Simplifying, Consolidating & Documenting LLDB’s Scripting Functionalities

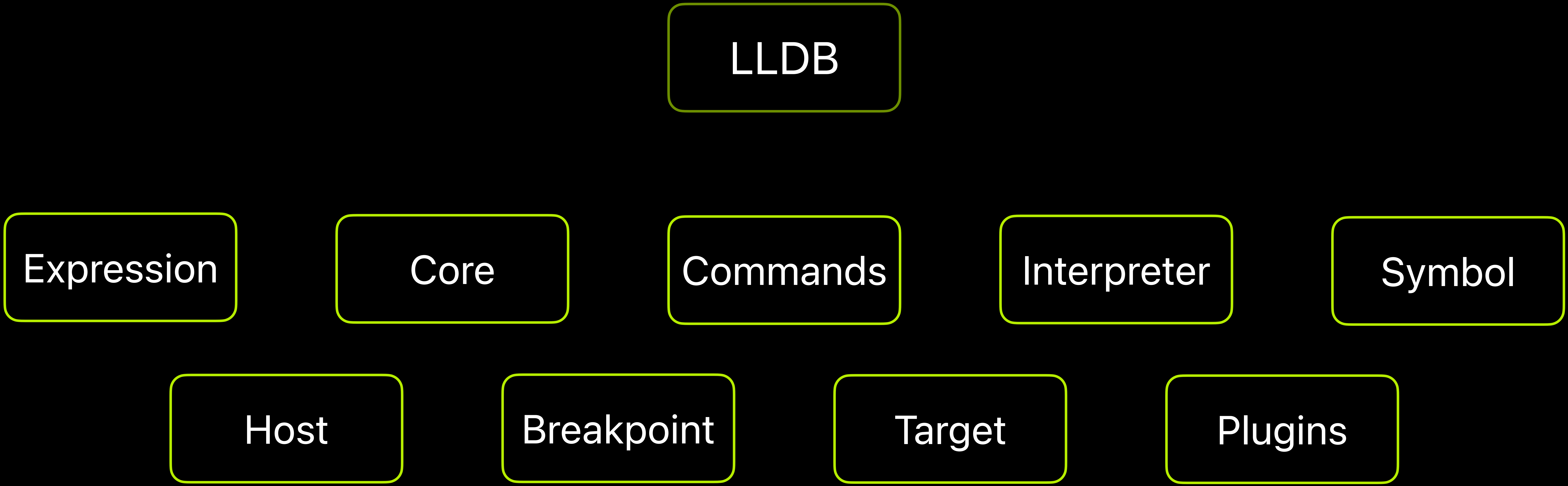
Ismail Bennani

EuroLLVM 2024 | Apple Inc | April 11th 2024

“LLVM Project is a collection of modular and reusable compiler and toolchain technologies”

