□□□□UTF-8/16/32□□□□□□Python□

11.2.4 □□□□

□□□□□□□□□□□□char, wchar_t□□C++□□□□□Python str□C++□□□□□str□□□□□□□□□□□□□□□Unicode□□□□□□□□□□□□□□

□C++□□□□□□□□□□□□□□□□□□□□□□str□□□

```
m.def("pass_char", [](char c) { return c; });
m.def("pass_wchar", [](wchar_t w) { return w; });
```

```
example.pass_char("A")
'A'
```

□□C++□□□□□□□□□□□□□□`char c = 0x65`□□pybind11□□□□□□□Python□□□□□□□□□□□□□□`chr()` Python□□□□□□□□□□□□□□

```
>>> example.pass_char(0x65)
TypeError

>>> example.pass_char(chr(0x65))
'A'
```

□□□□□□8-bit□□□□□□□`int8_t`□`uint8_t`□□□□□□□

11.2.5 Grapheme clusters

A single grapheme may be represented by two or more Unicode characters. For example ‘é’ is usually represented as U+00E9 but can also be expressed as the combining character sequence U+0065 U+0301 (that is, the letter ‘e’ followed by a combining acute accent). The combining character will be lost if the two-character sequence is passed as an argument, even though it renders as a single grapheme.

```
>>> example.pass_wchar("é")
'é'

>>> combining_e_acute = "e" + "\u0301"

>>> combining_e_acute
'é'

>>> combining_e_acute == "é"
False

>>> example.pass_wchar(combining_e_acute)
'e'
```

Normalizing combining characters before passing the character literal to C++ may resolve *some* of these issues:

```
>>> example.pass_wchar(unicodedata.normalize("NFC", combining_e_acute))
'é'
```

In some languages (Thai for example), there are graphemes that cannot be expressed as a single Unicode code point, so there is no way to capture them in a C++ character type.

11.2.6 c++17 string_view

C++17 string views are automatically supported when compiling in C++17 mode. They follow the same rules for encoding and decoding as the corresponding STL string type (for example, a `std::u16string_view` argument will be passed UTF-16-encoded data, and a returned `std::string_view` will be decoded as UTF-8).

11.3 STL□□

11.3.1 □□□□

□□□□□`pybind11/stl.h`□□□□□□ `std::vector<>` / `std::deque<>` / `std::list<>` / `std::array<>` / `std::valarray<>` , `std::set<>` / `std::unordered_set<>` , □ `std::map<>` / `std::unordered_map<>` □Python `list` , `set` □ `dict` □□□□□□ `std::pair<>` □ `std::tuple<>` □□□□□ `pybind11/pybind11.h`□□□□□□

□□□□□□□□□□□Python□C++□□

> Note: □□□□□□□□□□□□□□

11.3.2 C++17□□□□

`pybind11/stl.h` □□C++17□ `std::optional<>` □ `std::variant<>` □C++14□ `std::experimental::optional<>` □

C++11□□□□□□□□□□□□□□□□Boost□□pybind11□□□□□□□□□□ `type_caster` □□□□□□□□

```
// `boost::optional` as an example -- can be any `std::optional`-like
container
namespace pybind11 { namespace detail {
    template <typename T>
    struct type_caster<boost::optional<T>> :
optional_caster<boost::optional<T>> {};
}}
```

□□□□□□□□□□□□□□□□□□□□□□□□Similarly, a specialization can be provided for custom variant types:

```
// `boost::variant` as an example -- can be any `std::variant`-like
container
namespace pybind11 { namespace detail {
    template <typename... Ts>
    struct type_caster<boost::variant<Ts...>> :
variant_caster<boost::variant<Ts...>> {};

    // Specifies the function used to visit the variant -- `apply_visitor`
instead of `visit`
    template <>
    struct visit_helper<boost::variant> {
        template <typename... Args>
        static auto call(Args &&...args) ->
decltype(boost::apply_visitor(args...)) {
            return boost::apply_visitor(args...);
        }
    };
}} // namespace pybind11::detail
```

The `visit_helper` specialization is not required if your `name::variant` provides a `name::visit()` function. For any other function name, the specialization must be included to tell pybind11 how to visit the variant.

> Warning: When converting a `variant` type, pybind11 follows the same rules as when determining which function overload to call (Overload resolution order), and so the same caveats hold. In particular, the order in which the `variant`'s alternatives are listed is important, since pybind11 will try conversions in this order. This means that, for example, when converting `variant<int, bool>`, the `bool` variant will never be selected, as any Python `bool` is already an `int` and is convertible to a C++ `int`. Changing the order of alternatives (and using `variant<bool, int>`, in this example) provides a solution.

11.3.3 □□opaque□□

pybind11□□□□□□□□□□□□□□□STL□□□□□□□□□□□□vector□□□□□□□□□□□□□□□□□□□□lists of hash maps of pairs of elementary and custom types□

□□□□□□□□□□□□□□□□□□□Python□C++□□□□□□□□□□□□□□□□□□□pass-by-reference□□□□

□□□□□□□□□□□□

```cpp
void append_1(std::vector<int> &v) {
   v.push_back(1);
}
```

□Python□□□□□

```python
>>> v = [5, 6]
>>> append_1(v)
>>> print(v)
[5, 6]
```

□□□□□□□□□□□□STL□□□□□□□□□□□□□Python□□□□□□□□□□□□□`def_readwrite`□`def_readonly`□□□□STL□□□□□□

```cpp
/* ... definition ... */

class MyClass {
    std::vector<int> contents;
};

/* ... binding code ... */

py::class_<MyClass>(m, "MyClass")
    .def(py::init<>())
    .def_readwrite("contents", &MyClass::contents);
```

□□□□□□□□□□□□□□□□□□□□□append□□□□□□□□□□

```python
>>> m = MyClass()
>>> m.contents = [5, 6]
>>> print(m.contents)
[5, 6]
>>> m.contents.append(7)
>>> print(m.contents)
[5, 6]
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□`PYBIND11_MAKE_OPAQUE(T)`□□□□□□□□□□□□□□□□□□□□□□□□□*opaque*□□opaque□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`std::vector<int>`□□□opaque□□□□□□□□□□□□□□□□□□

```cpp
PYBIND11_MAKE_OPAQUE(std::vector<int>);
```

□□□□□□□□□□□□□□□□□□□□□□□□□`type_caster`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`std::vector<int>`□□□□□□□□□□□□□□□□□□opaque□□□□□`class_`□□□□□Python□□□□□□□□□□□□□□□□□□

```
py::class_<std::vector<int>>(m, "IntVector")
    .def(py::init<>())
    .def("clear", &std::vector<int>::clear)
    .def("pop_back", &std::vector<int>::pop_back)
    .def("__len__", [](const std::vector<int> &v) { return v.size(); })
    .def("__iter__", [](std::vector<int> &v) {
       return py::make_iterator(v.begin(), v.end());
    }, py::keep_alive<0, 1>()) /* Keep vector alive while iterator is used
*/
    // ....
```

11.3.4 □□STL□□

□□STL□□□□□□Python□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□ `pybind11/stl_bind.h` □□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
// Don't forget this
#include <pybind11/stl_bind.h>

PYBIND11_MAKE_OPAQUE(std::vector<int>);
PYBIND11_MAKE_OPAQUE(std::map<std::string, double>);

// ...

// later in binding code:
py::bind_vector<std::vector<int>>(m, "VectorInt");
py::bind_map<std::map<std::string, double>>(m, "MapStringDouble");
```

□□STL□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Module-local class bindings □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `py::module_local` □□□□□□□□□□□ `py::module_local` □□□□□□□□□□strings□Eigen□□□□□□□□□□STL□□□□□□□□□□□□□module-local□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `std::vector<int>` □□

□□□□□□ `py::module_local()` □ `py_module_local(false)` □□□□□□□□□□□STL□□□□□□□□□□□□

```
py::bind_vector<std::vector<int>>(m, "VectorInt",
py::module_local(false));
```

□□`std::vector<int>`□□□□□□

11.4 □□□□

□□□□□□□□□□□□`pybind11/functional.h`□

□□□□□□□□□

C++11□□□□□□□□□□lambda□□□□□□□`std::function<>`□lambda□□□□□□□□□□□lambda□□□□□□□□□□□□□□□□□□□□□□□lambda□□□□□□□□□lambda□□□□□□□□□□□□□

□□□□□□□□□□□□□□`int -> int`□□□□□□□□□□□□□□□□□

```
int func_arg(const std::function<int(int)> &f) {
    return f(10);
}
```

□□lambda□□□□□□□`f`□□□

```
std::function<int(int)> func_ret(const std::function<int(int)> &f) {
    return [f](int i) {
        return f(i) + 1;
    };
}
```

□C++□□□□□□□python□□□□□□□□□`py::cpp_function`□□□□□□□□□□□□

```
py::cpp_function func_cpp() {
    return py::cpp_function([](int i) { return i+1; },
       py::arg("number"));
}
```

□□`pybind11/functional.h`□□□□□□□□□□□□□□□□□□□□□□□□□

```
#include <pybind11/functional.h>

PYBIND11_MODULE(example, m) {
    m.def("func_arg", &func_arg);
    m.def("func_ret", &func_ret);
    m.def("func_cpp", &func_cpp);
}
```

Python□□□□□□□□

```
$ python
>>> import example
>>> def square(i):
...     return i * i
...
>>> example.func_arg(square)
100L
>>> square_plus_1 = example.func_ret(square)
>>> square_plus_1(4)
17L
>>> plus_1 = func_cpp()
>>> plus_1(number=43)
44L
```

Warning

□□□□□C++□□□□□□□Python□□□Python□C++□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□C++□□□□□□□□□□□□□□Pybind11□□□□□□□□□□C++□□□□□□□□□□□C++ -> Python -> C++□□□□

11.5 Chrono

□□ `pybind11/chrono` □□□C++11 chrono□Python datatime□□□□□□□□□□□□python floats□□ `time.monotonic()` □ `time.perf_counter()` □□□□□ `time.process_time()` □durations

□□□□

11.5.1 C++11□□□□□

□□□□□□□□□□□□□□□C++11□□□□□□□□□□□□C++11□□□Python□□□□□□□□□□□□□□□

□□□□□□□□□□`std::chrono::system_clock`□□□wall time□□□□□□

□□□□□□□□□□`std::chrono::steady_clock`□□steady_clock□□□

□□□□□□□□□□`std::chrono::high_resolution_clock`□□□□□□□□□□□□□□□□□□system clock □ steady clock□□□□□□□□□□□□□□□□□□□□□□□□□Python□□□Python□□□datetime□□□□□□□□timedelta□□□

11.5.2 □□□□□

C++□Python

- `std::chrono::system_clock::time_point` → `datetime.datetime`
- `std::chrono::duration` → `datetime.timedelta`
- `std::chrono::[other_clocks]::time_point` → `datetime.timedelta`

Python□C++

- `datetime.datetime` or `datetime.date` or `datetime.time` → `std::chrono::system_clock::time_point`
- `datetime.timedelta` → `std::chrono::duration`
- `datetime.timedelta` → `std::chrono::[other_clocks]::time_point`
- `float` → `std::chrono::duration`
- `float` → `std::chrono::[other_clocks]::time_point`

11.6 Eigen

□□□□Eigen□□□□□□

11.7 □□□□□□□

□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□Python C API□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□

The following snippets demonstrate how this works for a very simple `inty` type that that should be convertible from Python types that provide a `__int__(self)` method.

```
struct inty { long long_value; };

void print(inty s) {
    std::cout << s.long_value << std::endl;
}
```

The following Python snippet demonstrates the intended usage from the Python side:

```
class A:
    def __int__(self):
        return 123


from example import print

print(A())
```

To register the necessary conversion routines, it is necessary to add an instantiation of the `pybind11::detail::type_caster<T>` template. Although this is an implementation detail, adding an instantiation of this type is explicitly allowed.

```
namespace pybind11 { namespace detail {
    template <> struct type_caster<inty> {
    public:
        /**
         * This macro establishes the name 'inty' in
         * function signatures and declares a local variable
         * 'value' of type inty
         */
        PYBIND11_TYPE_CASTER(inty, _("inty"));

        /**
         * Conversion part 1 (Python->C++): convert a PyObject into a inty
         * instance or return false upon failure. The second argument
         * indicates whether implicit conversions should be applied.
         */
        bool load(handle src, bool) {
            /* Extract PyObject from handle */
            PyObject *source = src.ptr();
            /* Try converting into a Python integer value */
            PyObject *tmp = PyNumber_Long(source);
            if (!tmp)
                return false;
            /* Now try to convert into a C++ int */
            value.long_value = PyLong_AsLong(tmp);
            Py_DECREF(tmp);
            /* Ensure return code was OK (to avoid out-of-range errors
etc) */
            return !(value.long_value == -1 && !PyErr_Occurred());
        }

        /**
         * Conversion part 2 (C++ -> Python): convert an inty instance
into
         * a Python object. The second and third arguments are used to
         * indicate the return value policy and parent object (for
         * ``return_value_policy::reference_internal``) and are generally
         * ignored by implicit casters.
         */
        static handle cast(inty src, return_value_policy /* policy */,
handle /* parent */) {
            return PyLong_FromLong(src.long_value);
        }
```

```
    };
}} // namespace pybind11::detail
```

Note: A `type_caster<T>` defined with `PYBIND11_TYPE_CASTER(T, ...)` requires that `T` is default-constructible (`value` is first default constructed and then `load()` assigns to it).

Warning: When using custom type casters, it’s important to declare them consistently in every compilation unit of the Python extension module. Otherwise, undefined behavior can ensue.

12. Python C++□□

pybind11□□□□□C++□□□□□Python□□□□□□□□□□□□□□□□□C++□□□Python□□□□□□□□
Python C API□

12.1 Python□□

12.1.1 □□□□□

□□□□□Python□□□□□□C++□□□□□□□□□□□□□□□□□□□□□□□ `handle`, `object`, `bool_`, `int_`, `float_`, `str`, `bytes`, `tuple`, `list`, `dict`, `slice`, `none`, `capsule`, `iterable`, `iterator`, `function`, `buffer`, `array`, □ `array_t`.

> Warning: Be sure to review the Gotchas before using this heavily in your C++ API.

12.1.2 □C++□□□□□□Python□□

□□□□□□□□`dict`□□□□□□□□□

```
using namespace pybind11::literals; // to bring in the `_a` literal
py::dict d("spam"_a=py::none(), "eggs"_a=42);
```

tuple□□□□□□`py::make_tuple()`□□□□

```
py::tuple tup = py::make_tuple(42, py::none(), "spam");
```

□□□□□□□□□□□□□Python□□□□

simple namespace□□□□□□□□

```
using namespace pybind11::literals;  // to bring in the `_a` literal
py::object SimpleNamespace =
py::module_::import("types").attr("SimpleNamespace");
py::object ns = SimpleNamespace("spam"_a=py::none(), "eggs"_a=42);
```

namespace□□□□□□□`py::delattr()`□`py::getattr()`□`py::setattr()`□□□□Simple namespaces□□□□□□□□□□□□□□

12.1.3 □□□□

□□□□□□□□□□□□□C++□□□□□Python□□□□□□□`py::cast()`□□□□

```
MyClass *cls = ...;
py::object obj = py::cast(cls);
```

□□□□□□□□□□□□

```
py::object obj = ...;
MyClass *cls = obj.cast<MyClass *>();
```

□□□□□□□□□□□□□□`cast_error`□□□

12.1.4 □C++□□□Python□

□C++□□□□□Python□□□□Python□□□sys.path)□□□□□□□□□□□□□

```
// Equivalent to "from decimal import Decimal"
py::object Decimal = py::module_::import("decimal").attr("Decimal");

// Try to import scipy
py::object scipy = py::module_::import("scipy");
return scipy.attr("__version__");
```

12.1.5 □□Python□□

□□ `operator()` □□□□Python□□□□□□□

```
// Construct a Python object of class Decimal
py::object pi = Decimal("3.14159");

// Use Python to make our directories
py::object os = py::module_::import("os");
py::object makedirs = os.attr("makedirs");
makedirs("/tmp/path/to/somewhere");
```

One can convert the result obtained from Python to a pure C++ version if a `py::class_` or type conversion is defined.

```
py::function f = <...>;
py::object result_py = f(1234, "hello", some_instance);
MyClass &result = result_py.cast<MyClass>();
```

12.1.6 □□Python□□□□□

□□ `.attr` □□□□□□□Python□□□

```
// Calculate e^π in decimal
py::object exp_pi = pi.attr("exp")();
py::print(py::str(exp_pi));
```

In the example above `pi.attr("exp")` is a *bound method*: it will always call the method for that same instance of the class. Alternately one can create an *unbound method* via the Python class (instead of instance) and pass the `self` object explicitly, followed by other arguments.

```
py::object decimal_exp = Decimal.attr("exp");

// Compute the e^n for n=0..4
for (int n = 0; n < 5; n++) {
    py::print(decimal_exp(Decimal(n)));
}
```

12.1.7 □□□□□

□□□□□□□□Python□□□□□□□

```
def f(number, say, to):
    ...  # function code


f(1234, say="hello", to=some_instance)  # keyword call in Python
```

C++□□□□□□□□

```
using namespace pybind11::literals; // to bring in the `_a` literal
f(1234, "say"_a="hello", "to"_a=some_instance); // keyword call in C++
```

12.1.8 □□□□

□□□□`*args`□`**kwargs`□□□□□□□□□□□□

```
// * unpacking
py::tuple args = py::make_tuple(1234, "hello", some_instance);
f(*args);

// ** unpacking
py::dict kwargs = py::dict("number"_a=1234, "say"_a="hello",
"to"_a=some_instance);
f(**kwargs);

// mixed keywords, * and ** unpacking
py::tuple args = py::make_tuple(1234);
py::dict kwargs = py::dict("to"_a=some_instance);
f(*args, "say"_a="hello", **kwargs);
```

Generalized unpacking according to PEP448 is also supported:

```
py::dict kwargs1 = py::dict("number"_a=1234);
py::dict kwargs2 = py::dict("to"_a=some_instance);
f(**kwargs1, "say"_a="hello", **kwargs2);
```

12.1.9 □□□□

□□□□□Python□□□C++□□□□□□Python□□□□□ `object` □□□□□□□□□□□□□□□□dict□□□□□□□□□ `operator[]` □ `obj.attr()` □□ `object` □□□C++□□□□□

```cpp
#include <pybind11/numpy.h>
using namespace pybind11::literals;

py::module_ os = py::module_::import("os");
py::module_ path = py::module_::import("os.path");  // like 'import os.path as path'
py::module_ np = py::module_::import("numpy");  // like 'import numpy as np'

py::str curdir_abs = path.attr("abspath")(path.attr("curdir"));
py::print(py::str("Current directory: ") + curdir_abs);
py::dict environ = os.attr("environ");
py::print(environ["HOME"]);
py::array_t<float> arr = np.attr("ones")(3, "dtype"_a="float32");
py::print(py::repr(arr + py::int_(1)));
```

□ `object` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `obj.cast()` □

> **Note**
>
> If a trivial conversion via move constructor is not possible, both implicit and explicit casting (calling `obj.cast()`) will attempt a “rich” conversion. For instance, `py::list env = os.attr("environ");` will succeed and is equivalent to the Python code `env = list(os.environ)` that produces a list of the dict keys.

12.1.10 □□□□

Python□□□□□□□ `py::error_already_set` □□□□□□□□□□□“□C++□□□Python□□”□

12.1.11 Gotchas

Default-Constructed Wrappers

□□□□□□□□□□□□□□□□□□□□□Python□□□□□ `py::none` □□□ `PyObject*` □□□□□□□□□□ `static_cast<bool>(my_wrapper)` □□□□

Assigning py::none() to wrappers

□□□□□C++□□□□□□□`py::str`□`py::dict`□□□□□□□□□□`py::none`□□□□□□□□□□□□□□□□□□`None`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Python□`py::str(py::none)`□□□□None□□

12.2 NumPy

12.2.1 □□□□□buffer protocol□

Python□□□Matrix□□

```cpp
class Matrix {
public:
    Matrix(size_t rows, size_t cols) : m_rows(rows), m_cols(cols) {
        m_data = new float[rows*cols];
    }
    float *data() { return m_data; }
    size_t rows() const { return m_rows; }
    size_t cols() const { return m_cols; }
private:
    size_t m_rows, m_cols;
    float *m_data;
};
```

□□□□□□□□□Matrix□□□□□buffer□□□□□□□□Matrices□□□□□□NumPy arrays□□□□□□□□□□□□□□□□□□□python□□`np.array(matrix_instance, copy = False)`□

```
py::class_<Matrix>(m, "Matrix", py::buffer_protocol())
   .def_buffer([](Matrix &m) -> py::buffer_info {
        return py::buffer_info(
            m.data(),                               /* Pointer to buffer */
            sizeof(float),                          /* Size of one scalar */
            py::format_descriptor<float>::format(), /* Python struct-style format descriptor */
            2,                                      /* Number of dimensions */
            { m.rows(), m.cols() },                 /* Buffer dimensions */
            { sizeof(float) * m.cols(),             /* Strides (in bytes) for each index */
              sizeof(float) }
        );
    });
```

□□□□□□□□□□□□□□□□`py:class_`□□□□□□□`py::buffer_protocol()`□□□□□□□`def_buffer()`□□□□□□□□□□□□matrix□□□□`py::buffer_info`□□□□□`py::buffer_info`□□□□□□Python□□□□□□□□

```
struct buffer_info {
    void *ptr;
    py::ssize_t itemsize;
    std::string format;
    py::ssize_t ndim;
    std::vector<py::ssize_t> shape;
    std::vector<py::ssize_t> strides;
};
```

□□□□□□□□Python buffer□□□□□□C++□□□□□□□□□`py::buffer`□□□□□□□□□□buffer□□□Eigen□□□□□□□□□□□□□□□□□buffer□□□□□□□□NumPy matrix□□

```
/* Bind MatrixXd (or some other Eigen type) to Python */
typedef Eigen::MatrixXd Matrix;

typedef Matrix::Scalar Scalar;
constexpr bool rowMajor = Matrix::Flags & Eigen::RowMajorBit;

py::class_<Matrix>(m, "Matrix", py::buffer_protocol())
    .def(py::init([](py::buffer b) {
        typedef Eigen::Stride<Eigen::Dynamic, Eigen::Dynamic> Strides;

        /* Request a buffer descriptor from Python */
        py::buffer_info info = b.request();

        /* Some sanity checks ... */
        if (info.format != py::format_descriptor<Scalar>::format())
            throw std::runtime_error("Incompatible format: expected a
double array!");

        if (info.ndim != 2)
            throw std::runtime_error("Incompatible buffer dimension!");

        auto strides = Strides(
            info.strides[rowMajor ? 0 : 1] / (py::ssize_t)sizeof(Scalar),
            info.strides[rowMajor ? 1 : 0] / (py::ssize_t)sizeof(Scalar));

        auto map = Eigen::Map<Matrix, 0, Strides>(
            static_cast<Scalar *>(info.ptr), info.shape[0], info.shape[1],
strides);

        return Matrix(map);
    }));
```

□□□□□Eigen□□□□□`def_buffer()`□□□□□□□□□□

```
.def_buffer([](Matrix &m) -> py::buffer_info {
    return py::buffer_info(
        m.data(),                                /* Pointer to buffer */
        sizeof(Scalar),                          /* Size of one scalar */
        py::format_descriptor<Scalar>::format(), /* Python struct-style
format descriptor */
        2,                                       /* Number of dimensions
*/
        { m.rows(), m.cols() },                  /* Buffer dimensions */
        { sizeof(Scalar) * (rowMajor ? m.cols() : 1),
          sizeof(Scalar) * (rowMajor ? 1 : m.rows()) }
                                                 /* Strides (in bytes) for
each index */
    );
 })
```

□□□□Eigen□□□□□□□□(□□□□□□□)□□□□Eigen□□□

12.2.2 Arrays

□□□□□□□ `py::buffer` □□□ `py::array` □□□□□□□□□□□□□NumPy array□□□□□□□□□□□□□□□ Python□□□□

□□□□□□□□□□□□□□□□□□□□□□□□□NumPy array□□□□□ `py::array_t<T>` □□□□□□□□□□□□□□□□□□□□□□NumPy array□

```
void f(py::array_t<double> array);
```

□□□□□□□□□□□□□□int□□□□□□□□□□□□□□□□□□□□□□□□□□□NumPy array□□□□□□□□ `pybind11/numpy.h` □□□□□□□□□□□□NumPy□□□□□□□□□□□□□NumPy□□□□□□□□NumPy□□□□1.7.0□

NumPy array□□C□□□□□□ Fortran□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `py::array::c_style` □ `py::array::f_style` □

```
void f(py::array_t<double, py::array::c_style | py::array::forcecast>
array);
```

`py::array::forcecast`□□□

arrays□□□□□NumPy API□□□□

- `.dtype()`□□□□□□□□□□
- `.strides()`□□□□strides□□□□
- `.squeeze()`□□□□□□□□□□□□□□□□□□
- `.view(dtype)`□□□□dtype□□□□□□□□
- `.reshape({i, j, ...})`□□□□shape□□□□□□`.resize({})`□□□□
- `.index_at(i, j, ...)`□□□□□□□□□□□□□

□□□□□□□□□□□(□□□□)□

12.2.3 □□□□□

□□□`py::array_t`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`PYBIND11_NUMPY_DTYPE`□□□□□

```
struct A {
    int x;
    double y;
};

struct B {
    int z;
    A a;
};

// ...
PYBIND11_MODULE(test, m) {
    // ...

    PYBIND11_NUMPY_DTYPE(A, x, y);
    PYBIND11_NUMPY_DTYPE(B, z, a);
    /* now both A and B can be used as template arguments to py::array_t
*/
}
```

□□□□□□□□□□□□□□`std::complex`□□□□□□□□□□□□□□□`arrays`□□□□□□□□□C++□□□`std::array`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□plain□□□□□□□□□□□□□□□□□□□□□□□□□□□□

12.2.4 □□□□□

□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□NumPy□□□□□□□□□□□□□□□□□

```cpp
double my_func(int x, float y, double z);
```

□□`pybind11/numpy.h`□□□□□□□□

```cpp
m.def("vectorized_func", py::vectorize(my_func));
```

□□□□□□□□□□□□□□□□□□□□□`numpy.vectorize()`□□□□□□□□□□□□□□□□□□□□□□□□□□□□c++□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□NumPy □□□□`numpy.dtype.float64`□

```python
x = np.array([[1, 3], [5, 7]])
y = np.array([[2, 4], [6, 8]])
z = 3
result = vectorized_func(x, y, z)
```

□□`z`□□□□□□4□□□□□□`x`□`y`□□□□□□□□□□□□□`numpy.dtype.int64`□□□□□`numpy.dtype.int32`□`numpy.dtype.float32`□□

> **Note**
>
> □□□□□□□□□□□□□□□□□□POD□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□(the code is somewhat contrived, since it could have been done more simply using `vectorize`).

```cpp
#include <pybind11/pybind11.h>
#include <pybind11/numpy.h>

namespace py = pybind11;

py::array_t<double> add_arrays(py::array_t<double> input1,
py::array_t<double> input2) {
    py::buffer_info buf1 = input1.request(), buf2 = input2.request();

    if (buf1.ndim != 1 || buf2.ndim != 1)
        throw std::runtime_error("Number of dimensions must be one");

    if (buf1.size != buf2.size)
        throw std::runtime_error("Input shapes must match");

    /* No pointer is passed, so NumPy will allocate the buffer */
    auto result = py::array_t<double>(buf1.size);

    py::buffer_info buf3 = result.request();

    double *ptr1 = static_cast<double *>(buf1.ptr);
    double *ptr2 = static_cast<double *>(buf2.ptr);
    double *ptr3 = static_cast<double *>(buf3.ptr);

    for (size_t idx = 0; idx < buf1.shape[0]; idx++)
        ptr3[idx] = ptr1[idx] + ptr2[idx];

    return result;
}

PYBIND11_MODULE(test, m) {
    m.def("add_arrays", &add_arrays, "Add two NumPy arrays");
}
```

12.2.5 □□□□

□□ `array` □ `array_t<T>` □□□□□□□□□□□ `unchecked<N>` □ `mutable_unchecked<N>` □□□ `N` □□□□□□□

```
m.def("sum_3d", [](py::array_t<double> x) {
    auto r = x.unchecked<3>(); // x must have ndim = 3; can be non-
writeable
    double sum = 0;
    for (py::ssize_t i = 0; i < r.shape(0); i++)
        for (py::ssize_t j = 0; j < r.shape(1); j++)
            for (py::ssize_t k = 0; k < r.shape(2); k++)
                sum += r(i, j, k);
    return sum;
});
m.def("increment_3d", [](py::array_t<double> x) {
    auto r = x.mutable_unchecked<3>(); // Will throw if ndim != 3 or
flags.writeable is false
    for (py::ssize_t i = 0; i < r.shape(0); i++)
        for (py::ssize_t j = 0; j < r.shape(1); j++)
            for (py::ssize_t k = 0; k < r.shape(2); k++)
                r(i, j, k) += 1.0;
}, py::arg().noconvert());
```

□□ `array` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `auto r = myarray.mutable_unchecked<float, 2>()` □

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `arr_t.unchecked()` □ `arr.unchecked<T>()` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□□□array□□□□□□□□□□□□□□□shape, strides, writeable flag□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□reshape, typically by limiting the scope of the returned instance.

The returned proxy object supports some of the same methods as `py::array` so that it can be used as a drop-in replacement for some existing, index-checked uses of `py::array`:

- `.ndim()` returns the number of dimensions
- `.data(1, 2, ...)` and `r.mutable_data(1, 2, ...)` returns a pointer to the `const T` or `T` data, respectively, at the given indices. The latter is only available to proxies obtained via `a.mutable_unchecked()`.
- `.itemsize()` returns the size of an item in bytes, i.e. `sizeof(T)`.
- `.ndim()` returns the number of dimensions.
- `.shape(n)` returns the size of dimension `n`

- `.size()` returns the total number of elements (i.e. the product of the shapes).
- `.nbytes()` returns the number of bytes used by the referenced elements (i.e. `itemsize()` times `size()`).

12.2.6 □□□

Python 3 provides a convenient `...` ellipsis notation that is often used to slice multidimensional arrays. For instance, the following snippet extracts the middle dimensions of a tensor with the first and last index set to zero. In Python 2, the syntactic sugar `...` is not available, but the singleton `Ellipsis` (of type `ellipsis`) can still be used directly.

```
a = ...  # a NumPy array
b = a[0, ..., 0]
```

The function `py::ellipsis()` function can be used to perform the same operation on the C++ side:

```
py::array a = /* A NumPy array */;
py::array b = a[py::make_tuple(0, py::ellipsis(), 0)];
```

12.2.7 □□□□

□□□□□□□C/C++ buffer□□□□□□□□□□□□□□□□□□□□□□□`memoryview`□□□□□□□□□□□`2*4 uint8_t`□□□`memoryview`□□□□□□□□

```
const uint8_t buffer[] = {
    0, 1, 2, 3,
    4, 5, 6, 7
};
m.def("get_memoryview2d", []() {
    return py::memoryview::from_buffer(
        buffer,                                     // buffer pointer
        { 2, 4 },                                   // shape (rows, cols)
        { sizeof(uint8_t) * 4, sizeof(uint8_t) }    // strides in bytes
    );
})
```

□□□□□`memoryview`□□Python□□□□□□□□□□□□buffer□□□□□□□□C++□□□buffer□□□□□□□□□`memoryview`□□□□□□□□□□□□

□□□□□□□`memoryview::from_memory`□□□□□□□□□□□□□□□□□□

```
m.def("get_memoryview1d", []() {
    return py::memoryview::from_memory(
        buffer,               // buffer pointer
        sizeof(uint8_t) * 8   // buffer size
    );
})
```

> Note: `memoryview::from_memory` is not available in Python 2.

12.3 □□□□

12.3.1 □C++□□□Python print□□

C++□□□□□`std::out`□□□□Python□□□□□□`print`□□pybind11□□□□`py::print`□□□□□□□Python□`sys.stdout`□□

□□□□□Python `print`□□□`sep`, `end`, `file`, `flush`□□□□

```cpp
py::print(1, 2.0, "three"); // 1 2.0 three
py::print(1, 2.0, "three", "sep"_a="-"); // 1-2.0-three

auto args = py::make_tuple("unpacked", true);
py::print("->", *args, "end"_a="<-"); // -> unpacked True <-
```

12.3.2 □ostream□□□□□□

C++□□□□□□`std::cout`□`std::cerr`□□□□□□□□□□Python□□□`sys.stdout`□`sys.stderr`□□□□□□□□□□□□`py::print`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Python streams□□□□□□□

```cpp
#include <pybind11/iostream.h>

...

// Add a scoped redirect for your noisy code
m.def("noisy_func", []() {
    py::scoped_ostream_redirect stream(
        std::cout,                               // std::ostream&
        py::module_::import("sys").attr("stdout") // Python output
    );
    call_noisy_func();
});
```

> **Warning**
>
> `pybind11/iostream.h`□□□□□□□□□□□□□□□□□□□□□□□ostream□□□□□□□□□□□□□□□□□□□□□□□□□□□□(□□□)□□□□□□□□ostream□□□□□□□□□

□□□□□□□□□□□□□□□□`scoped_ostream_redirect`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Jupyter notebook□C++□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□`py::scoped_estream_redirect <scoped_estream_redirect>`□□□□□□□□□□□□□□□□`py::call_guard`□□□□□□

```
// Alternative: Call single function using call guard
m.def("noisy_func", &call_noisy_function,
      py::call_guard<py::scoped_ostream_redirect,
                     py::scoped_estream_redirect>());
```

The redirection can also be done in Python with the addition of a context manager, using the `py::add_ostream_redirect() <add_ostream_redirect>` function:

```
py::add_ostream_redirect(m, "ostream_redirect");
```

The name in Python defaults to `ostream_redirect` if no name is passed. This creates the following context manager in Python:

```
with ostream_redirect(stdout=True, stderr=True):
    noisy_function()
```

It defaults to redirecting both streams, though you can use the keyword arguments to disable one of the streams if needed.