The LLVM Project website

LLVM
LT
LL
LLD
la
Clang
LD
LLDB
ML
MLIR
A
FLANG
OL
PO



LLDB

Expression

Core

Commands

Interpreter

Symbol

Host

Breakpoint

Target

Plugins

LLDB

Expression

Core

Commands

Interpreter

Symbol

Host

Breakpoint

Target

Plugins

Private

Public

API

LLDB

Expression

Core

Commands

Interpreter

Symbol

Host

Breakpoint

Target

Plugins

Private

Public

API

CLI

IDEs

Python

LLDB

Private

Public

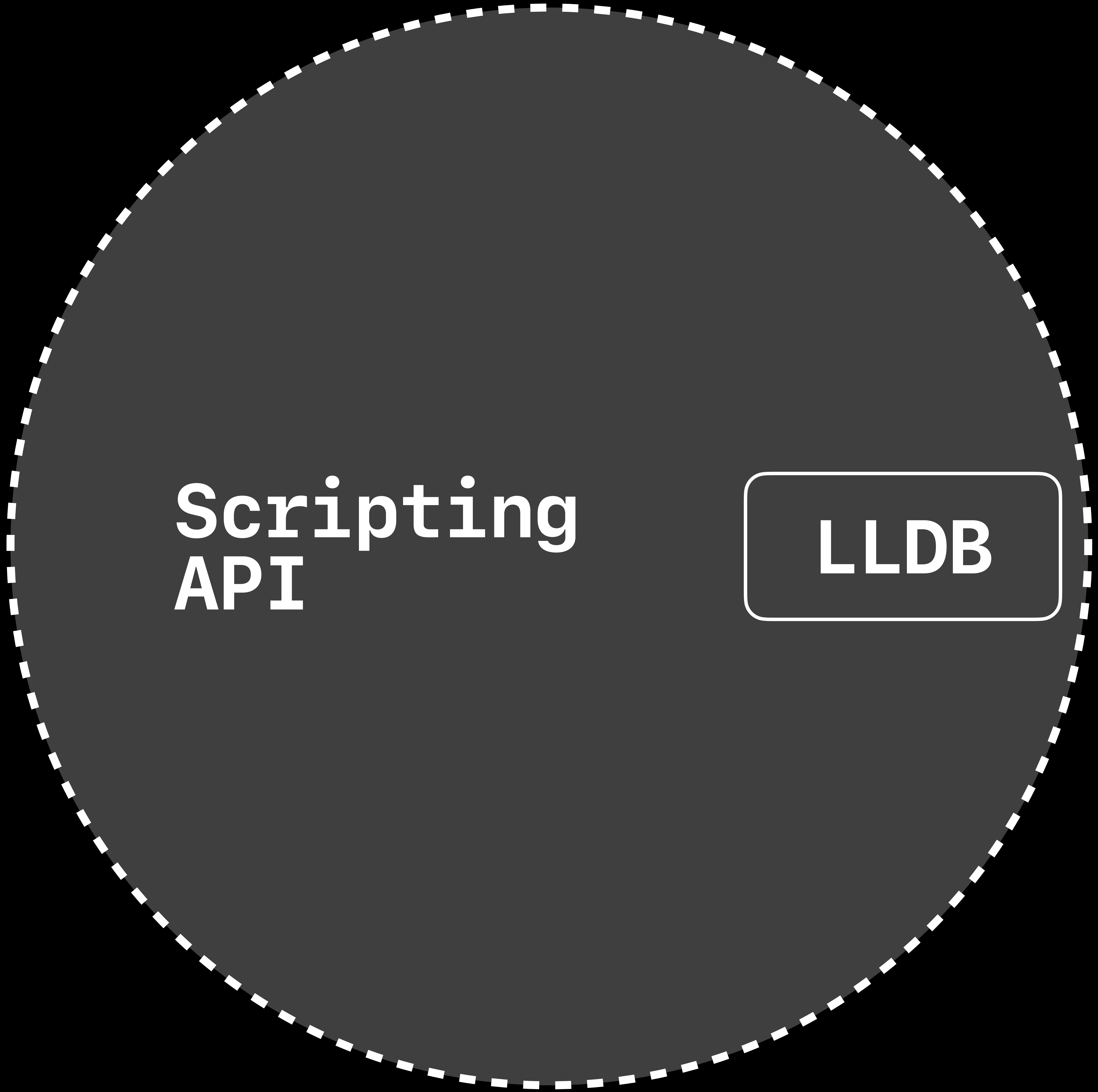
API

CLI

IDEs

Python

LLDB
Private
Public
API
(lldb)
CLI
IDEs
py
lldb.py
py
Python

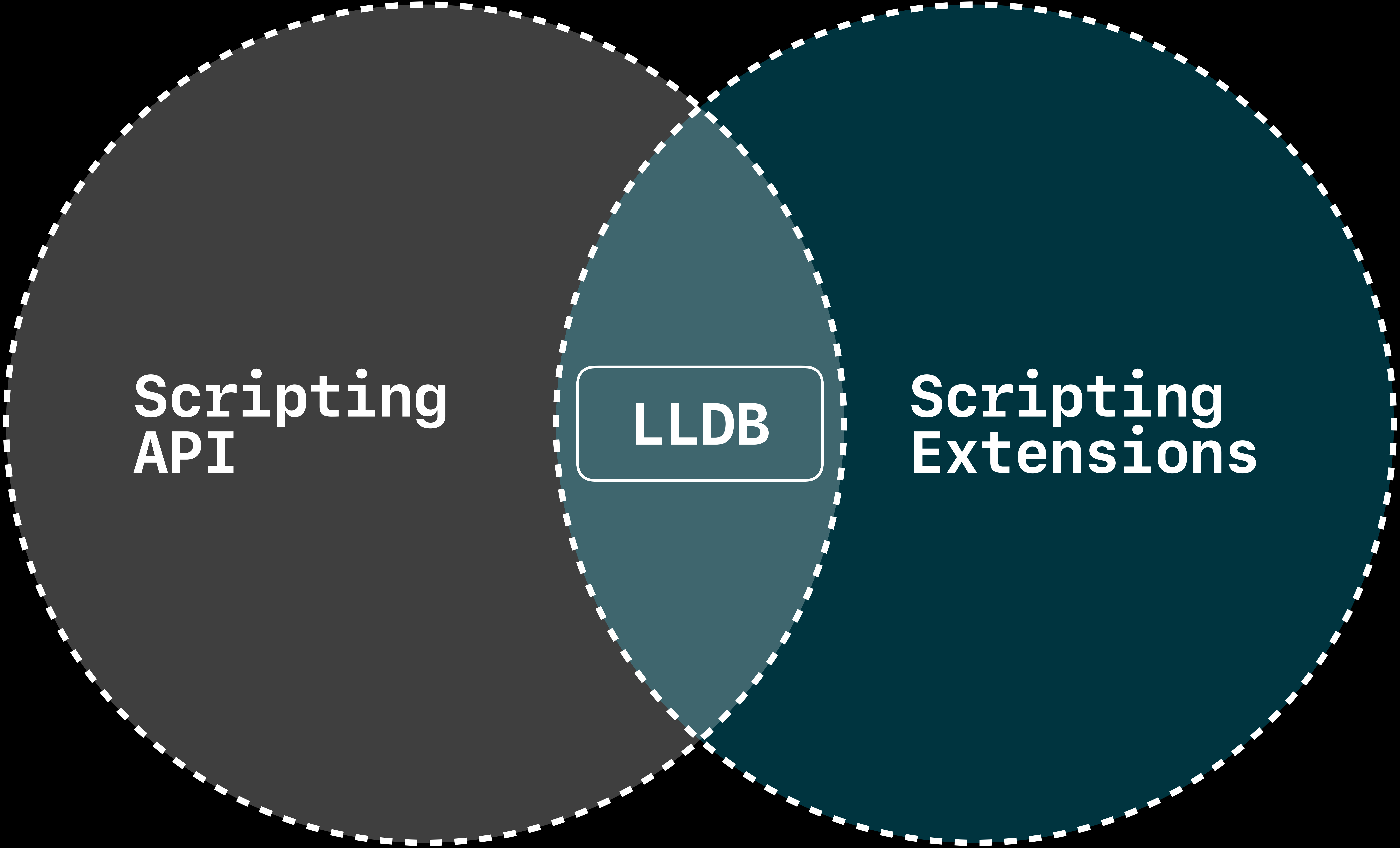


Scripting API

LLDB

Scripting API

```
(lldb) script

>>> target = lldb.dbg.CreateTarget(“a.out”)
>>> bkpt = target.BreakpointCreateByLocation("main.c", 42)

>>> process = target.Launch(lldb.SBLaunchInfo(None), lldb.SBError())

>>> thread = process.GetSelectedThread()
>>> frame_0 = thread.GetFrameAtIndex(0)

>>> frame_0.FindVariable(“foo”)
(int) foo = 19
```


Scripting API
LLDB
Scripting Extensions

Scripting Extensions

Data Formatter

Scripted Process

Custom Command

Breakpoint Command

Operating System Plugin

Scripted Thread Plan

Target Stop Hook

Watchpoint Command

Scripting Extensions

Data Formatter

Custom Command

Scripted Thread Plan

Watchpoint Command

Target Stop Hook

Scripted Process

Breakpoint Command

Operating System Plugin

Scripting Extensions

Data Formatter Example:

```
class MySingleChildProvider:
    def __init__(self, valobj, dict):
        self.valobj = valobj

    def num_children(self):
        return 1

    def has_children(self):
        return True

    def get_child_index(self, name):
        return 0
```

Scripting Extensions

Data Formatter Example:

```
def get_child_at_index(self, index):
    if index != 0 or not self.valobj.IsValid():
        return None
    return self.valobj.GetChildAtIndex(0)

def update(self):
    pass
```

Scripting Extensions

Data Formatter

Custom Command

Scripted Thread Plan

Watchpoint Command

Target Stop Hook

Scripted Process

Breakpoint Command

Operating System Plugin

1. **Improve discoverability**
2. **Keep documentation up-to-date**
3. **Reduce boilerplate code**
4. **Reduce high maintenance cost**

1. Improve discoverability
2. **Keep documentation up-to-date**
3. Reduce boilerplate code
4. Reduce high maintenance cost