12.3.3 □□□□□□□□□Python□□□

pybind11 provides the `eval`, `exec` and `eval_file` functions to evaluate Python expressions and statements. The following example illustrates how they can be used.

```
// At beginning of file
#include <pybind11/eval.h>

...

// Evaluate in scope of main module
py::object scope = py::module_::import("__main__").attr("__dict__");

// Evaluate an isolated expression
int result = py::eval("my_variable + 10", scope).cast<int>();

// Evaluate a sequence of statements
py::exec(
    "print('Hello')\n"
    "print('world!');",
    scope);

// Evaluate the statements in an separate Python file on disk
py::eval_file("script.py", scope);
```

C++11 raw string literals are also supported and quite handy for this purpose. The only requirement is that the first statement must be on a new line following the raw string delimiter `R"(`, ensuring all lines have common leading indent:

```
py::exec(R"(
    x = get_answer()
    if x == 42:
        print('Hello World!')
    else:
        print('Bye!')
    )", scope
);
```

13. □□□□□

□□pybind11□□□□□□□C++□□Python□□□□□□□□□□□□□□Python□□C++□□□□□□□□□□□ pybind11□□□□□□□□□□□□□□□□□□□□□□□□□

13.1 □□□□

□□□□□□□□□□□□□□□□Cmake□□□`pybind11::embed`□□□□

```
cmake_minimum_required(VERSION 3.4)
project(example)

find_package(pybind11 REQUIRED)  # or `add_subdirectory(pybind11)`

add_executable(example main.cpp)
target_link_libraries(example PRIVATE pybind11::embed)
```

`main.cpp`□□□□□□□□

```
#include <pybind11/embed.h> // everything needed for embedding
namespace py = pybind11;

int main() {
    py::scoped_interpreter guard{}; // start the interpreter and keep it
alive

    py::print("Hello, World!"); // use the Python API
}
```

□□□□□□□Python API□□□□□□□□□□pybind11 Python□□□□□RAII guard□ `scoped_interpreter`□□□□□□□□□□□□□□□guard□□□□□□□□□□□□□□□□□□□□□□□□□Python□ □□□□□□

13.2 □□Python□□

□12.3.3□□□□□□□□□□□□□□ `eval` □ `exec` □ `eval_file` □□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□

```cpp
#include <pybind11/embed.h>
namespace py = pybind11;

int main() {
    py::scoped_interpreter guard{};

    py::exec(R"(
        kwargs = dict(name="World", number=42)
        message = "Hello, {name}! The answer is {number}".format(**kwargs)
        print(message)
    )");
}
```

□□□□□pybind11 API□□□□□□□□□□□□□12□□□□

```cpp
#include <pybind11/embed.h>
namespace py = pybind11;
using namespace py::literals;

int main() {
    py::scoped_interpreter guard{};

    auto kwargs = py::dict("name"_a="World", "number"_a=42);
    auto message = "Hello, {name}! The answer is
{number}"_s.format(**kwargs);
    py::print(message);
}
```

□□□□□□□□□□□□□

```cpp
#include <pybind11/embed.h>
#include <iostream>

namespace py = pybind11;
using namespace py::literals;

int main() {
    py::scoped_interpreter guard{};

    auto locals = py::dict("name"_a="World", "number"_a=42);
    py::exec(R"(
        message = "Hello, {name}! The answer is
{number}".format(**locals())
    )", py::globals(), locals);

    auto message = locals["message"].cast<std::string>();
    std::cout << message;
}
```

12.3 □□□□

□□`module_::import()`□□□□Python□□□

```cpp
py::module_ sys = py::module_::import("sys");
py::print(sys.attr("path"));
```

□□□□□□□□□□□□□□□□□□□□□□□□`sys.path`□□□□□□□□□□□□□□□Python□□□

```python
"""calc.py located in the working directory"""


def add(i, j):
    return i + j
```

```cpp
py::module_ calc = py::module_::import("calc");
py::object result = calc.attr("add")(1, 2);
int n = result.cast<int>();
assert(n == 3);
```

□□□□□□□□□□□□□□□□□□□□□`module_::reload()`□□□□□□□□□□□□□□□□□□□□□
□□

12.4 □□□□□□

□□□`PYBIND11_EMBEDDED_MODULE`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
□□□□

```cpp
#include <pybind11/embed.h>
namespace py = pybind11;

PYBIND11_EMBEDDED_MODULE(fast_calc, m) {
    // `m` is a `py::module_` which is used to bind functions and classes
    m.def("add", [](int i, int j) {
        return i + j;
    });
}

int main() {
    py::scoped_interpreter guard{};

    auto fast_calc = py::module_::import("fast_calc");
    auto result = fast_calc.attr("add")(1, 2).cast<int>();
    assert(result == 3);
}
```

Unlike extension modules where only a single binary module can be created, on the embedded side an unlimited number of modules can be added using multiple `PYBIND11_EMBEDDED_MODULE` definitions (as long as they have unique names).

These modules are added to Python’s list of builtins, so they can also be imported in pure Python files loaded by the interpreter. Everything interacts naturally:

```
"""py_module.py located in the working directory"""
import cpp_module

a = cpp_module.a
b = a + 1
#include <pybind11/embed.h>
namespace py = pybind11;

PYBIND11_EMBEDDED_MODULE(cpp_module, m) {
    m.attr("a") = 1;
}

int main() {
    py::scoped_interpreter guard{};

    auto py_module = py::module_::import("py_module");

    auto locals = py::dict("fmt"_a="{} + {} = {}",
**py_module.attr("__dict__"));
    assert(locals["a"].cast<int>() == 1);
    assert(locals["b"].cast<int>() == 2);

    py::exec(R"(
        c = a + b
        message = fmt.format(a, b, c)
    )", py::globals(), locals);

    assert(locals["c"].cast<int>() == 3);
    assert(locals["message"].cast<std::string>() == "1 + 2 = 3");
}
```

12.5 □□□□□□□□

□ `scoped_interpreter` □□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ □ `initialize_interpreter` / `finalize_interpreter` □□□□□□□□□□□□□□□□□□□

□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ CPython□□□

Warning

Creating two concurrent `scoped_interpreter` guards is a fatal error. So is calling `initialize_interpreter` for a second time after the interpreter has already been initialized.

Do not use the raw CPython API functions `Py_Initialize` and `Py_Finalize` as these do not properly handle the lifetime of pybind11's internal data.

14. □□

14.1 □□□□□□□

pybind11□□□□□□□□`PYBIND11_DECLARE_HOLDER_TYPE()`□`PYBIND11_OVERRIDE_*`□□□□□□□□□□□□□□□(□□□□□□□□□□□)□□□□□□□□□□□□□□□□

```
PYBIND11_OVERRIDE(MyReturnType<T1, T2>, Class<T3, T4>, func)
```

□□□□□□□□□5□□□□□□□□□□□3□□□□□□□□□□□□□□□□□□□□□□□□`PYBIND11_TYPE`□□□□□

```
// Version 1: using a type alias
using ReturnType = MyReturnType<T1, T2>;
using ClassType = Class<T3, T4>;
PYBIND11_OVERRIDE(ReturnType, ClassType, func);

// Version 2: using the PYBIND11_TYPE macro:
PYBIND11_OVERRIDE(PYBIND11_TYPE(MyReturnType<T1, T2>),
                  PYBIND11_TYPE(Class<T3, T4>), func)
```

`PYBIND11_MAKE_OPAQUE`□□□□□□□□□□

14.2 □□□□□□□GIL□

□Python□□□C++□□□□□□□□GIL□`gil_scoped_release`□`gil_scoped_acquire`□□□□□□□□□□□□□GIL□□□□□□□□C++□□□□□Python□□□□□□□□□□□□

```
class PyAnimal : public Animal {
public:
    /* Inherit the constructors */
    using Animal::Animal;

    /* Trampoline (need one for each virtual function) */
    std::string go(int n_times) {
        /* Acquire GIL before calling Python code */
        py::gil_scoped_acquire acquire;

        PYBIND11_OVERRIDE_PURE(
            std::string, /* Return type */
            Animal,      /* Parent class */
            go,          /* Name of function */
            n_times      /* Argument(s) */
        );
    }
};

PYBIND11_MODULE(example, m) {
    py::class_<Animal, PyAnimal> animal(m, "Animal");
    animal
        .def(py::init<>())
        .def("go", &Animal::go);

    py::class_<Dog>(m, "Dog", animal)
        .def(py::init<>());

    m.def("call_go", [](Animal *animal) -> std::string {
        /* Release GIL before calling into (potentially long-running) C++
code */
        py::gil_scoped_release release;
        return call_go(animal);
    });
}
```

□□□□□□`call_guard`□□□□□`call_go`□□□□

```
m.def("call_go", &call_go, py::call_guard<py::gil_scoped_release>());
```

14.3 □□□□□□□□□□□□

□□□

```
py::class_<Pet> pet(m, "Pet");
pet.def(py::init<const std::string &>())
   .def_readwrite("name", &Pet::name);

py::class_<Dog>(m, "Dog", pet /* <- specify parent */)
    .def(py::init<const std::string &>())
    .def("bark", &Dog::bark);
```

□□`Pet`□□□□□□□`basic`□□□□□`Dog`□□□□□□□□□□□`class_<Dog>`□□□□`Pet`□□□□□□□□□□□`Pet`□□□□□□□□□□□□`Pet`□□□`Dog`□□□□□□□□□□□□

```
py::object pet = (py::object) py::module_::import("basic").attr("Pet");

py::class_<Dog>(m, "Dog", pet)
    .def(py::init<const std::string &>())
    .def("bark", &Dog::bark);
```

□□□□□□□□□□□□□□□□`class_`□□pybind11□□□□□□□Python□□□□□□□□□□□`import`□□□□□`basic`□□□□□□□□□□□□

```
py::module_::import("basic");

py::class_<Dog, Pet>(m, "Dog")
    .def(py::init<const std::string &>())
    .def("bark", &Dog::bark);
```

□□□□□□□□□□□□□□□□□□□□□□

□□□pybind11□□□□□□□□□□□□□□□□□□□□□□GCC/Clang□`-fvisibility=hidden`□□

```
class PYBIND11_EXPORT Dog : public Animal {
    ...
};
```

□□□□□□□□□□□□□C++□□□□□□□□□□□□□□□□capsule□□□pybind11□□□□□□□□□□□□□□□□□□□□

```
auto data = reinterpret_cast<MyData *>(py::get_shared_data("mydata"));
if (!data)
    data = static_cast<MyData *>(py::set_shared_data("mydata", new
MyData(42)));
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`MyData`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

14.4 □□□□

pybind11□□□Python capsules□□□□□□□□□□□□□□□□□□

```
auto cleanup_callback = []() {
    // perform cleanup here -- this function is called with the GIL held
};

m.add_object("_cleanup", py::capsule(cleanup_callback));
```

□□□□□□□□□□□□□□cleanup□□□

□□□□□□□□□capsule□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
auto cleanup_callback = []() { /* ... */ };
m.attr("BaseClass").attr("_cleanup") = py::capsule(cleanup_callback);
```

□□□□□□□□Python□□□□□□□`_cleanup`□□□□□□□□API□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□cleanup□□□□□□□□□□□□□

```
// Register a callback function that is invoked when the BaseClass object
is collected
py::cpp_function cleanup_callback(
    [](py::handle weakref) {
        // perform cleanup here -- this function is called with the GIL
held

        weakref.dec_ref(); // release weak reference
    }
);

// Create a weak reference with a cleanup callback and initially leak it
(void) py::weakref(m.attr("BaseClass"), cleanup_callback).release();
```

15. [illegible]

15.1 “ImportError: dynamic module does not define init function”

1. [illegible]`PYBIND11_MODULE`[illegible].so[illegible]
2. [illegible]`Python`[illegible]`Python2`[illegible]`Python3`[illegible]

15.2 “Symbol not found: __Py_ZeroStruct _PyInstanceMethod_Type”

[illegible]15.1

15.3 “SystemError: dynamic module not initialized properly”

[illegible]15.1

15.4 [illegible]**Python**[illegible]

[illegible]15.1

15.5[illegible]

[illegible]`C++`[illegible]

```
void increment(int &i)
{
    i++;
}
void increment_ptr(int *i)
{
    (*i)++;
}
```

□ `Python` □□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□ □□□□□□□ `Python` □□□□ `str` □ `int` □ `bool` □ `float` □□□□□□□□□□□□□□□□□□□□ `Python` □□□□□□□□□□□□□□□□□□□□ □□□□□□□□□□

```python
def increment(i):
    i += 1  # nope..
```

`pybind11` □□□□□□□□□□□□□□□□□□□□ `increment` □□ `increment_ptr` □□□□□□□□□□□ `Python` □□□ `lambda` □□□□□□□□□□□□□□□□□□□□□ □□□□□ `lambda` □□□□□□□□□□□□□□□□□□□□□

```cpp
int foo(int &i)
{
    i++;
    return 123;
}
```

□□□□□:

```cpp
m.def("foo",
    [](int i) {
        int rv = foo(i);
        return std::make_tuple(rv, i);
    });
```

15.6 □□□□□□□□?

□□□□□□□□□□□□□□□□□□□□□□□ `example.cpp`

```cpp
void init_ex1(py::module_ &);
void init_ex2(py::module_ &);
/* ... */
PYBIND11_MODULE(example, m) {
    init_ex1(m);
    init_ex2(m);
    /* ... */
}
```

`ex1.cpp`:

```cpp
void init_ex1(py::module_ &m) {
    m.def("add",
        [](int a, int b) {
            return a + b;
        });
}
```

`ex2.cpp`:

```cpp
void init_ex2(py::module_ &m) {
    m.def("sub",
    [](int a, int b) {
        return a - b;
    });
}
```

`python` □□□

```python
import example

example.add(1, 2)  # 3
example.sub(1, 1)  # 0
```

□□□□□□□`init_ex`□□□
□□□□

1. □□□□□□□□□□□□□□
2. □□□□□□□□□□□□□
3. □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

15.7 “recursive template instantiation exceeded maximum depth of 256”

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`GCC/Clang`□□`-ftemplate-depth=1024`□□□□□□□□□□□□□□□C++14□□□□□□□□□□□□□□□□

15.8 “‘SomeClass’ declared with greater visibility than the type of its field ‘SomeClass::member’ [-Wattributes]”

□□□□□□□□□□□□□□□□□□`-fvisibility`□□.pybind11□□□ pybind□□□□□□`py::object`□`py::list`□□□□□□□□□□□□□□□□□□□□□□□□□pybind□□□□□`-fvisibility=hidden`□ □□□□□`-fvisibility=hidden`□□□□□□□`pybind`□□□□□`pybind`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□□`Python`□□□□□□□□□□□□□□□□`POSIX`□□□□□□□□□□`RTLD_local`□□□`dlopen`□□□□□`Python`□□□ □□□□□□□□□□`-fvisibility=hidden`□,□□□□□□□□□□□□□□□□□□□□□□□□. □□□`-fvisibility=hidden`□□□□□□□□□□□□□□□□□□□□□□□□□□□.)

15.9 □□□□□□□□□□□□□□?