1. Improve discoverability

2. Keep documentation up-to-date

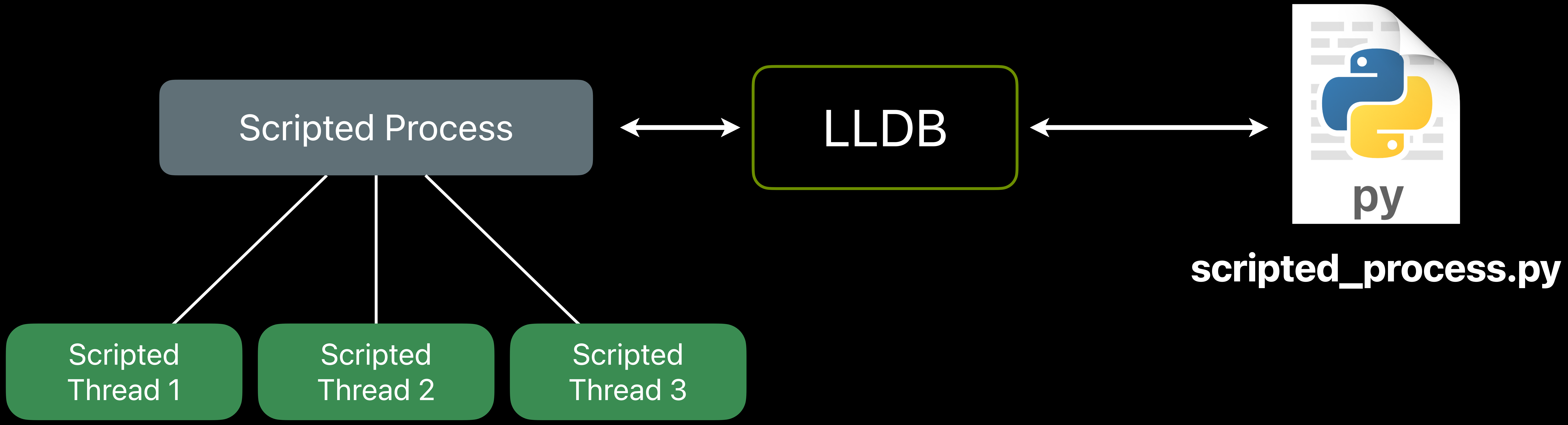
3. Reduce boilerplate code

4. Reduce high maintenance cost

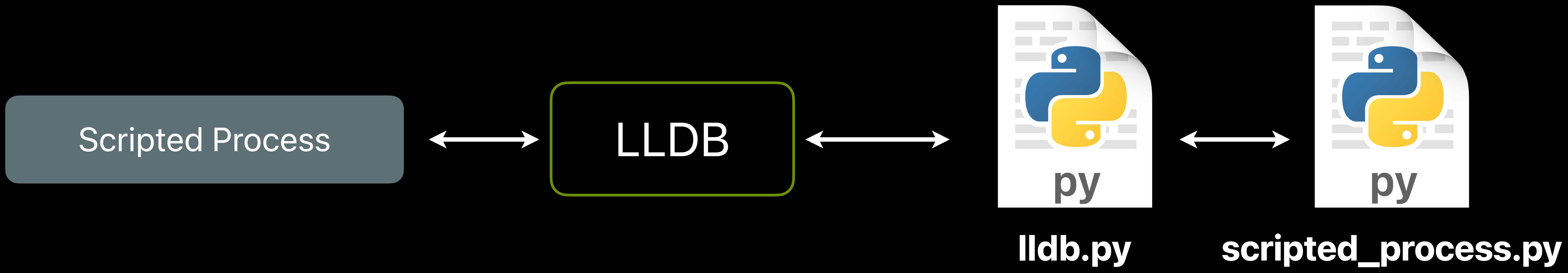
1. Improve discoverability
2. Keep documentation up-to-date
3. Reduce boilerplate code
4. **Reduce high maintenance cost**

1. Improve discoverability
2. Keep documentation up-to-date
3. Reduce boilerplate code
4. Reduce high maintenance cost

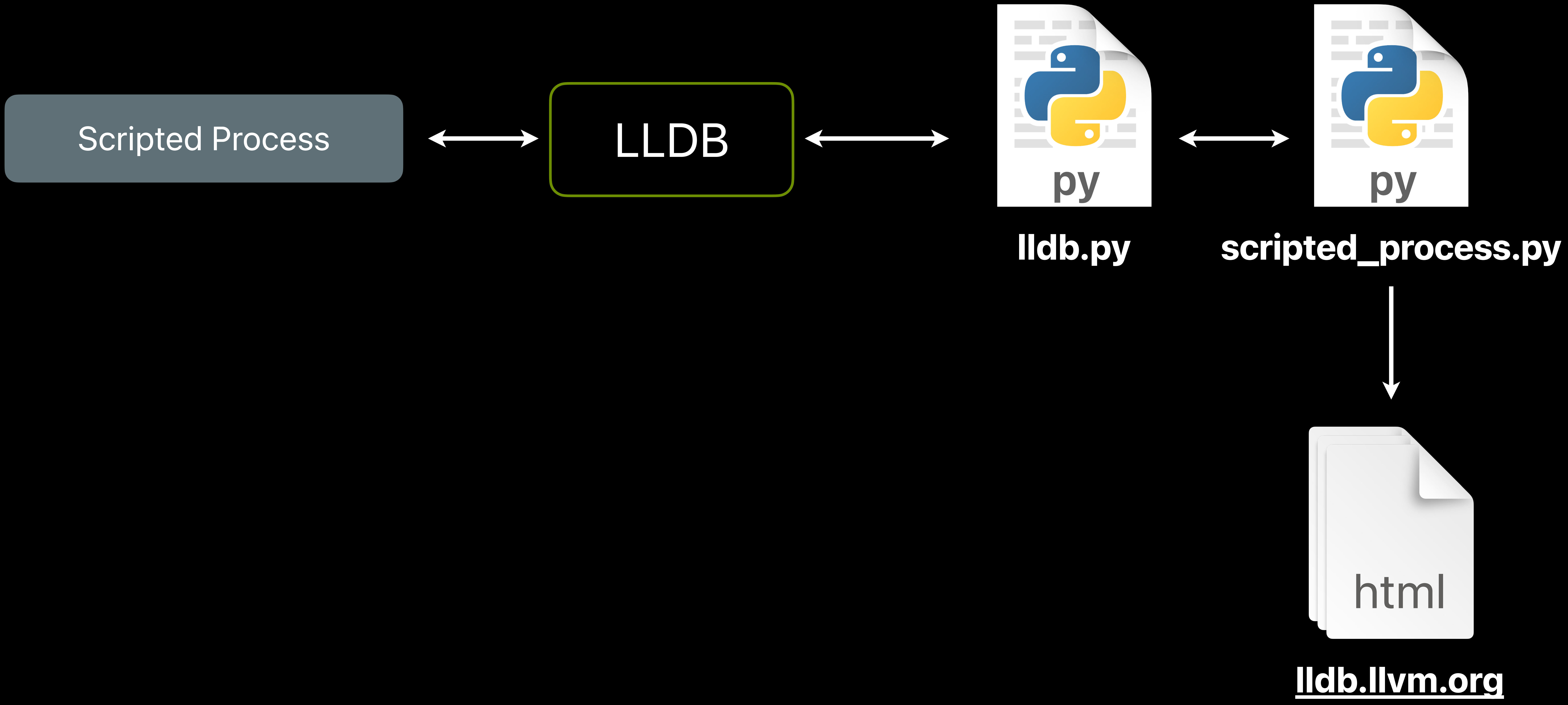
Scripted Process 101

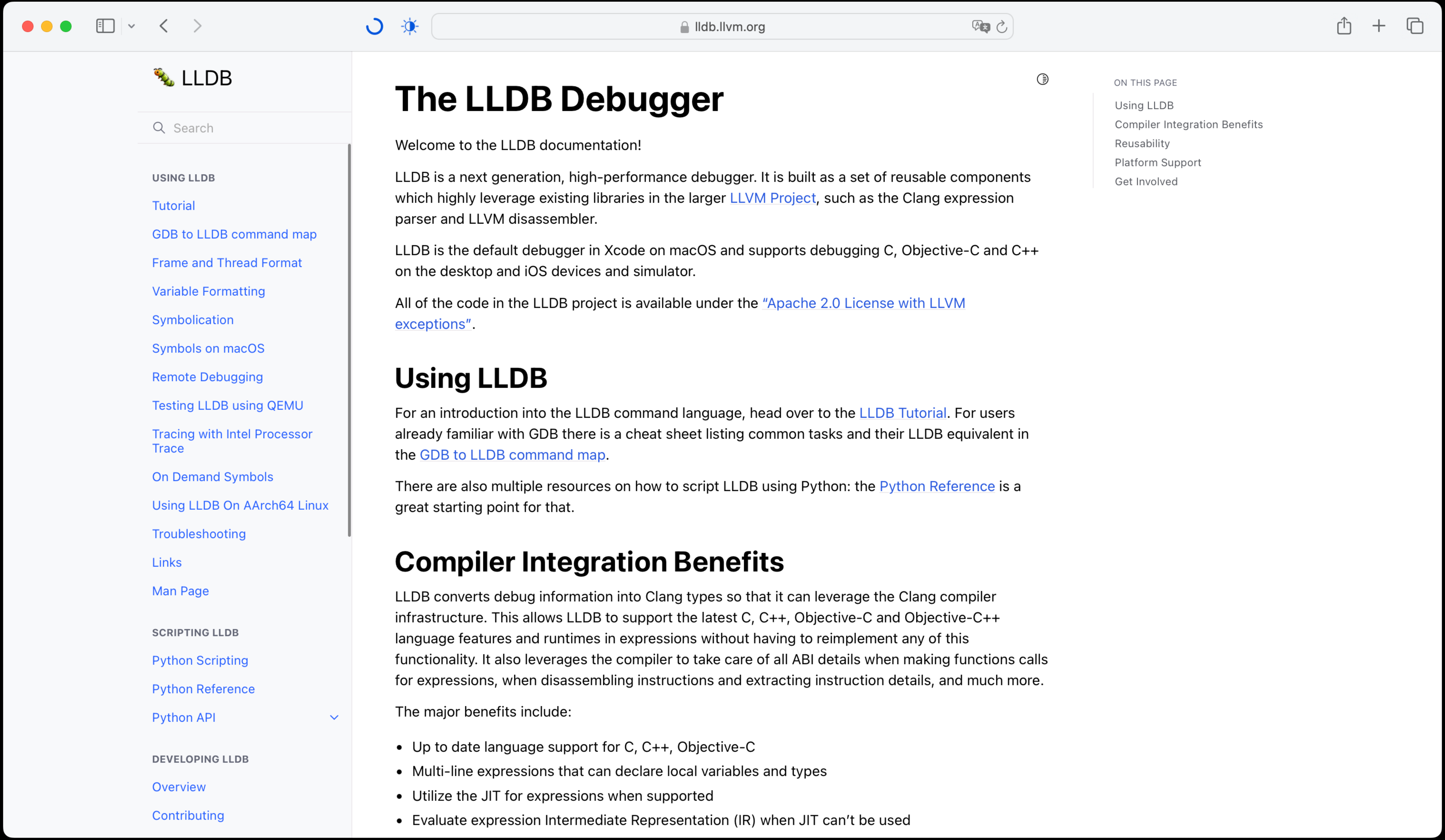


Scripted Process 101



Scripted Process 101





The LLDB Debugger

Welcome to the LLDB documentation!

LLDB is a next generation, high-performance debugger. It is built as a set of reusable components which highly leverage existing libraries in the larger LLVM Project, such as the Clang expression parser and LLVM disassembler.

LLDB is the default debugger in Xcode on macOS and supports debugging C, Objective-C and C++ on the desktop and iOS devices and simulator.

All of the code in the LLDB project is available under the "Apache 2.0 License with LLVM exceptions".

Using LLDB

For an introduction into the LLDB command language, head over to the LLDB Tutorial. For users already familiar with GDB there is a cheat sheet listing common tasks and their LLDB equivalent in the GDB to LLDB command map.