□□□□□□□□□`pybind11` □□

```
__ZN8pybind1112cpp_functionC1Iv8Example2JRNSt3__16vectorINS3_12basic_strin
gIwNS3_
11char_traitsIwEENS3_9allocatorIwEEEENS8_ISA_EEEEEJNS_4nameENS_7siblingENS
_9is_
methodEA28_cEEEMT0_FT_DpT1_EDpRKT2_
```

□□□□□□□□□□□□□□□□

```
pybind11::cpp_function::cpp_function<void, Example2,
std::__1::vector<std::__1::basic_
string<wchar_t, std::__1::char_traits<wchar_t>,
std::__1::allocator<wchar_t> >,
std::__1::allocator<std::__1::basic_string<wchar_t,
std::__1::char_traits<wchar_t>,
std::__1::allocator<wchar_t> > > >&, pybind11::name, pybind11::sibling,
pybind11::is_method, char [28]>(void (Example2::*)
(std::__1::vector<std::__1::basic_
string<wchar_t, std::__1::char_traits<wchar_t>,
std::__1::allocator<wchar_t> >,
std::__1::allocator<std::__1::basic_string<wchar_t,
std::__1::char_traits<wchar_t>,
std::__1::allocator<wchar_t> > > >&), pybind11::name const&,
pybind11::sibling
const&, pybind11::is_method const&, char const (&) [28])
```

□□□□□□□□□□□□□196 □□□□□□□□□□□□□□□□□□□□□□□□111 □□□□□□□□□□□□□□□□□□□□□□□□□□□□——□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `-fvisibility=hidden` □□□ □□ `Visual Studio` □□ `-fvisibility=hidden` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ pybind□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `GCC` □ `Clang` □□□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

15.10 □□□□□□□□Windows□Visual Studio 2008

`Python` □□□ `Windows` □□□□□□□□□□□□ `C++11` □□□□□□□□□□□ `Visual Studio` □□□□□□□□□□□□□□□□□□□□□□ `Visual Studio 2015` □□□□□□□□□□□□ `Visual Studio 2008` □□□ `Python` □□□□□□□

□□□□□□□□□□□□□□□□□□`DLL`□□□□□□□/□`C`□□□□□□□□□□□□□□□□□□`malloc()`□□□`free()`□□□□□□□□□`ABI`□□□□□□□`pybind11`□□□□□□□□□□□□

15.11 □□□□□□□□□□□□□□Ctrl-C□

`Ctrl-C`□`Python`□□□□□□□□□`GIL`□□□□□□□□□□□□□□□□□□□□□□□□□□□□ PyErr_CheckSignals() □□□□□□□ Python □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ py::error_already_set □□□□□□□□□□□ KeyboardInterrupt□□□□□□□□□□□□□□□

```
PYBIND11_MODULE(example, m){
    m.def("long running_func",
        [](){
            for (;;)
            {
                if (PyErr_CheckSignals() != 0)
                throw py::error_already_set();
                // Long running iteration
            }
            });
}
```

15.12 CMake□□□□□□Python□□

□□`CMake`□□□□□□□□□□□□`Python`□□□□□□□□□□□□□□□□□□□`Python`□□□□□□□□□`CMakeCache.txt`□□□`-DPYTHON_EXECUTABLE=$(which python)`□□`CMake`□□□□□□□□□□`$(which python)`□□`python`□□□□□□□□□`-DPYBIND11_FINDPYTHON=ON`□□□□□□`CMake FindPython`□□□□`pybind11`□□□□□□□`CMake 3.12+□3.15+`□`3.18.2+`□□□□□□□□□□`pybind11`□□`CMakeLists.txt`□□□□

15.13 CMake□pybind11□Python□□□□□□

`CMake` □□□□□ `Python` □□□□□□□ `find_package(PythonInterp)` □ `find_package(PythonLibs)` □ `pybind11` □□□□□□□□□□□ `pybind11` □□□□□□□ `pybind11` □□□□□□□□□□□ `Python` □□ `CMake` □□□□□□□□□□□□□ `Python` □□□□□□□□ `CMake Python` □□□□□□□□ `pybind11` □□□□□□□□□□ □□□ `Python2.7` □ `3.x` □□□□□□□□□ `CMake` □□□

```
find_package(PythonInterp)
find_package(PythonLibs)
find_package(pybind11)
```

□□□□ `Python2.7` □ `pybind11` □□□□□□ □□□□□□□□□□□

```
find_package(pybind11)
find_package(PythonInterp)
find_package(PythonLibs)
```

□□ `pybind11` □□ `Python3.x` □□□□□□□ `find_package(PythonLibs)` □□□□ □□□□□□□□□□□□

1. □□□□ `CMake` □□ `find_package(PythonInterp)` □ `find_package(PythonLibs)` □□□ `pybind11` □□ `Python` □□□□□□□□□□□□□□□□ `pybind11` □□□□ `CMake` □□□
2. □ `PYBIND11_FINDPYTHON` □□□ `True` □□□□ `CMake` □□□ `find_package(Python COMPONENTS Interpreter Development)` □3.12+□3.15+□□□3.18.2+ □□□□□□□□□□□□ `Pybind11` □□□□ `CMake FindPython` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□ `Python` □□□□□□□
3. □ `PYBIND11_NOPYTHON` □□□ `TRUE` □ `Pybind11` □□□□ `Python` □□ `Python` □□□□□□ `pybind11_add_module` □□□□□□□□□□□□□□□□□□□□□ `scikit-build` □ `Python` □□□

15.14 □□□□□□□□□□

□□□□□□□□□ BibTeX □□□□□□□□□□□ pybind11□

```
@misc{pybind11,
author = {Wenzel Jakob and Jason Rhinelander and Dean Moldovan},
year = {2017},
note = {https://github.com/pybind/pybind11},
title = {pybind11 -- Seamless operability between C++11 and Python} }
```

16.□□

16.1 c/c++□□□□□□

- c□□□□

```
char ca;
unsigned char uca;
```

- c++□□□□□□□

```
vector
stl
```

pybind11□□□□

1. □□□□

1.1 □□□□□

□□□python3-dev□□□□pybind11□□□□□□□□□□□include pybind11□□□□□□python3□□□□□□□□cmake□□□□□

```
set(PYTHON_TARGET_VER 3.6)
find_package(PythonInterp ${PYTHON_TARGET_VER} EXACT)
find_package(PythonLibs ${PYTHON_TARGET_VER} EXACT REQUIRED)

include_directories(pybind11_include_path)
include_directories(${PYTHON_INCLUDE_DIRS})
```

1.2 □□□□

```
#include <pybind11/pybind11.h>

int add(int i, int j) {
    return i + j;
}

PYBIND11_MODULE(example, m) {
    m.doc() = "pybind11 example plugin"; // optional module docstring
    m.def("add", &add, "A function which adds two numbers");
}
```

□`PYBIND11_MODULE`□□□□□□□□□□□□□□Python□`import`□□□□□□□□□□□□□□□□□□□□□`py::module_`□□□□m□□□□□□□□□□□□□□`module_::def()`□□□□□□□□□□□□□□

1.2.1 □□□□□

□□`py::arg`□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
m.def("add", &add, "A function which adds two numbers",
      py::arg("i"), py::arg("j"));
```

□□□□□□□

```
// regular notation
m.def("add1", &add, py::arg("i"), py::arg("j"));
// shorthand
using namespace pybind11::literals;
m.def("add2", &add, "i"_a, "j"_a);
```

Python□□□□□

```
import example
example.add(i=1, j=2)  #3L
```

1.2.2 □□□□□

pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`arg`□□□□□□□□□□□□

```
m.def("add", &add, "A function which adds two numbers",
      py::arg("i") = 1, py::arg("j") = 2);
```

□□□□□□□□□

```
// regular notation
m.def("add1", &add, py::arg("i") = 1, py::arg("j") = 2);
// shorthand
m.def("add2", &add, "i"_a=1, "j"_a=2);
```

1.2.3 [illegible]

[illegible]

[illegible]Python[illegible]Python[illegible]

```
m.def("add", static_cast<int(*)(int, int)>(&add), "A function which adds two int numbers");
m.def("add", static_cast<double(*)(double, double)>(&add), "A function which adds two double numbers");
```

[illegible]C++14[illegible]

```
m.def("add", py::overload_cast<int, int>(&add), "A function which adds two int numbers");
m.def("add", py::overload_cast<double, double>(&add), "A function which adds two double numbers");
```

[illegible]`py::overload_cast`[illegible](`void (Pet::*)`)[illegible]const[illegible]`py::const`[illegible]

1.3 [illegible]

[illegible]`attr`[illegible]Python[illegible]C++[illegible]attriutes[illegible]`py::cast`[illegible]

```
PYBIND11_MODULE(example, m) {
    m.attr("the_answer") = 42;
    py::object world = py::cast("World");
    m.attr("what") = world;
}
``

Python□□□□□□
```pyhton
>>> import example
>>> example.the_answer
42
>>> example.what
'World'
```

1.4 □□□□□□□

□□□□□□□□□C++□□□□□□□`Pet`□□□□□□

```
struct Pet {
    Pet(const std::string &name) : name(name) { }
    void setName(const std::string &name_) { name = name_; }
    const std::string &getName() const { return name; }

    std::string name;
};
```

□□□□□□□□□□
```

```
#include <pybind11/pybind11.h>
namespace py = pybind11;

PYBIND11_MODULE(example, m) {
    py::class_<Pet>(m, "Pet")
        .def(py::init<const std::string &>())
        .def("setName", &Pet::setName)
        .def("getName", &Pet::getName)
        .def("__repr__",
            [](const Pet &a) {
                return "<example.Pet named '" + a.name + "'>";
            });
}
```

`class_`□□□C++ class□ struct□□□□`init()`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
□□□□□□□□□□□□□□

□□`print(p)`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`__repr__`□□□□□□□□□□□□□□□
□□□□□□Pet□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

Python□□□□□□□

```
>>> import example
>>> p = example.Pet("Molly")
>>> print(p)
<example.Pet named 'Molly'>
>>> p.getName()
u'Molly'
>>> p.setName("Charly")
>>> p.getName()
u'Charly'
```

□□□□□□□□□□`class_::def_static`□□□□

1.4.1 □□□□

□□`class_::def_readwrite`□□□□□□□□□□□□□□□□`class_::def_readonly`□□□□□□□□□□□□□

```
py::class_<Pet>(m, "Pet")
    .def(py::init<const std::string &>())
    .def_readwrite("name", &Pet::name)
    // ... remainder ...
```

Python□□□□□□□□

```
>>> p = example.Pet("Molly")
>>> p.name
u'Molly'
>>> p.name = "Charly"
>>> p.name
u'Charly'
```

□□`Pet::name`□□□□□□□□□□□□□□setter□getters□□□

```
class Pet {
public:
    Pet(const std::string &name) : name(name) { }
    void setName(const std::string &name_) { name = name_; }
    const std::string &getName() const { return name; }
private:
    std::string name;
};
```

□□□□`class_::def_property()`(□□□□□□`class_::def_property_readonly()`)□□□□□□□□□□□□□□□setter□geter□□□

```
py::class_<Pet>(m, "Pet")
    .def(py::init<const std::string &>())
    .def_property("name", &Pet::getName, &Pet::setName)
    // ... remainder ...
```

□□□□□□□read□□□□nullptr□□□□

□□□□□`class_::def_readwrite_static()`, `class_::def_readonly_static()` `class_::def_property_static()`, `class_::def_property_readonly_static()`□□□□□□□□□□□□

1.4.2 □□□□

□□□Pyhton□□□□□□□□□□□□

```
>>> class Pet:
...     name = "Molly"
...
>>> p = Pet()
>>> p.name = "Charly"  # overwrite existing
>>> p.age = 2  # dynamically add a new attribute
```

□□□□□□□C++□□□□□□□□□□□□□□□□□□□□□□`class_::def_readwrite`□
`class_::def_property`□□□□□□□□□□□□□□□□□□

```
>>> p = example.Pet()
>>> p.name = "Charly"  # OK, attribute defined in C++
>>> p.age = 2  # fail
AttributeError: 'Pet' object has no attribute 'age'
```

□□C++□□□□□□□□□□□□□□`py::class_`□□□□□□□`py::dynamic_attr`□□□

```
py::class_<Pet>(m, "Pet", py::dynamic_attr())
    .def(py::init<>())
    .def_readwrite("name", &Pet::name);
```

□□□□□□□□□□□□□□□□□□□

```
>>> p = example.Pet()
>>> p.name = "Charly"  # OK, overwrite value in C++
>>> p.age = 2  # OK, dynamically add a new attribute
>>> p.__dict__  # just like a native Python class
{'age': 2}
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`__dict__`□□Python□□□□□□□□□□□□□□□pybind11□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□□□□□

1.4.3 □□□□

□□□□□□□□□□□□□□□□□□□□□□□

```
struct Pet {
    Pet(const std::string &name, int age) : name(name), age(age) { }

    void set(int age_) { age = age_; }
    void set(const std::string &name_) { name = name_; }

    std::string name;
    int age;
};

// method 1
py::class_<Pet>(m, "Pet")
   .def(py::init<const std::string &, int>())
   .def("set", static_cast<void (Pet::*)(int)>(&Pet::set), "Set the pet's
age")
   .def("set", static_cast<void (Pet::*)(const std::string &)>(&Pet::set),
"Set the pet's name");

// method 2
py::class_<Pet>(m, "Pet")
    .def("set", py::overload_cast<int>(&Pet::set), "Set the pet's age")
    .def("set", py::overload_cast<const std::string &>(&Pet::set), "Set
the pet's name");
```

1.5 □□□□□□

□□C□□□□□□□□□□□□□□

```
enum Flags {
    Read = 4,
    Write = 2,
    Execute = 1
};

py::enum_<Flags>(m, "Flags", py::arithmetic())
    .value("Read", Flags::Read)
    .value("Write", Flags::Write)
    .value("Execute", Flags::Execute)
    .export_values();
```

`enum_::export_values()` □□□□□□□□□□□□□□C++11□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□ `__members__` □□□□ `name` □□□□□□□□□□□□□□unicode□□□□ `str(enum)` □□□□□□□□□□□□□□□□□□

1.6 □□*args□**kwargs□□

Python□□□□□□□□□□□□□□□□□□□□□□□

```python
def generic(*args, **kwargs):
    ...  # do something with args and kwargs
```

□□□□□□□pybind11□□□□□□□□□

```cpp
void generic(py::args args, const py::kwargs& kwargs) {
    /// .. do something with args
    if (kwargs)
        /// .. do something with kwargs
}

/// Binding code
m.def("generic", &generic);
```

`py::args` □□□ `py::tuple` □ `py::kwargs` □□□ `py::dict` □

2. □□□□□□

2.1 □□□□□

Python□C++□□□□□□□□□□□□□□□□□□□□□□□□□□no-trivial□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□□C++□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□`model::def()`□`class_def()`□□□□□□□`return_value_policy::automatic`□

□□

```
/* Function declaration */
Data *get_data() { return _data; /* (pointer to a static data structure)
*/ }
...

/* Binding code */
m.def("get_data", &get_data); // <-- KABOOM, will cause crash when called
from Python
```

□Python□□□`get_data()`□□□□□□□□C++□□□□□□□□□□Python□□□□□□□□□□□□□□□□□`return_value_policy::automatic`□□□pybind11□□□□□□□`_data`□□□□□

□Python□□□□□□□□`_data`□Python□□□□pybind11□□□□C++□□□□operator delete()□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□`return_value_policy::reference`□□□□□□□□□□□□□□□□□□□□□□

```
m.def("get_data", &get_data, py::return_value_policy::reference);
```

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□□□□□	□□
`return_value_policy::take_ownership`	□□□□□□□□□□□□□□□□□□□□□□ □□Pyhton□□□□□□□delete□□□□
`return_value_policy::copy`	□□□□□□□Python□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□
`return_value_policy::move`	□□`std::move`□□□□□□□□□□□□□□ □Python□□□□□□□□□□□□□□□□□ □□□
`return_value_policy::reference`	□□□□□□□□□□□□□□□□C++□□□□□□□ □□□□□□□□□□□□□□□□□□□□□Pytho □□□□□C++□□□□□□□□□□□□□□□
`return_value_policy::reference_internal`	□□□□□□□□□□□□□□□□□□□□□□ `this`□`self`□□□□□□□□reference □□`keep_alive<0, 1>`□□□□□□□□ Python□□□□□□□□□□□□□□□□□□□□ `def_property`□`def_readwrite` getter□□□□□□□□□□□□
`return_value_policy::automatic`	□□□□□□□□□□□□□□□ `return_value_policy::take_ow` □□□□□□□□□□□□□ `return_value_policy::copy`□□ □□□□□□□□□□□□□□□□□□□□□`py::cl` □□□□□□□
`return_value_policy::automatic_reference`	□□□□□□□□□□□□□□□□□□□□□ `return_value_policy::referer` □C++□□□□□□□Python□□□□□ `pybind11/stl.h`□□casters□□□□ □□□□□□□□□□□□□□□

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```
class_<MyClass>(m, "MyClass")
    .def_property("data", &MyClass::getData, &MyClass::setData,
                  py::return_value_policy::copy);
```

□□□□□□□□□□□□□□□□□□□getter□setter□□□□□setter□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□cpp_function□□□□□□□□□□□□

```
class_<MyClass>(m, "MyClass")
    .def_property("data"
        py::cpp_function(&MyClass::getData,
py::return_value_policy::copy),
        py::cpp_function(&MyClass::setData)
    );
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□free□□

□□□

1. □□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□
2. □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
3. □□C++□Python□□□□□□□□□□□□□□□□crash□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

2.2 □□□□□□□

□□□

□□□**keep alive**□

□□□C++□□□□□□□□□C++□□□□□□□□□□□□□□`keep_alive<Nurse, Patient>`□□□□□□□Nurse□□□□□□Patient□□□□□□0□□□□□□1□□□□□□□□□□1□□□□□□□this□□□□□□□□□□□□□□2□□□Nurse□□□□□□□□□□□None□□□□□□□□□□□□□

□nurse□□□□pybind11□□□□□□□□□□□□□□□nurse□□□□□□□□□□□□nurse□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□□□□“Could not cativate keep_alive!“□□□□□□□□□□□□□□□□review□□□□□□□□□□

□□□□□□□□□□list append□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
py::class_<List>(m, "List").def("append", &List::append, py::keep_alive<1,
2>());
```

□□□□□□□□□□□□□□□□□□□□□□□□1□□□this□□□□□0□□□□□□□□□□□□□□□□□□□void□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
py::class_<Nurse>(m, "Nurse").def(py::init<Patient &>(), py::keep_alive<1,
2>());
```

> Note: `keep_alive` □Boost.Python□□ `with_custodian_and_ward` □ `with_custodian_and_ward_postcall` □□□

Call guard

`call_guard<T>` □□□□□□□T□□□scope guard□□□□□□□□□□□□□□□□

```
m.def("foo", foo, py::call_guard<T>());
```

□□□□□□□□□

```
m.def("foo", [](args...) {
    T scope_guard;
    return foo(args...); // forwarded arguments
});
```

□□□□□□□T□□□□□□□`gil_scoped_release`□□□□□□□□□□□□

`call_guard`□□□□□□□□□□□□□`call_guard<T1, T2, T3 ...>`□□□□□□□□□□□□□□□□□□□

> See also: `test/test_call_policies.cpp`□□□□□□□□□□□`keep_alive`□`call_guard`□□□□

2.3 Keyword-only□□

Python3□□□keyword-only□□□□□□□□□□`*`□□□□□□□

```
def f(a, *, b):  # a can be positional or via keyword; b must be via keyword
    pass

f(a=1, b=2)  # good
f(b=2, a=1)  # good
f(1, b=2)  # good
f(1, 2)  # TypeError: f() takes 1 positional argument but 2 were given
```

pybind11□□□`py::kw_only`□□□□□□□□□□

```
m.def("f", [](int a, int b) { /* ... */ },
      py::arg("a"), py::kw_only(), py::arg("b"));
```

□□□□□□□□□`py::args`□□□□□

2.4 Positional-only□□

python3.8□□□Positional-only□□□□□pybind11□□`py::pos_only()`□□□□□□□□

```
m.def("f", [](int a, int b) { /* ... */ },
       py::arg("a"), py::pos_only(), py::arg("b"));
```

□□□□□□□□□□□□□`a`□□□□□□□□□keyword-only□□□□□□□

2.5 Non-converting□□

□□□□□□□□□□□□□□□□

- □□`py::implicitly_convertible<A,B>()`□□□□□□
- □□□□□□□□□□□□□□□□□□
- □□□□□□□□float□□□□□□`std::complex<float>`□□□□□
- Calling a function taking an Eigen matrix reference with a numpy array of the wrong type or of an incompatible data layout.

□□`py::arg`□□□`.noconvert()`□□□□
□□□□□□□

```
m.def("floats_only", [](double f) { return 0.5 * f; },
py::arg("f").noconvert());
m.def("floats_preferred", [](double f) { return 0.5 * f; }, py::arg("f"));
```

□□□□□□□□□□□□`TypeError`□□□

```
>>> floats_preferred(4)
2.0
>>> floats_only(4)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: floats_only(): incompatible function arguments. The following
argument types are supported:
    1. (f: float) -> float

Invoked with: 4
```

□□□□□□□□□□□`_a`□□□□□□□□□□□□□□`py::arg().noconvert()`□

3. □□□□□

3.1 □□□□□

□□□□□□□□□□□□□□□

```
struct Pet {
    Pet(const std::string &name) : name(name) { }
    std::string name;
};

struct Dog : Pet {
    Dog(const std::string &name) : Pet(name) { }
    std::string bark() const { return "woof!"; }
};
```

pybind11□□□□□□□□□□□□□□□□1□□C++□□□□□□□□`class_`□□□□□□2□□□□□□□`class_`□□□□□□□□□□□□□□□□□□□□

```
py::class_<Pet>(m, "Pet")
   .def(py::init<const std::string &>())
   .def_readwrite("name", &Pet::name);

// Method 1: template parameter:
py::class_<Dog, Pet /* <- specify C++ parent type */>(m, "Dog")
    .def(py::init<const std::string &>())
    .def("bark", &Dog::bark);

// Method 2: pass parent class_ object:
py::class_<Dog>(m, "Dog", pet /* <- specify Python parent type */)
    .def(py::init<const std::string &>())
    .def("bark", &Dog::bark);
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
>>> p = example.Dog("Molly")
>>> p.name
u'Molly'
>>> p.bark()
u'woof!'
```

□□□□□□□□□□□□□□□□□□□□□□□Python□□□

```
// □□□□□□□□□□□□□□
m.def("pet_store", []() { return std::unique_ptr<Pet>(new Dog("Molly"));
});
```

```
>>> p = example.pet_store()
>>> type(p)  # `Dog` instance behind `Pet` pointer
Pet          # no pointer downcasting for regular non-polymorphic types
>>> p.bark()
AttributeError: 'Pet' object has no attribute 'bark'
```

`pet_store`□□□□□□□Dog□□□□□□□□□□□□□□□□Python□□□□□Pet□□C++□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□

```
struct PolymorphicPet {
    virtual ~PolymorphicPet() = default;
};

struct PolymorphicDog : PolymorphicPet {
    std::string bark() const { return "woof!"; }
};

// Same binding code
py::class_<PolymorphicPet>(m, "PolymorphicPet");
py::class_<PolymorphicDog, PolymorphicPet>(m, "PolymorphicDog")
    .def(py::init<>())
    .def("bark", &PolymorphicDog::bark);

// Again, return a base pointer to a derived instance
m.def("pet_store2", []() { return std::unique_ptr<PolymorphicPet>(new
PolymorphicDog); });
```

```
>>> p = example.pet_store2()
>>> type(p)
PolymorphicDog  # automatically downcast
>>> p.bark()
u'woof!'
```

pybind11[illegible]C++[illegible]

3.2 Python[illegible]C++[illegible]

[illegible]Python[illegible]

```
class Animal {
public:
    virtual ~Animal() { }
    virtual std::string go(int n_times) = 0;
};

class Dog : public Animal {
public:
    std::string go(int n_times) override {
        std::string result;
        for (int i=0; i<n_times; ++i)
            result += "woof! ";
        return result;
    }
};

std::string call_go(Animal *animal) {
    return animal->go(3);
}

PYBIND11_MODULE(example, m) {
    py::class_<Animal>(m, "Animal")
        .def("go", &Animal::go);

    py::class_<Dog, Animal>(m, "Dog")
        .def(py::init<>());

    m.def("call_go", &call_go);
}
```

□□□□□□□□□□Python□□□□□Animal□□□□□□“No constructor defined!“□

□□□□□□□□□□□□□Animal□□□□□□□□

```
class PyAnimal : public Animal {
public:
    /* Inherit the constructors */
    using Animal::Animal;

    /* Trampoline (need one for each virtual function) */
    std::string go(int n_times) override {
        PYBIND11_OVERRIDE_PURE(
            std::string, /* Return type */
            Animal,      /* Parent class */
            go,          /* Name of function in C++ (must match Python
name) */
            n_times      /* Argument(s) */
        );
    }
};
```

□□□□□□□□□□□`PYBIND11_OVERRIDE_PURE`□□□□□□□□□□□□□□□`PYBIND11_OVERRIDE`□`PYBIND11_OVERRIDE_PURE_NAME`□`PYBIND11_OVERRIDE_NAME`□□□□□□□□□□□C□□□□Python□□□□□□□□□□□`__str__`□□□

```
std::string toString() override {
  PYBIND11_OVERRIDE_NAME(
      std::string, // Return type (ret_type)
      Animal,      // Parent class (cname)
      "__str__",   // Name of method in Python (name)
      toString,    // Name of function in C++ (fn)
  );
}
```

Animal□□□□□□□□□□□□□□

```
PYBIND11_MODULE(example, m) {
    py::class_<Animal, PyAnimal /* <--- trampoline*/>(m, "Animal")
        .def(py::init<>())
        .def("go", &Animal::go);

    py::class_<Dog, Animal>(m, "Dog")
        .def(py::init<>());

    m.def("call_go", &call_go);
}
```

pybind11□□□`class_`□□□□□□□□□PyAnimal□□□□□□□Python□□□Animal□□

□□

```
py::class_<Animal, PyAnimal /* <--- trampoline*/>(m, "Animal");
    .def(py::init<>())
    .def("go", &PyAnimal::go); /* <--- THIS IS WRONG, use &Animal::go */
```

□□□Python□□□□□□□□□□□□□`Animal::go`□□□□□□□□□□□□□□

```python
from example import *
d = Dog()
call_go(d)     # u'woof! woof! woof! '
class Cat(Animal):
    def go(self, n_times):
        return "meow! " * n_times

c = Cat()
call_go(c)   # u'meow! meow! meow! '
```

□□□□□□□Python□□□□□□□□□□□□□□□□□□□□□□C++□□□□(□□`__init__`)□□□□□□□□□□□□□□□□□□□□□C++□□□□□□□□□□□□□□□□□□□□□□□pybind11 2.6□□□□□□□□□□□□`TypeError`□□□

```python
class Dachshund(Dog):
    def __init__(self, name):
        Dog.__init__(self)  # Without this, a TypeError is raised.
        self.name = name

    def bark(self):
        return "yap!"
```

□□□□□□□□`__init__`□□□□□□`supper()`□□□□□□□□□□□`supper()`□□□□□□□□□□□□Python□C++□□□□□□□□□Python MRO□C++□□□□□□□□□□

3.3 □□□□□□

□□□□□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□Animal□Dog□□□□

```cpp
class Animal {
public:
    virtual std::string go(int n_times) = 0;
    virtual std::string name() { return "unknown"; }
};
class Dog : public Animal {
public:
    std::string go(int n_times) override {
        std::string result;
        for (int i=0; i<n_times; ++i)
            result += bark() + " ";
        return result;
    }
    virtual std::string bark() { return "woof!"; }
};
```

□□□□□Animal□□□□□□□□□□□Python□□□□□`Dog`□□□□□□□`Dog`□□□□□□□□□□□`bark()`□□□□Animal□`go()`□`name()`□□□□□□□Dog□□□□□name□□□□

```
class PyAnimal : public Animal {
public:
    using Animal::Animal; // Inherit constructors
    std::string go(int n_times) override { PYBIND11_OVERRIDE_PURE(std::string, Animal, go, n_times); }
    std::string name() override { PYBIND11_OVERRIDE(std::string, Animal, name, ); }
};
class PyDog : public Dog {
public:
    using Dog::Dog; // Inherit constructors
    std::string go(int n_times) override { PYBIND11_OVERRIDE(std::string, Dog, go, n_times); }
    std::string name() override { PYBIND11_OVERRIDE(std::string, Dog, name, ); }
    std::string bark() override { PYBIND11_OVERRIDE(std::string, Dog, bark, ); }
};
```

> □□□ `name()` □ `bark()` □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
class Husky : public Dog {};
class PyHusky : public Husky {
public:
    using Husky::Husky; // Inherit constructors
    std::string go(int n_times) override { PYBIND11_OVERRIDE_PURE(std::string, Husky, go, n_times); }
    std::string name() override { PYBIND11_OVERRIDE(std::string, Husky, name, ); }
    std::string bark() override { PYBIND11_OVERRIDE(std::string, Husky, bark, ); }
};
```

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
template <class AnimalBase = Animal> class PyAnimal : public AnimalBase {
public:
    using AnimalBase::AnimalBase; // Inherit constructors
    std::string go(int n_times) override {
PYBIND11_OVERRIDE_PURE(std::string, AnimalBase, go, n_times); }
    std::string name() override { PYBIND11_OVERRIDE(std::string,
AnimalBase, name, ); }
};
template <class DogBase = Dog> class PyDog : public PyAnimal<DogBase> {
public:
    using PyAnimal<DogBase>::PyAnimal; // Inherit constructors
    // Override PyAnimal's pure virtual go() with a non-pure one:
    std::string go(int n_times) override { PYBIND11_OVERRIDE(std::string,
DogBase, go, n_times); }
    std::string bark() override { PYBIND11_OVERRIDE(std::string, DogBase,
bark, ); }
};
```

□□

□□□□pybind11□□□□□□

```
py::class_<Animal, PyAnimal<>> animal(m, "Animal");
py::class_<Dog, Animal, PyDog<>> dog(m, "Dog");
py::class_<Husky, Dog, PyDog<Husky>> husky(m, "Husky");
// ... add animal, dog, husky definitions
```

□□□Husky□□□□□□□□□□□□□□□□□□□□□□□□□□□□

Python□□□□□□

```
class ShihTzu(Dog):
    def bark(self):
        return "yip!"
```

3.4 □□□□□□□

□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□`std::unique_ptr`□□□□□□□□□□□□□□□□□□□□□□□□□□Pybind11□□□□`py::nodelete`□□□□□□□□□□□□□C++□□□□□□□□□□□□□□

```
/* ... definition ... */

class MyClass {
private:
    ~MyClass() { }
};

/* ... binding code ... */

py::class_<MyClass, std::unique_ptr<MyClass, py::nodelete>>(m, "MyClass")
    .def(py::init<>())
```

3.5 □□□□

□□□□A□B□□□□A□□□□□B□

```
py::class_<A>(m, "A")
    /// ... members ...

py::class_<B>(m, "B")
    .def(py::init<A>())
    /// ... members ...

m.def("func",
    [](const B &) { /* .... */ }
);
```

□□func□□□A□□a□Pyhton□□□□`func(B(a))`□□C++□□□□□`func(a)`□□□A□□□□B□□

□□□□B□□□□A□□□□□□□□□□□□□□□□□Python□□□□□□□□□

```
py::implicitly_convertible<A, B>();
```

3.6 □□□□□

□□□□□□□□`Vector2`□□□□□□□□□□□□□□□□□□□□□□

```cpp
class Vector2 {
public:
    Vector2(float x, float y) : x(x), y(y) { }

    Vector2 operator+(const Vector2 &v) const { return Vector2(x + v.x, y + v.y); }
    Vector2 operator*(float value) const { return Vector2(x * value, y * value); }
    Vector2& operator+=(const Vector2 &v) { x += v.x; y += v.y; return *this; }
    Vector2& operator*=(float v) { x *= v; y *= v; return *this; }

    friend Vector2 operator*(float f, const Vector2 &v) {
        return Vector2(f * v.x, f * v.y);
    }

    std::string toString() const {
        return "[" + std::to_string(x) + ", " + std::to_string(y) + "]";
    }
private:
    float x, y;
};
```

□□□□□□□□□□

```
#include <pybind11/operators.h>

PYBIND11_MODULE(example, m) {
    py::class_<Vector2>(m, "Vector2")
        .def(py::init<float, float>())
        .def(py::self + py::self)
        .def(py::self += py::self)
        .def(py::self *= float())
        .def(float() * py::self)
        .def(py::self * float())
        .def(-py::self)
        .def("__repr__", &Vector2::toString);
}
```

`.def(py::self * float())`□□□□□□□□□□□□

```
.def("__mul__", [](const Vector2 &a, float b) {
    return a * b;
}, py::is_operator())
```

3.7 □□□□□

Python□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`copy`□□□□□□□□□□□

□Python3□□□pickle□□□□□□□□□□□□□□□□`__copy__`□`__deepcopy__`□□□□□□□□□□□Python2.7□□□□pybind11□□□cPickle□□□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□□□□□□□□□

```
py::class_<Copyable>(m, "Copyable")
    .def("__copy__",  [](const Copyable &self) {
        return Copyable(self);
    })
    .def("__deepcopy__", [](const Copyable &self, py::dict) {
        return Copyable(self);
    }, "memo"_a);
```

> Note: □□□□□□□□□□□□

3.8 □□□□

pybind11□□□□□□□□□□□□□□□□□□□□□`class_`□□□□□□□□

```
py::class_<MyType, BaseType1, BaseType2, BaseType3>(m, "MyType")
   ...
```

□□□□□□□□□□□□□□□□□holder□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□Python□□□□□□□C++□□□□□□□C++□□Python□□

□□□□□□□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□`multiple_inheritance`□□□

```
py::class_<MyType, BaseType2>(m, "MyType", py::multiple_inheritance());
```

□□□□□□□□□□□□□□□□□

3.9 □□protected□□□□

□□□□□Python□□protected □□□□

```
class A {
protected:
    int foo() const { return 42; }
};

py::class_<A>(m, "A")
    .def("foo", &A::foo); // error: 'foo' is a protected member of 'A'
```

□□□□□□□□□□□□□□□□□□□□Python□□□□protected □□□□□□□□□□□□□

```cpp
class A {
protected:
    int foo() const { return 42; }
};

class Publicist : public A { // helper type for exposing protected functions
public:
    using A::foo; // inherited with different access modifier
};

py::class_<A>(m, "A") // bind the primary class
    .def("foo", &Publicist::foo); // expose protected methods via the publicist
```

□□ `&Publicist::foo` □ `&A::foo` □□□□□□□□□□□□□□□□□□□□□□ `Publicist` □□□□□□□□□□□□ `public` □

□□□□□□Python□□□ `protected` □□□□□publicist pattern□□□□trampoline□□□

```
class A {
public:
    virtual ~A() = default;

protected:
    virtual int foo() const { return 42; }
};

class Trampoline : public A {
public:
    int foo() const override { PYBIND11_OVERRIDE(int, A, foo, ); }
};

class Publicist : public A {
public:
    using A::foo;
};

py::class_<A, Trampoline>(m, "A") // <-- `Trampoline` here
    .def("foo", &Publicist::foo); // <-- `Publicist` here, not
`Trampoline`!
```

3.10 □□final□

□C++11□□□□□□□□□□ `findal` □□□□□□□□□□□□□□□□□ `py::is_final` □□□□□□□□□□□□□□□□Python□□□□□□□□□□C++□□□□□□□□□□final□

```
class IsFinal final {};

py::class_<IsFinal>(m, "IsFinal", py::is_final());
```

□Python□□□□□□□□□□□□□□□□□

```
class PyFinalChild(IsFinal):
    pass

TypeError: type 'IsFinal' is not an acceptable base type
```

4. □□□□

4.1 C++□□□□□Python□□□□□

□Python□□pybind11□□C++□□□□pybind11□□□C++□□□□□□□□□□□□Python□□□□□□□□ Python□□□□□□□□□□

pybind11□□□`std::exception`□□□□□□□□□□□□□□□Python□□□□□□□□□□□□□□□□Python□□□□□□□□□Python C API□□□□□□□□□□□□C++□□□□□□□□□□□□□□□pybind11□□□□□□□□ Python□□□