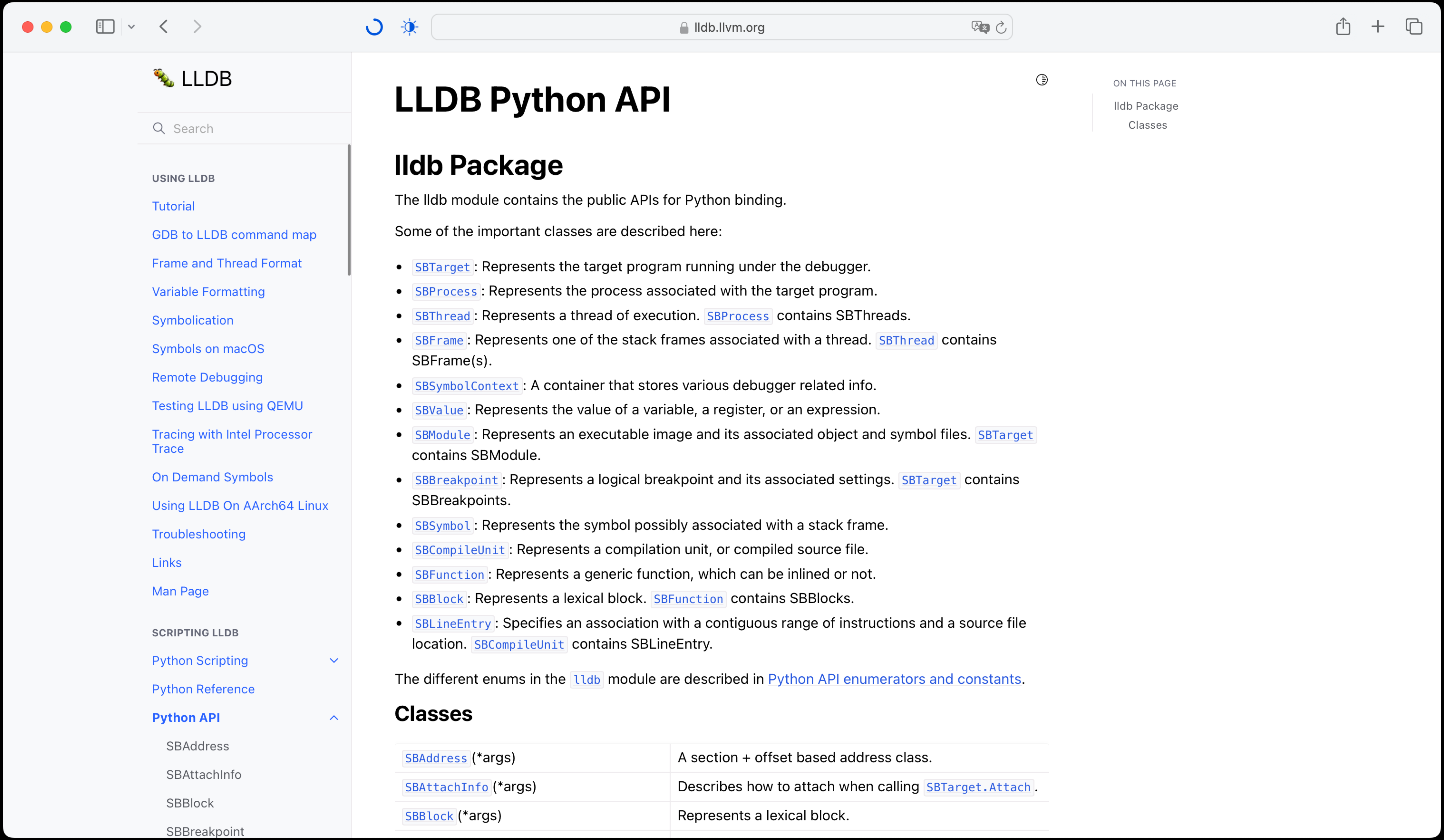
There are also multiple resources on how to script LLDB using Python: the Python Reference is a great starting point for that.

Compiler Integration Benefits

LLDB converts debug information into Clang types so that it can leverage the Clang compiler infrastructure. This allows LLDB to support the latest C, C++, Objective-C and Objective-C++ language features and runtimes in expressions without having to reimplement any of this functionality. It also leverages the compiler to take care of all ABI details when making functions calls for expressions, when disassembling instructions and extracting instruction details, and much more.

The major benefits include:

- Up to date language support for C, C++, Objective-C
- Multi-line expressions that can declare local variables and types
- Utilize the JIT for expressions when supported
- Evaluate expression Intermediate Representation (IR) when JIT can't be used



LLDB

Search

USING LLDB

Tutorial

GDB to LLDB command map

Frame and Thread Format

Variable Formatting

Symbolication

Symbols on macOS

Remote Debugging

Testing LLDB using QEMU

Tracing with Intel Processor Trace

On Demand Symbols

Using LLDB On AArch64 Linux

Troubleshooting

Links

Man Page

SCRIPTING LLDB

Python Scripting

Python Reference

Python API

SBAddress

SBAttachInfo

SBBlock

SBBreakpoint

LLDB Python API

lldb Package

The lldb module contains the public APIs for Python binding.

Some of the important classes are described here:

- `SBTarget`: Represents the target program running under the debugger.
- `SBProcess`: Represents the process associated with the target program.
- `SBThread`: Represents a thread of execution. `SBProcess` contains SBThreads.
- `SBFrame`: Represents one of the stack frames associated with a thread. `SBThread` contains SBFrame(s).
- `SBSymbolContext`: A container that stores various debugger related info.
- `SBValue`: Represents the value of a variable, a register, or an expression.
- `SBModule`: Represents an executable image and its associated object and symbol files. `SBTarget` contains SBModule.
- `SBBreakpoint`: Represents a logical breakpoint and its associated settings. `SBTarget` contains SBBreakpoints.
- `SBSymbol`: Represents the symbol possibly associated with a stack frame.
- `SBCompileUnit`: Represents a compilation unit, or compiled source file.
- `SBFunction`: Represents a generic function, which can be inlined or not.
- `SBBlock`: Represents a lexical block. `SBFunction` contains SBBlocks.
- `SBLineEntry`: Specifies an association with a contiguous range of instructions and a source file location. `SBCompileUnit` contains SBLineEntry.

The different enums in the `lldb` module are described in Python API enumerators and constants.

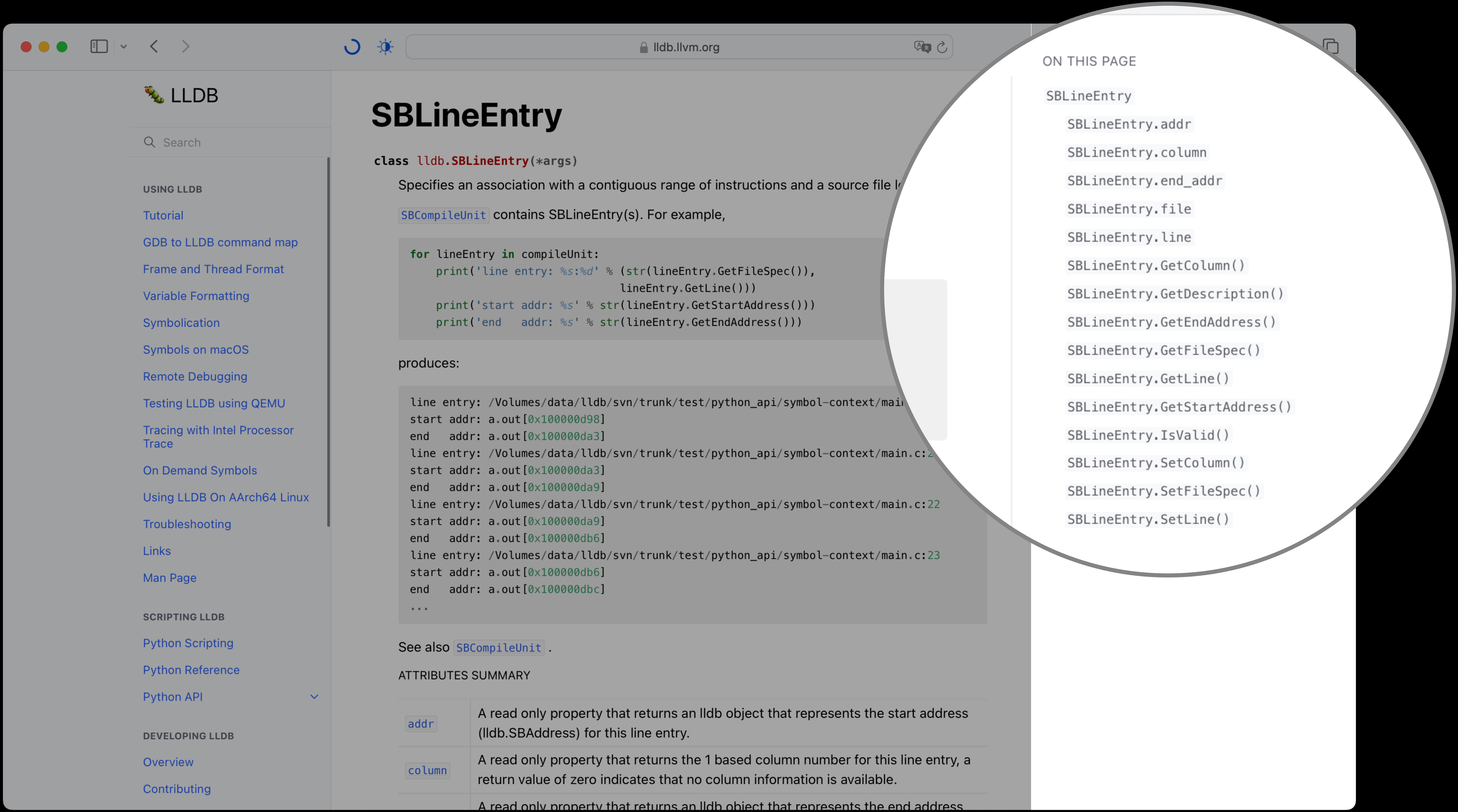
Classes

`SBAddress`(*args)	A section + offset based address class.
`SBAttachInfo`(*args)	Describes how to attach when calling `SBTarget.Attach`.
`SBBlock`(*args)	Represents a lexical block.

ON THIS PAGE

lldb Package

Classes



LLDB

Search

USING LLDB

Tutorial

GDB to LLDB command map

Frame and Thread Format

Variable Formatting

Symbolication

Symbols on macOS

Remote Debugging

Testing LLDB using QEMU

Tracing with Intel Processor Trace

On Demand Symbols

Using LLDB On AArch64 Linux

Troubleshooting

Links

Man Page

SCRIPTING LLDB

Python Scripting

Python Reference

Python API

DEVELOPING LLDB

Overview

Contributing

SBLineEntry

`class lldb.SBLineEntry(*args)`

Specifies an association with a contiguous range of instructions and a source file l

`SBCompileUnit` contains SBLineEntry(s). For example,

```
for lineEntry in compileUnit:
    print('line entry: %s:%d' % (str(lineEntry.GetFileSpec()),
                                 lineEntry.GetLine()))
    print('start addr: %s' % str(lineEntry.GetStartAddress()))
    print('end   addr: %s' % str(lineEntry.GetEndAddress()))
```

produces:

```
line entry: /Volumes/data/lldb/svn/trunk/test/python_api/symbol-context/mai
start addr: a.out[0x100000d98]
end   addr: a.out[0x100000da3]
line entry: /Volumes/data/lldb/svn/trunk/test/python_api/symbol-context/main.c:2
start addr: a.out[0x100000da3]
end   addr: a.out[0x100000da9]
line entry: /Volumes/data/lldb/svn/trunk/test/python_api/symbol-context/main.c:22
start addr: a.out[0x100000da9]
end   addr: a.out[0x100000db6]
line entry: /Volumes/data/lldb/svn/trunk/test/python_api/symbol-context/main.c:23
start addr: a.out[0x100000db6]
end   addr: a.out[0x100000dbc]
...
```

See also `SBCompileUnit` .