Exception thrown by C++	Translated to Python exception type
`std::exception`	`RuntimeError`
`std::bad_alloc`	`MemoryError`
`std::domain_error`	`ValueError`
`std::invalid_argument`	`ValueError`
`std::length_error`	`ValueError`
`std::out_of_range`	`IndexError`
`std::range_error`	`ValueError`
`std::overflow_error`	`OverflowError`
`pybind11::stop_iteration`	`StopIteration` (used to implement custom iterators)
`pybind11::index_error`	`IndexError` (used to indicate out of bounds access in `__getitem__`, `__setitem__`, etc.)
`pybind11::key_error`	`KeyError` (used to indicate out of bounds access in `__getitem__`, `__setitem__` in dict-like objects, etc.)
`pybind11::value_error`	`ValueError` (used to indicate wrong value passed in `container.remove(...)`)
`pybind11::type_error`	`TypeError`

Exception thrown by C++	Translated to Python exception type
`pybind11::buffer_error`	`BufferError`
`pybind11::import_error`	`ImportError`
`pybind11::attribute_error`	`AttributeError`
Any other exception	`RuntimeError`

□□□□□□□□□□□□□□□□□□□□□Python□□□□Python□□□□□□□□
`pybind11::error_already_set`□

□□□□□□□□□□□□□□□□□□Python□□□□`handle::call()`□□□`cast_error`□□□

4.2 □□□□□□□□

□□□□□□□□□□□□□□□□pybind11□□□□□□□□□□□□□□□□□□□□pybind11 class□□□□□□□□□□□□□□□global□□□□□□□□C++□□□`what()`□□□C++□Python□□□□□□□□□□□□□□□□

```
py::register_exception<CppExp>(module, "PyExp");
```

□□□□□□□□□□□□□□□□□PyExp□Python□□□□□□□CppExp□□□□□□□□PyExp□□□

□□□□□□□□□□□□□□□□□□

```
py::register_local_exception<CppExp>(module, "PyExp");
```

□□□□□□□□handle□□□□□□□□□□

```
py::register_exception<CppExp>(module, "PyExp", PyExc_RuntimeError);
py::register_local_exception<CppExp>(module, "PyExp", PyExc_RuntimeError);
```

□□□PyExp□□□□□□PyExp□RuntimeError□

Python□□□□□□□□□□□Python□□Standard Exceptions□□□□□□□`PyExc_Exception`□

`py::register_exception_translator(translator)` □
`py::register_local_exception_translator(translator)` □□□□□□□□□□□□□□□□□□□□
□□□□□□□□□□□□□□□□□□□□□ `void(std::exception_ptr)` □

9.3 □C++□□□Python□□

□C++□□Python□□□□□□□□□□□□□Python□□□□□Python□□□□□□pybind11□□Python□□□□□ `pybind11::error_already_set` □□□□□□□□□□□□□C++□□□□□□□□□Python□□□ `error_already_set` □□□Python□□□□Python□□□□C++□□□□□

Exception raised in Python	Thrown as C++ exception type
Any Python `Exception`	`pybind11::error_already_set`

□□□□□

```cpp
try {
    // open("missing.txt", "r")
    auto file = py::module_::import("io").attr("open")("missing.txt",
"r");
    auto text = file.attr("read")();
    file.attr("close")();
} catch (py::error_already_set &e) {
    if (e.matches(PyExc_FileNotFoundError)) {
        py::print("missing.txt not found");
    } else if (e.matches(PyExc_PermissionError)) {
        py::print("missing.txt found but not accessible");
    } else {
        throw;
    }
}
```

□□□□□□□□C++□Python□□□□Python□□□□□□□□□□□□□ `error_already_set`.

```cpp
try {
    py::eval("raise ValueError('The Ring')");
} catch (py::value_error &boromir) {
    // Boromir never gets the ring
    assert(false);
} catch (py::error_already_set &frodo) {
    // Frodo gets the ring
    py::print("I will take the ring");
}

try {
    // py::value_error is a request for pybind11 to raise a Python exception
    throw py::value_error("The ball");
} catch (py::error_already_set &cat) {
    // cat won't catch the ball since
    // py::value_error is not a Python exception
    assert(false);
} catch (py::value_error &dog) {
    // dog will catch the ball
    py::print("Run Spot run");
    throw;  // Throw it again (pybind11 will raise ValueError)
}
```

9.4 □□Python C API□□□

□□□□□□pybind11 wrappers□□□□□□Python C API□□□□□□□□□□□Python C API□□□□□□□□□□□□□□□□□□□□pybind11□□□□□□□□

□□□Python C API□□□□Python□□□□□□□□□`throw py::error_already_set();`□□□□pybind11□□□□□□□□□Python□□□□□□□□□□□□□□□□□□□`PyErr_SetString`□

```cpp
PyErr_SetString(PyExc_TypeError, "C API type error demo");
throw py::error_already_set();

// But it would be easier to simply...
throw py::type_error("pybind11 wrapper type error");
```

□□□□`PyErr_Clear`□□□□□

□□Python□□□□□□□□□□□□□Python/pybind11□□□□□□□□□

9.5 □□unraiseable□□

□□Python□□□C++□□□□□□□□□□`noexcept(true)`□□□c++□□□□□□std::terminate()□□□□□□□□C++□□□□□□□Python□□□□□□□□□□□□□□□□□□`error_already_set`□□□□□□□□□`error_already_set::discard_as_unraisable()`□□□Python□□□

□□□□□□`__del__`□□□□□Python□□□□□□□□□□Python□□unraisable□□□□□□□□Python 3.8+□□□□□system hook□□□□auditing event□□□

□□noexcept□□□□□□try-catch□□□□□□`error_already_set`□□□□□□□□□□□□□pybind11□□□Python□□□□□□□Python□□□□□pybind11□□□□□□C++□□□noexcept□□□□□□□□□□□□□□□□□□□□□Python□□□□□□□`discard_as_unraisable`□□□□□□

```
void nonthrowing_func() noexcept(true) {
    try {
        // ...
    } catch (py::error_already_set &eas) {
        // Discard the Python error using Python APIs, using the C++ magic
        // variable __func__. Python already knows the type and value and
of the
        // exception object.
        eas.discard_as_unraisable(__func__);
    } catch (const std::exception &e) {
        // Log and discard C++ exceptions.
        third_party::log(e);
    }
}
```

5. [illegible]

6. python C++[illegible]

7. [illegible]

7.1 [illegible]

pybind11[illegible]`PYBIND11_DECLARE_HOLDER_TYPE()`[illegible]`PYBIND11_OVERRIDE_*`[illegible]([illegible])[illegible]

```
PYBIND11_OVERRIDE(MyReturnType<T1, T2>, Class<T3, T4>, func)
```

[illegible]5[illegible]3[illegible]`PYBIND11_TYPE`[illegible]

```
// Version 1: using a type alias
using ReturnType = MyReturnType<T1, T2>;
using ClassType = Class<T3, T4>;
PYBIND11_OVERRIDE(ReturnType, ClassType, func);

// Version 2: using the PYBIND11_TYPE macro:
PYBIND11_OVERRIDE(PYBIND11_TYPE(MyReturnType<T1, T2>),
                  PYBIND11_TYPE(Class<T3, T4>), func)
```

`PYBIND11_MAKE_OPAQUE`[illegible]

7.2 □□□□□□GIL□

□Python□□□C++□□□□□□□□□GIL□`gil_scoped_release`□`gil_scoped_acquire`□□□□□□□□□□□□□□□GIL□□□□□□□□□C++□□□□□□Python□□□□□□□□□□□□□

```
class PyAnimal : public Animal {
public:
    /* Inherit the constructors */
    using Animal::Animal;

    /* Trampoline (need one for each virtual function) */
    std::string go(int n_times) {
        /* Acquire GIL before calling Python code */
        py::gil_scoped_acquire acquire;

        PYBIND11_OVERRIDE_PURE(
            std::string, /* Return type */
            Animal,      /* Parent class */
            go,          /* Name of function */
            n_times      /* Argument(s) */
        );
    }
};

PYBIND11_MODULE(example, m) {
    py::class_<Animal, PyAnimal> animal(m, "Animal");
    animal
        .def(py::init<>())
        .def("go", &Animal::go);

    py::class_<Dog>(m, "Dog", animal)
        .def(py::init<>());

    m.def("call_go", [](Animal *animal) -> std::string {
        /* Release GIL before calling into (potentially long-running) C++
code */
        py::gil_scoped_release release;
        return call_go(animal);
    });
}
```

□□□□□□`call_guard`□□□□□`call_go`□□□□

```
m.def("call_go", &call_go, py::call_guard<py::gil_scoped_release>());
```

□□□□Mermaid□□□

□□□□□□□□□□□□□□ `Mermaid` □□□,□□□□□□□□□□□□□□□□,□□□□□□□□□□□□,□□□□□□□□,□□□□□□□□□□□□,□□ `markdown` □□□□.

□□□□□□□□□□□□□□□□□□:

- □□□□□□□□□□`Mermaid`□□□;
- □□□□□□□□□□`Mermaid`□□□;
- □□ `Gitbook` □□□□□□□□□□□□.

□□□Mermaid□□□

□□□

```
- □□□□
- □□□□
- □□□□
```

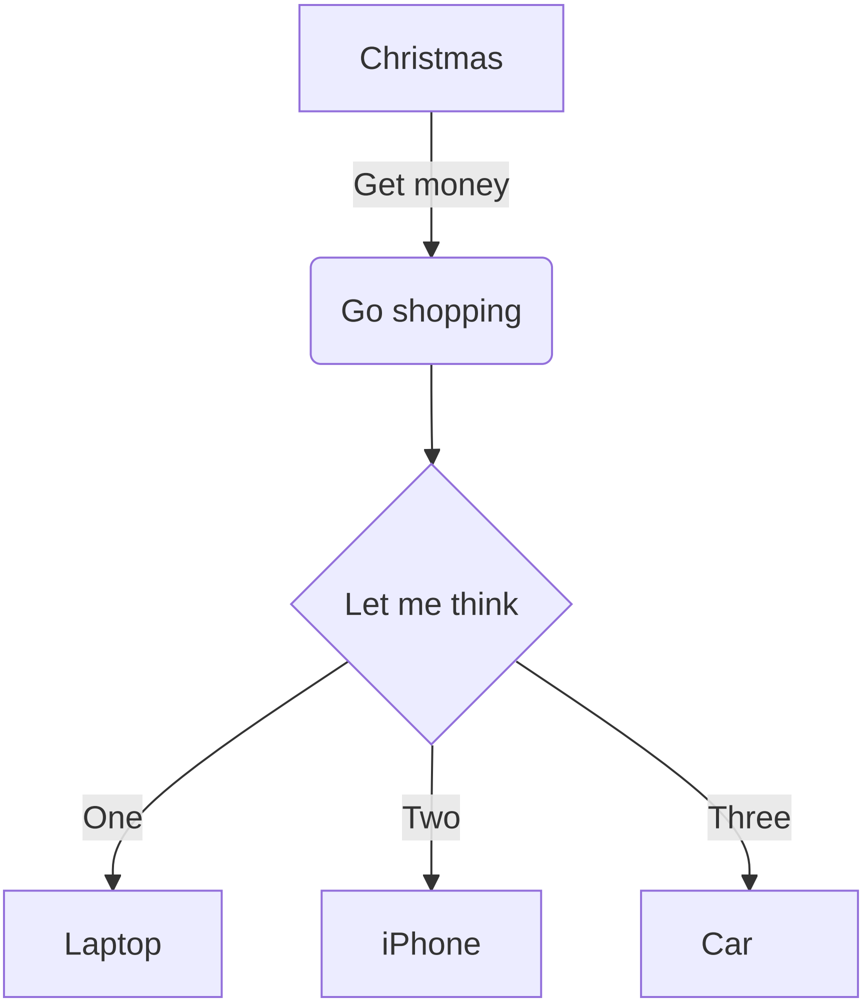
□□□□□□□□□□,□□□□□□□□□□□□□□□□□□□□□□□□.

`Mermaid`□□□□□ `Javascript` □□□□□□□□□.□□□ `markdown` □□□□□□□□□□□□□□□□□□,□□□□□□□□□□.

□□

```
graph TD
  A[Christmas] -->|Get money| B(Go shopping)
  B --> C{Let me think}
  C -->|One| D[Laptop]
  C -->|Two| E[iPhone]
  C -->|Three| F[fa:fa-car Car]
```

□□



- □□□□: https://github.com/mermaid-js/mermaid
- □□□□: https://mermaidjs.github.io/mermaid-live-editor/
- □□□□: https://mermaid-js.github.io/mermaid/#/flowchart
- □□□□: https://mermaid.nodejs.cn/syntax/flowchart.html

Mermaid□□□□□□

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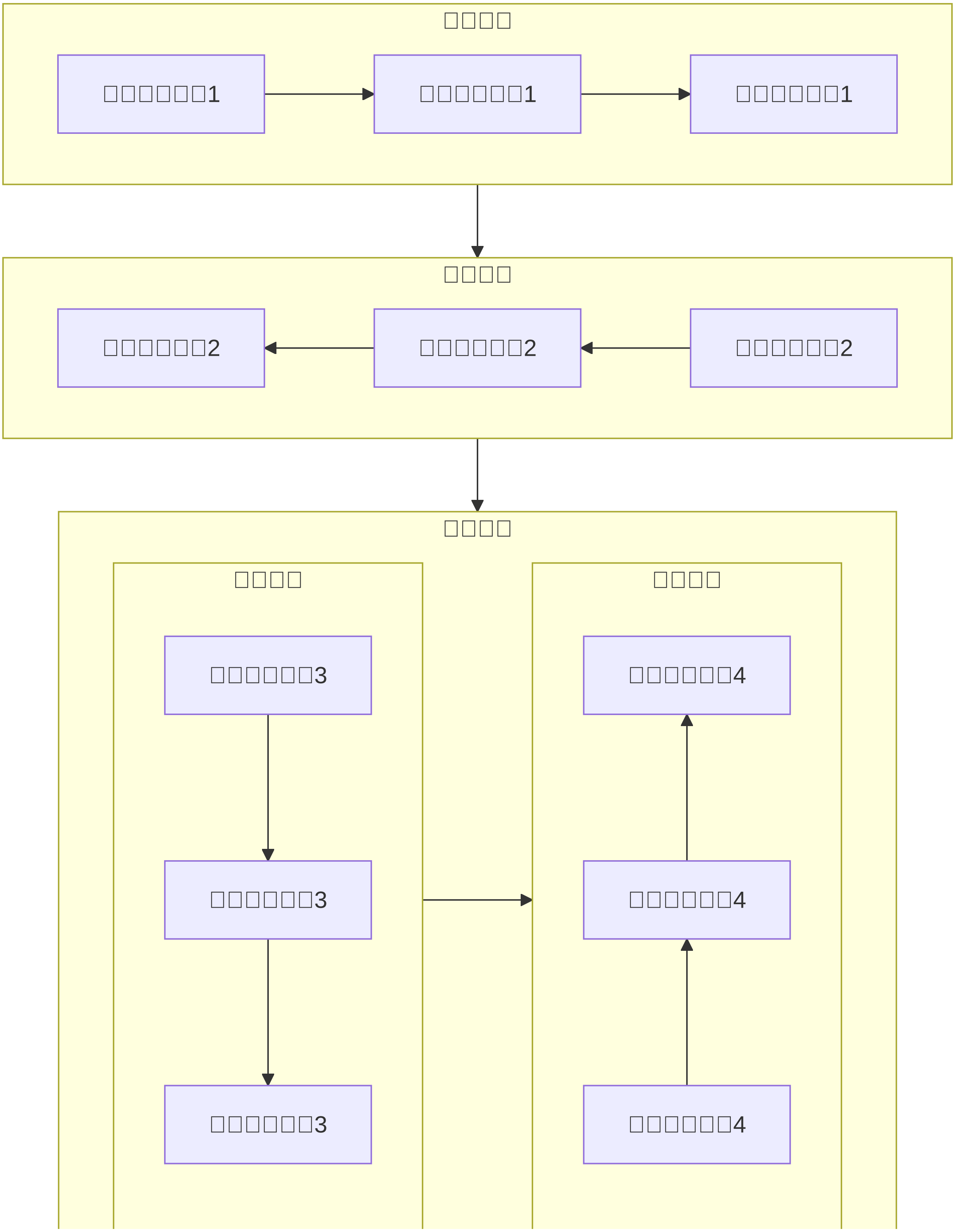
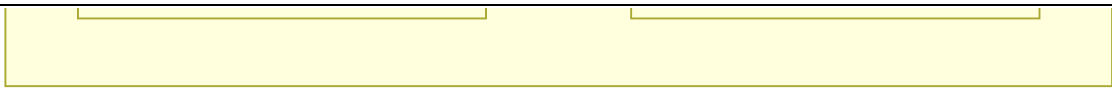
```
+ TB
+ BT
+ LR
+ RL
```





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> □□: □□□□□□□□□□□□□□,□□□□□□□□□□□□□.