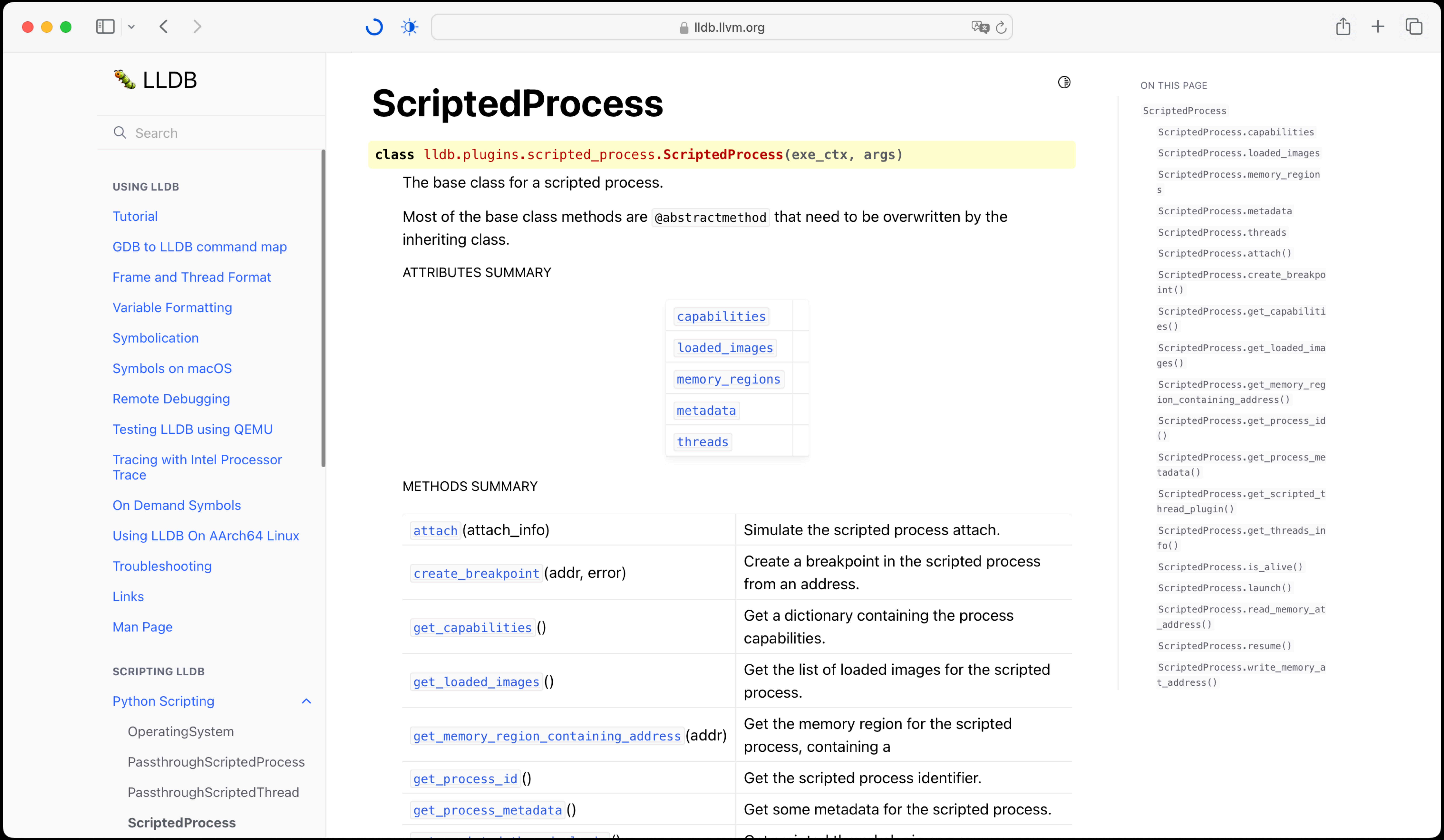
ATTRIBUTES SUMMARY

`addr`	A read only property that returns an lldb object that represents the start address (lldb.SBAddress) for this line entry.
`column`	A read only property that returns the 1 based column number for this line entry, a return value of zero indicates that no column information is available.
	A read only property that returns an lldb object that represents the end address

ON THIS PAGE

SBLineEntry

- SBLineEntry.addr
- SBLineEntry.column
- SBLineEntry.end_addr
- SBLineEntry.file
- SBLineEntry.line
- SBLineEntry.GetColumn()
- SBLineEntry.GetDescription()
- SBLineEntry.GetEndAddress()
- SBLineEntry.GetFileSpec()
- SBLineEntry.GetLine()
- SBLineEntry.GetStartAddress()
- SBLineEntry.IsValid()
- SBLineEntry.SetColumn()
- SBLineEntry.SetFileSpec()
- SBLineEntry.SetLine()



LLDB

Search

USING LLDB

Tutorial

GDB to LLDB command map

Frame and Thread Format

Variable Formatting

Symbolication

Symbols on macOS

Remote Debugging

Testing LLDB using QEMU

Tracing with Intel Processor Trace

On Demand Symbols

Using LLDB On AArch64 Linux

Troubleshooting

Links

Man Page

SCRIPTING LLDB

Python Scripting

OperatingSystem

PassthroughScriptedProcess

PassthroughScriptedThread

ScriptedProcess

ScriptedProcess

```
class lldb.plugins.scripted_process.ScriptedProcess(exe_ctx, args)
```

The base class for a scripted process.

Most of the base class methods are `@abstractmethod` that need to be overwritten by the inheriting class.