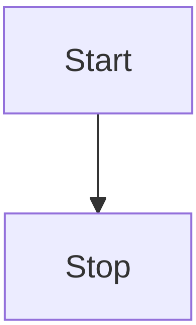
- TB

> □□□□: from **T**op to **B**ottom

□□

```
graph TB
    Start --> Stop
```

□□



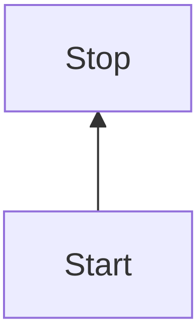
- BT

> □□□□: from **B**ottom to **T**op

□□

```
graph BT
    Start --> Stop
```

□□



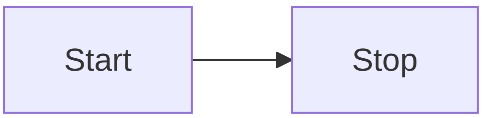
- LR

> □□□□: from **L**eft to **R**ight

□□

```
graph LR
    Start --> Stop
```

□□



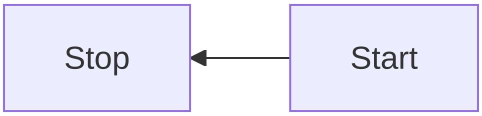
- RL

> □□□□: from **R**ight to **L**eft

□□

```
graph RL
    Start --> Stop
```

□□



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```
- □□□□
    + [□□]
        - [[□□□□]]
        - [(□□)]
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    + (□□□□)
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        - ({□□□□})
    + {□□}
        - {{□□□}}
        - {[□□□□]}
        - {(□□□□)}
    + >□□□□□]
```

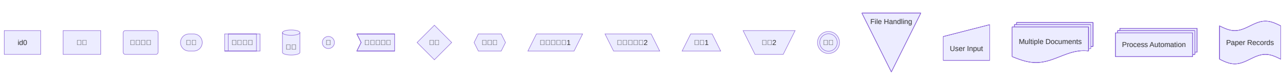

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> □□: □□□□□□□□,□□□□□□.

□□□□□

□□□□□,□□□□□□□□□,□□□□□□□□□ `id` □□,□□□□□□□□□□□□□□□.

> `id` □□□□□□□□□□□□□□□□□□□□□□□.

□□

```
graph TD
    id
```

□□

□□□□□

□□□□□,□□□□□,□□□□□□□□ `id` □□□□ `<node shape>` □□,□□□□□□□□□□□□□□□□□.

> `id` □□□□□□□□□,□□□□□□□□□□ `<node shape>` □□□□,□□ `id` □□□□□□□□□□.

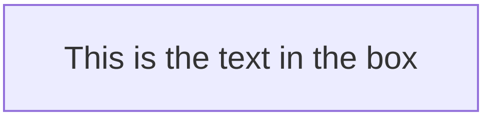
- □□

> □□□□: `[node description]` , `[]` □□□□□□□□□□□□,`node description` □□□□□□□□.

□□

```
graph LR
    id1[This is the text in the box]
```

□□



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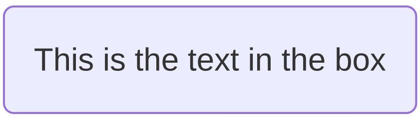
> □□□□: `(node description)` , `()` □□□□□□□□□□□□□□, `node description` □□□□□□□□.

□□

```
graph LR
    id1(This is the text in the box)
```

□□



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> □□□□: `([node description])` , `()` □□□□□ `[]` □□□□□□□□□□□□□□□□□□,□□□□□□□□, `node description` □□□□□□□□.

□□

```
graph LR
    id1([This is the text in the box])
```

□□

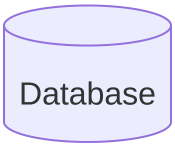
- □□

> □□□□: `[(node description)]` , `[]` □□□□□ `()` □□□□□□□□□□□□□, `node description` □□□□□□□□.

□□

```
graph LR
    id1[(Database)]
```

□□



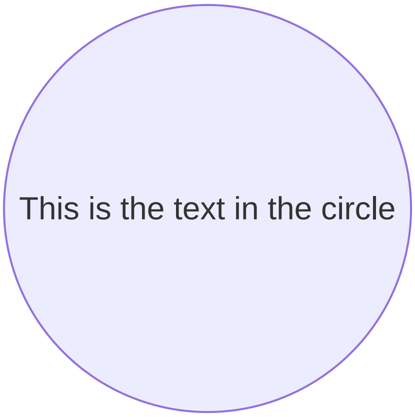
- □□

> □□□□: `((node description))` , `()` □□□□□ `()` □□□□□□□□□□□□□, `node description` □□□□□□□□.

□□

```
graph LR
    id1((This is the text in the circle))
```

□□



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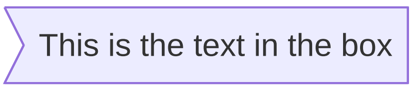
> □□□□: `>node description]` ,□□□□□□□ `>` ,□□□□□□□ `]` □□□□□□□□□,`node description` □□□□□□□□.

□□

```
graph LR
    id1>This is the text in the box]
```

□□



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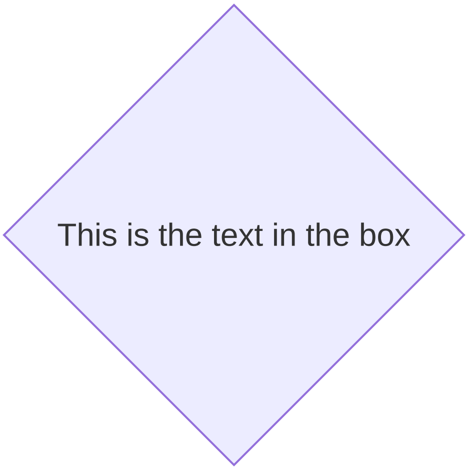
> □□□□: `{node description}` , `{}` □□□□□□□□, `node description` □□□□□□□.

□□

```
graph LR
    id1{This is the text in the box}
```

□□



- □□□

> □□□□: `{{node description}}` , `{}` □□□□□ `{}` □□□□□□□□□, `node description` □□□□□□□.

□□

```
graph LR
    id1\{\{This is the text in the box\}\}
```

> `Gitbook` □□□□□□□ `{}` □□□□□□,□□□□□□□□□□,□□□□□□□ `\` □□□□.

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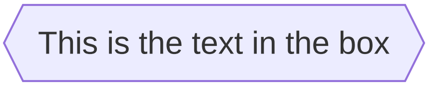

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> □□□□: `[/node description/]` , `[]` □□□□□ `//` □□□□□□□□□□□□□□, `node description` □□□□□□□□.

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```
graph TD
    id1[/This is the text in the box/]
```

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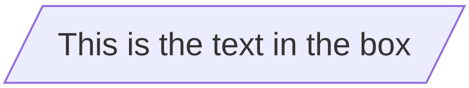

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```
graph TD
    id1[\This is the text in the box\]
```

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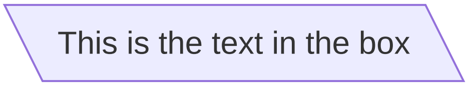

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```
graph TD
    A[/Christmas\]
```

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□□

```
graph TD
    B[\Go shopping/]
```

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```
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    - ==>
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    - □□□□□□□□□□(2)
        + ==□□□□==>
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        + ==□□□□===
        + ===|□□□□|
```
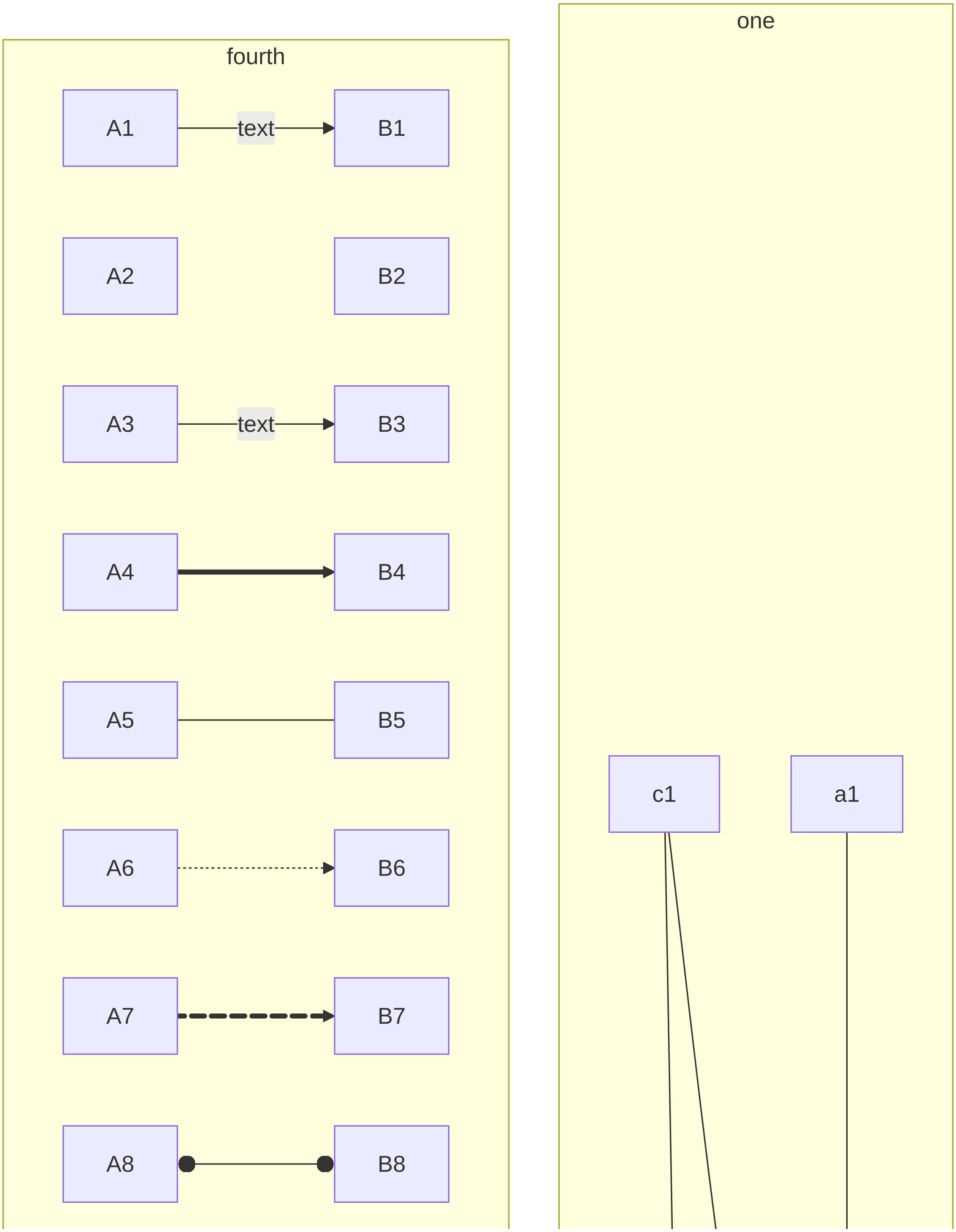
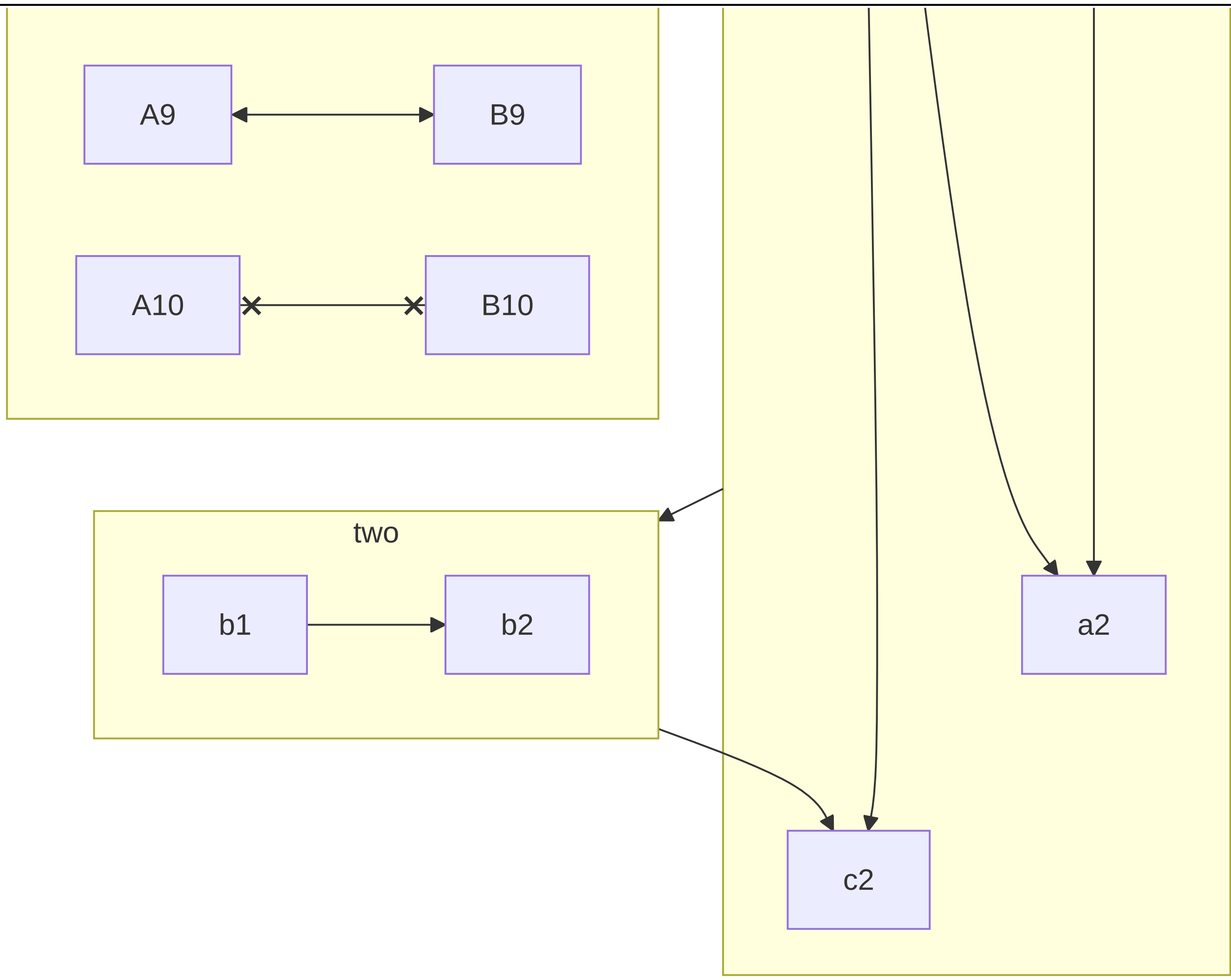


fourth
A1
text
B1
A2
B2
A3
text
B3
A4
B4
A5
B5
A6
B6
A7
B7
A8
B8
one
c1
a1


A9
B9
A10
B10
two
b1
b2
a2
c2

□□□□□□□□,□□□□□□□□□□□□□□□□□□□□,□□□□□□□□□□□□□□□□,□□ `--` □□□□,□□□□□□ `-.-` □□□□,□□□□□□□□□ `>` ,□□□□□□□□□ `-`.

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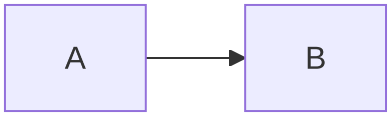
□□

```
graph LR
    A-->B
```

□□



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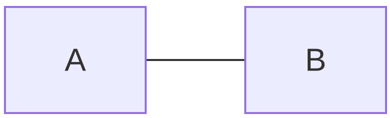
```
graph LR
    A --- B
```

□□



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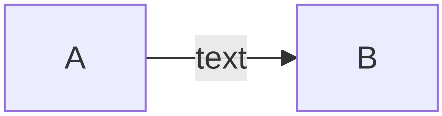
```
graph LR
    A-- text -->B
```

□□



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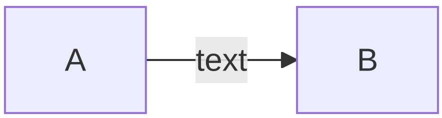
□□

```
graph LR
    A-->|text|B
```

□□



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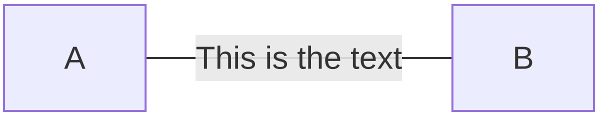
```
graph LR
    A-- This is the text ---B
```

□□



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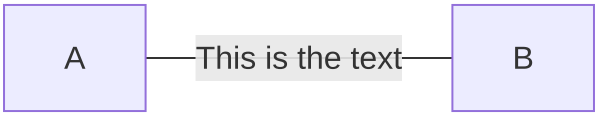
□□

```
graph LR
    A---|This is the text|B
```

□□



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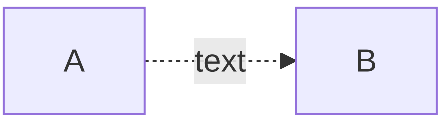
□□

```
graph LR
   A-. text .-> B
```

□□



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> □□□□: `==>` ,□□□□□□.

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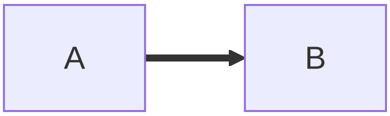
```
graph LR
   A ==> B
```

□□



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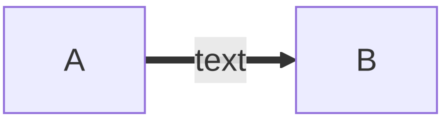
□□

```
graph LR
   A == text ==> B
```

□□



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> □□□□: `|connection line description|` ,□□ `||` □□□□□□□□□□.

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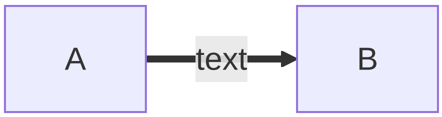
```
graph LR
   A ==>|text| B
```

□□



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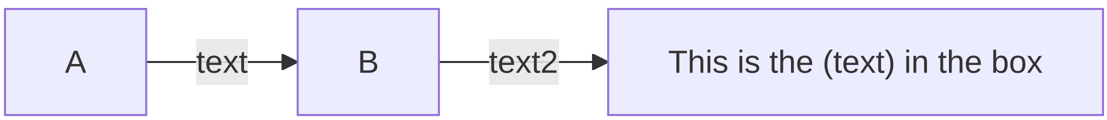
```
+ -->-->
+ &
+ ""
+ %%
+ subgraph
```



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□□□□□□□□, `A-->B-->C` □□□ `A-->B` □ `B-->C` □□.

```
graph LR
   A -- text --> B -- text2 --> C
```

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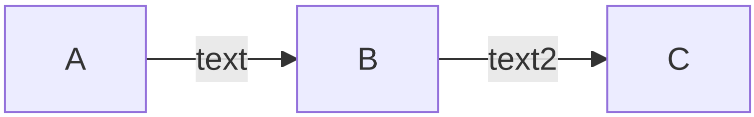

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□□□□□□□□,`A-->B & C` □□□ `A-->B` □ `A-->C` □□.

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```
graph LR
   a --> b & c--> d
```

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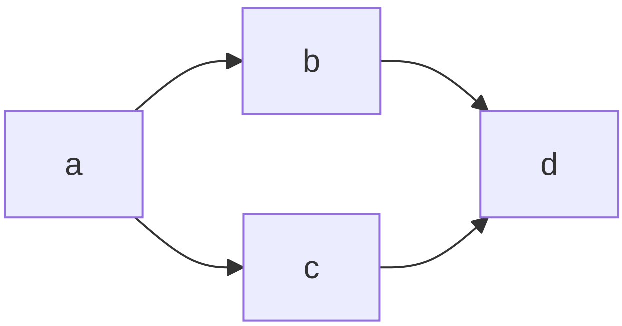

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□□□□□□□□□□□□□,`A & B --> C & D` □□□ `A-->C` ,`A-->D`,`B-->C` □ `B-->D` □□□□□□.

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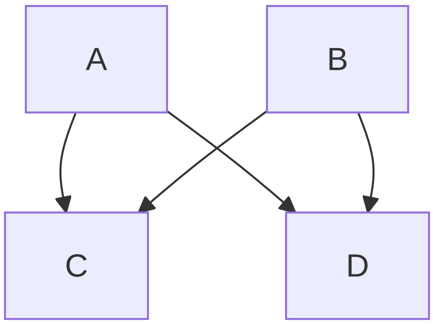
```
graph TB
    A & B--> C & D
```

□□



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□□□□□□□□□□□□□□□□□□ `""` □□□□,□□□ `[]` □ `()` □□ `{}` □□□□□□□.

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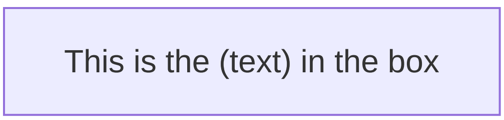
```
graph LR
    id1["This is the (text) in the box"]
```

□□



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□□ `Html` □□□□

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```
graph LR
    A["A double quote:#quot;"] -->B["A dec char:#9829;"]
```

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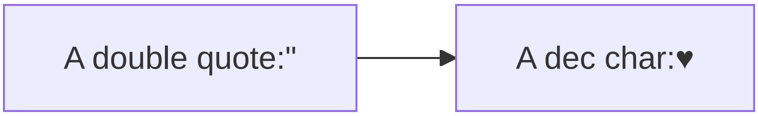

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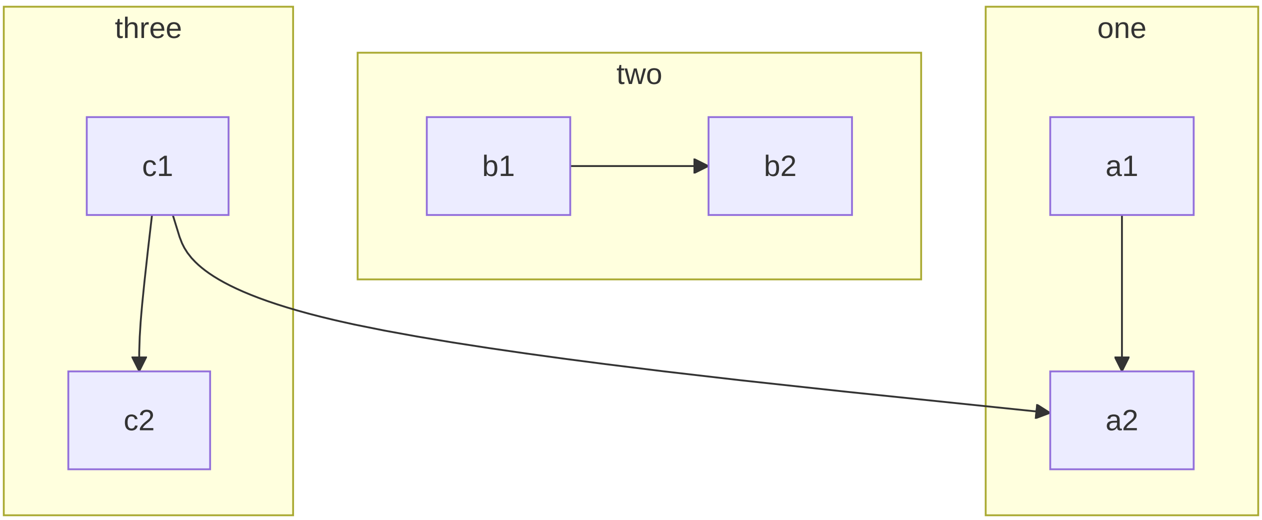
```
subgraph title
    graph definition
end
```

□□

```
graph TB
    c1-->a2
    subgraph one
    a1-->a2
    end
    subgraph two
    b1-->b2
    end
    subgraph three
    c1-->c2
    end
```



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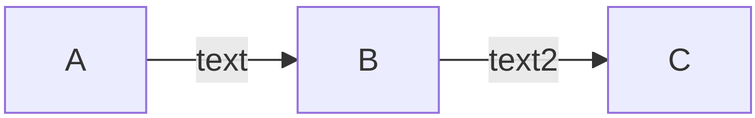
□□□ `%%` □□□□□□□□.

```
graph LR
%% this is a comment A -- text --> B{node}
   A -- text --> B -- text2 --> C
```



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```
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- □□□□□
- □□□□
```

`Mermaid` □□□□□□□□□□,□□□ `Markdown` □□□□□□□,□□□□□□□□□□□,□□□□□□□□□□□□□□□□□.

[illegible]

> [illegible],[illegible].

[illegible]	[illegible]	[illegible]
[illegible]	graph	`graph` [illegible]
[illegible]	subgraph	`subgraph` [illegible]
[illegible]	top	`TB` [illegible] `BT` ,[illegible]
[illegible]	bottom	`BT` [illegible] `TB` ,[illegible]
[illegible]	left	`LR` [illegible] `RL` ,[illegible]
[illegible]	right	`RL` [illegible] `LR` ,[illegible]

[illegible]

> [illegible],[illegible],[illegible],[illegible].

- [illegible]

[illegible]	[illegible]	[illegible]	[illegible]
`[]`	[illegible]	[illegible]	[illegible]
`()`	[illegible]	[illegible]	[illegible]
`{}`	[illegible]	[illegible]	[illegible]
`<>`	[illegible]	[illegible]	[illegible]
`--`	[illegible]	[illegible]	[illegible]
`-.`	[illegible]	[illegible]	[illegible]
`==`	[illegible]	[illegible]	[illegible]
`=:`	[illegible]	[illegible]	[illegible]

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`>`	□□□	□□□□□	□□
`-`	□□□	□□□□□	□□
`□□□`	□□□□□□□□□	□□□□□□□	□□
`--`	□□□□□□□□□□□	□□□□□□□	□□
`-.`	□□□□□□□□□□□	□□□□□□□	□□
`==`	□□□□□□□□□□□□□	□□□□□□□	□□
`=:`	□□□□□□□□□□□□□	□□□□□□□	□□□

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`[[]]`	□□□	□□□□	□□□
`[()]`	□□□	□□□□	□□
`[{}]`	□□□	□□□□	□□□
`(())`	□□	□□□□	□□
`([])`	□□□	□□□□	□□
`({})`	□□	□□□□	□□□
`□□□□`	□□□	□□□□	□□
`{[]}`	□□□□	□□□□	□□□
`{()}`	□□	□□□□	□□□
`-->`	□□□□□	□□□□□	□□
`---`	□□□□□	□□□□□	□□
`-.>`	□□□□□	□□□□□	□□□

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`-.->`	□□□□□	□□□□□	□□
`.->`	□□□□□	□□□□□	□□
`-.-`	□□□□□	□□□□□	□□
`.-`	□□□□□	□□□□□	□□
`==>`	□□□□□□□	□□□□□	□□
`===`	□□□□□□□	□□□□□	□□
`=:>`	□□□□□□□	□□□□□	□□□
`=:=>`	□□□□□□□	□□□□□	□□□
`=:=`	□□□□□□□	□□□□□	□□□
`:=`	□□□□□□□	□□□□□	□□□
`□□□`	□□□□□□□□□	□□□□□□□	□□
`--connection line description-->`	□□□□□□□□□□□□□□□	□□□□□□□	□□
`-.connection line description-.->`	□□□□□□□□□□□□□□□	□□□□□□□	□□
`--connection line description---`	□□□□□□□□□□□□□□□	□□□□□□□	□□
`-.connection line description-.-`	□□□□□□□□□□□□□□□	□□□□□□□	□□
`==connection line description==>`	□□□□□□□□□□□□□□□□□	□□□□□□□	□□
`=:connection line description=:=>`	□□□□□□□□□□□□□□□□□	□□□□□□□	□□□
`==connection line description===`	□□□□□□□□□□□□□□□□□	□□□□□□□	□□

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`=:connection line description=:=`	□□□□□□□□□□□□□□□□	□□□□□□□	□□□

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□□□□□□□□□□□□□□□□□,□□□□□ `JS` □ `CSS` □□□□□□□□□□□□□□□□,□□□□□□□□□.

> □□□□: https://mermaid-js.github.io/mermaid/#/flowchart?id=styling-and-classes

- □□□□ Interaction : https://mermaid-js.github.io/mermaid/#/flowchart?id=interaction
- □□□□ Styling and classes : https://mermaid-js.github.io/mermaid/#/flowchart?id=interaction
- □□□□ Basic support for fontawesome: https://mermaid-js.github.io/mermaid/#/flowchart?id=basic-support-for-fontawesome
- □□□□ https://mermaid-js.github.io/mermaid/#/flowchart?id=graph-declarations-with-spaces-between-vertices-and-link-and-without-semicolon

Reference

The following admonishments are implemented by the mdbook-admonish plugin and are automatically themed to match Catppuccin.

Directives

All supported directives are listed below.

`note`

> **Note**
>
> Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`abstract`, `summary`, `tldr`

> **Abstract**
>
> Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`info`, `todo`

Info

Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`tip`, `hint`, `important`

Tip

Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`success`, `check`, `done`

Success

Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`question`, `help`, `faq`

Question

Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`warning`, `caution`, `attention`

> **Warning**
>
> Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`failure`, `fail`, `missing`

> **Failure**
>
> Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`danger`, `error`

> **Danger**
>
> Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`bug`

> **Bug**
>
> Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`example`

Example

Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

`quote`, `cite`

Quote

Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.

Bienvenue sur notre site de développement 3D !

Bienvenue sur notre site dédié au développement 3D. Ici, vous trouverez des ressources, des tutoriels et des informations utiles pour vous lancer dans le monde passionnant de la 3D.

Info

A beautifully styled message.

Un example

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nulla et euismod nulla. Curabitur feugiat, tortor non consequat finibus, justo purus auctor massa, nec semper lorem quam in massa.

Une note

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nulla et euismod nulla. Curabitur feugiat, tortor non consequat finibus, justo purus auctor massa, nec semper lorem quam in massa.

Un warning

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Collapsing note

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Le javascript c'est yolo préférez Typescript

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nulla et euismod nulla. Curabitur feugiat, tortor non consequat finibus, justo purus auctor massa, nec semper lorem quam in massa.

Referencing* and *dereferencing

The opposite of *referencing* by using `&` is *dereferencing*, which is accomplished with the dereference operator, `*`.

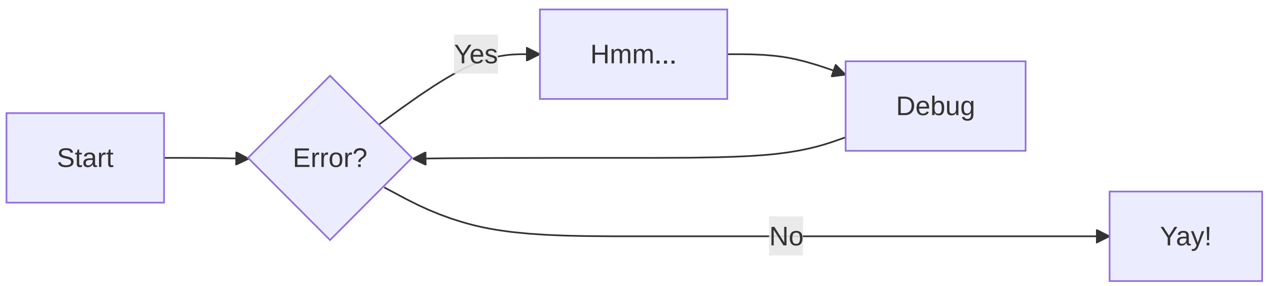
Bug

This syntax won’t work in Python 3:

```
print "Hello, world!"
```

À propos de nous

Nous sommes une équipe passionnée par la 3D et nous avons pour mission de partager nos connaissances avec la communauté. Vous trouverez ici des articles, des exemples de code et des démonstrations pour vous aider à démarrer votre voyage dans le développement 3D.



Pour commencer

Si vous êtes nouveau dans le domaine de la 3D, ne vous inquiétez pas ! Notre page “Getting Started” vous guidera à travers les étapes essentielles pour démarrer rapidement.

Restons en contact

N’hésitez pas à nous suivre sur les réseaux sociaux pour rester à jour avec nos dernières publications et annonces. Si vous avez des questions ou des commentaires, n’hésitez pas à nous contacter !

Mizux

Chapter 1

HTML:

$$e^{i\theta} = \cos\theta + i\sin\theta$$

$$\Rightarrow x + iy = re^{i\theta}$$

Markdown (requires `mdbook-katex`):

$$\oint_C f(x,y)\,\mathrm{d}A$$

Inspect element and use `Sources` tab (under `Debugger` on Firefox) to check that all CSS and fonts are properly loaded from GitHub pages instead of external CDN.

▼ Proof that $e^{ix} = \cos x + i\sin x$

$$\begin{aligned}
e^x &= \sum_{n=0}^{\infty} \frac{x^n}{n!} \implies e^{ix} = \sum_{n=0}^{\infty} \frac{(ix)^n}{n!} \\
\cos x &= \sum_{m=0}^{\infty} \frac{(-1)^m x^{2m}}{(2m)!} = \sum_{m=0}^{\infty} \frac{(ix)^{2m}}{(2m)!} \\
\sin x &= \sum_{s=0}^{\infty} \frac{(-1)^s x^{2s+1}}{(2s+1)!} = \sum_{s=0}^{\infty} \frac{(ix)^{2s+1}}{i(2s+1)!} \\
\cos x + i\sin x &= \sum_{l=0}^{\infty} \frac{(ix)^{2l}}{(2l)!} + \sum_{s=0}^{\infty} \frac{(ix)^{2s+1}}{(2s+1)!} = \sum_{n=0}^{\infty} \frac{(ix)^n}{n!} \\
&= e^{ix}
\end{aligned}$$

Fourier Transform:

$$f(t) = \int_{-\infty}^{\infty} F(\omega) i^{4t\omega} d\omega$$

$$F(\omega) = \int_{-\infty}^{\infty} f(t) i^{-4t\omega} dt$$

Pauli Matrices:

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$\sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

$$\sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

kroki

```
graph TD
  A[ Anyone ] -->|Can help | B( Go to github.com/yuzutech/kroki )
  B --> C{ How to contribute? }
  C --> D[ Reporting bugs ]
  C --> E[ Sharing ideas ]
  C --> F[ Advocating ]
```

```
    0       3
     *-------*      +y
  1 /|    2 /|       ^
   *-------* |       |
   | |4    | |7      | ↰
   | *-----|-*     ⤹  +------> +x
   |/      |/       / ⤴
   *-------*       v
  5       6      +z
```