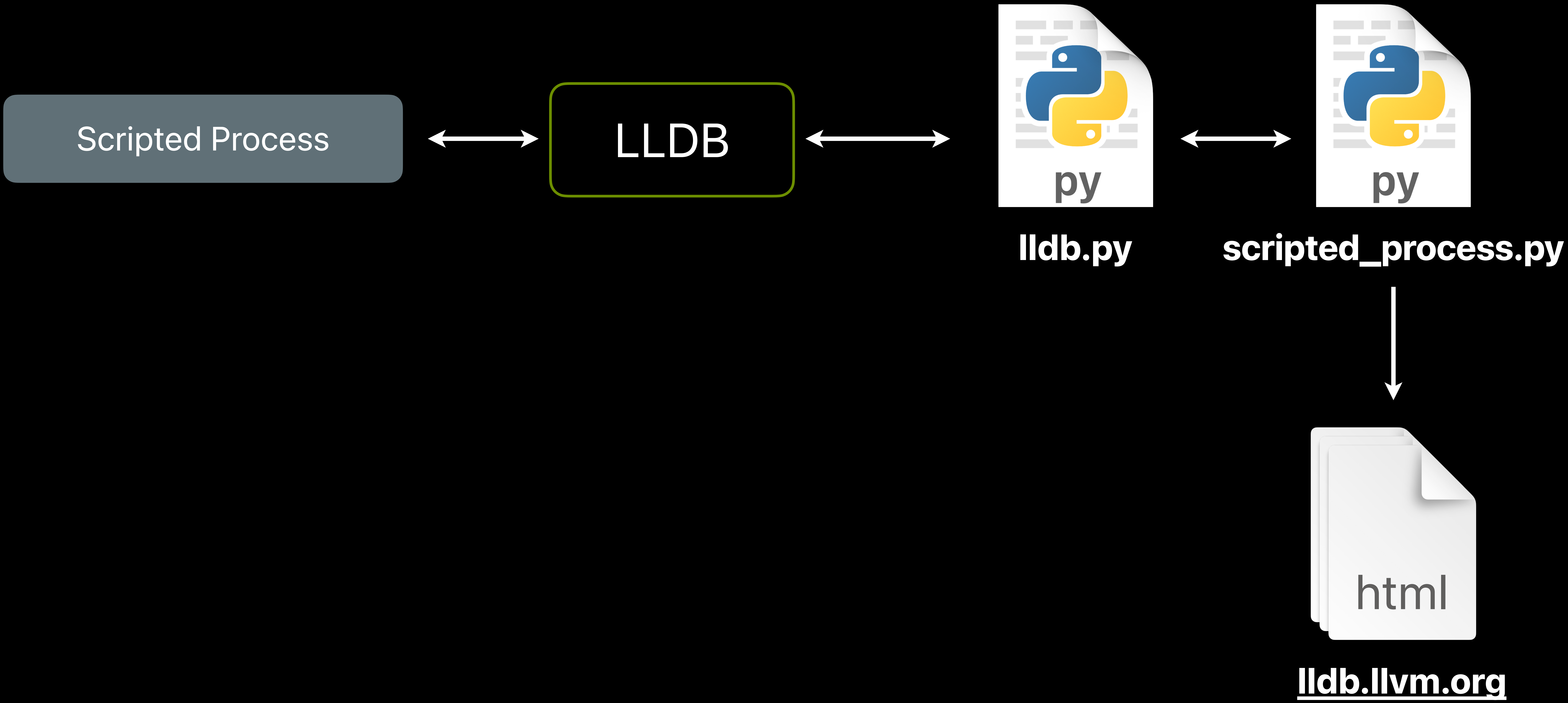
ATTRIBUTES SUMMARY

`capabilities`	
`loaded_images`	
`memory_regions`	
`metadata`	
`threads`	

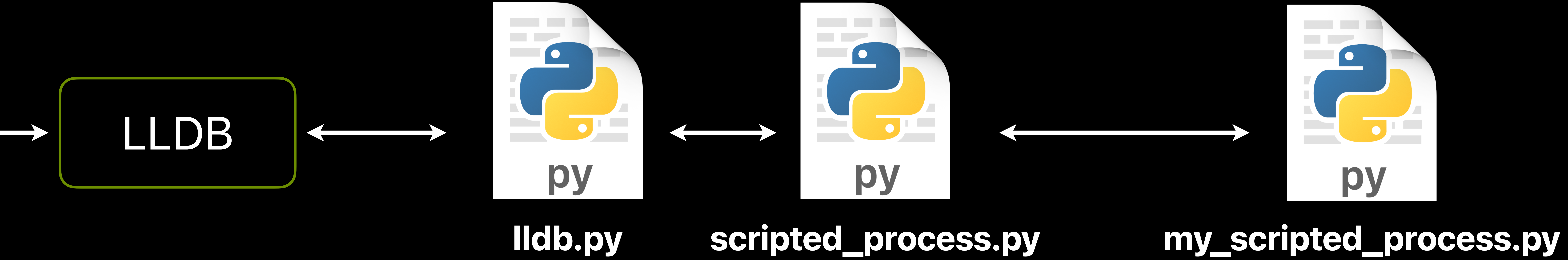
METHODS SUMMARY

`attach`(attach_info)	Simulate the scripted process attach.
`create_breakpoint`(addr, error)	Create a breakpoint in the scripted process from an address.
`get_capabilities`()	Get a dictionary containing the process capabilities.
`get_loaded_images`()	Get the list of loaded images for the scripted process.
`get_memory_region_containing_address`(addr)	Get the memory region for the scripted process, containing a
`get_process_id`()	Get the scripted process identifier.
`get_process_metadata`()	Get some metadata for the scripted process.

Scripted Process 101

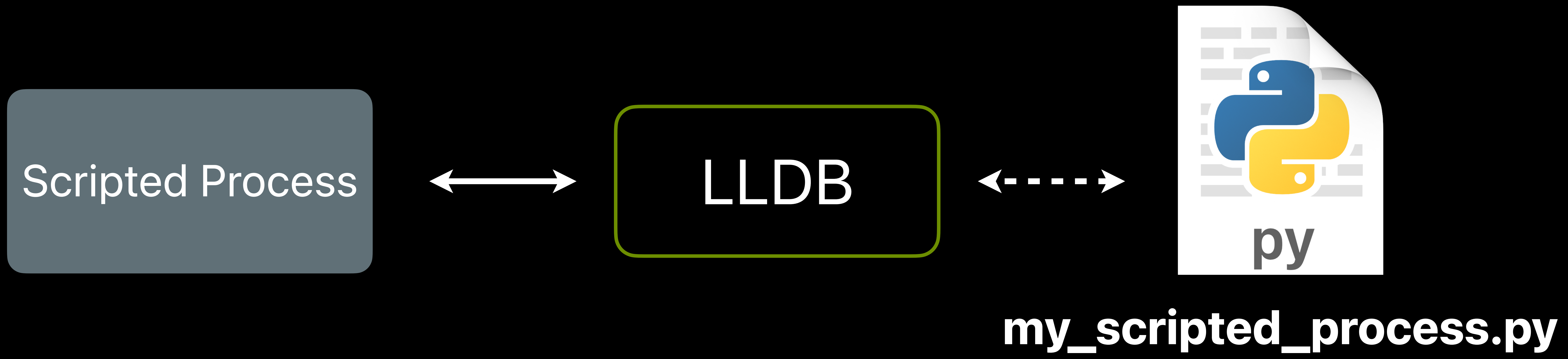


User scripted process implementation

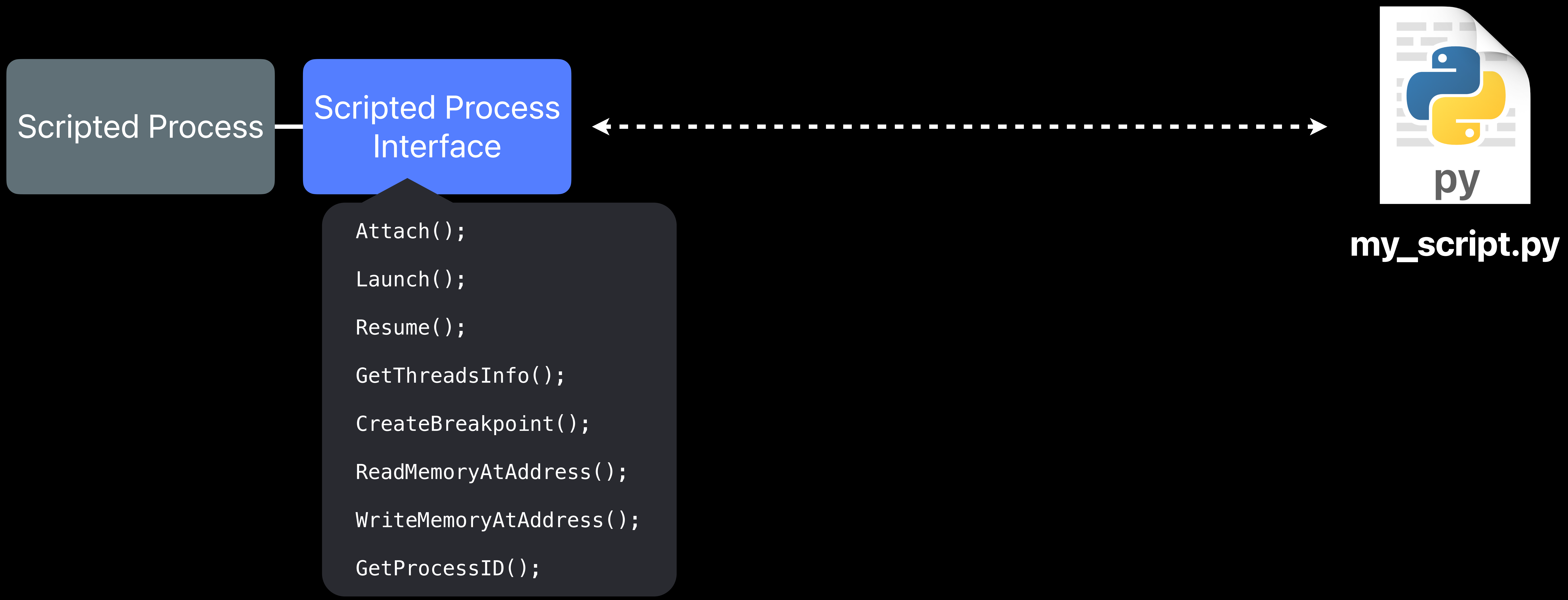


```
import lldb
from lldb.plugins.scripted_process import ScriptedProcess
from lldb.plugins.scripted_process import ScriptedThread

class MyScriptedProcess(ScriptedProcess):

    def __init__(self, target, args):
        super().__init__(target, args)
```

Scripting Interfaces Architecture

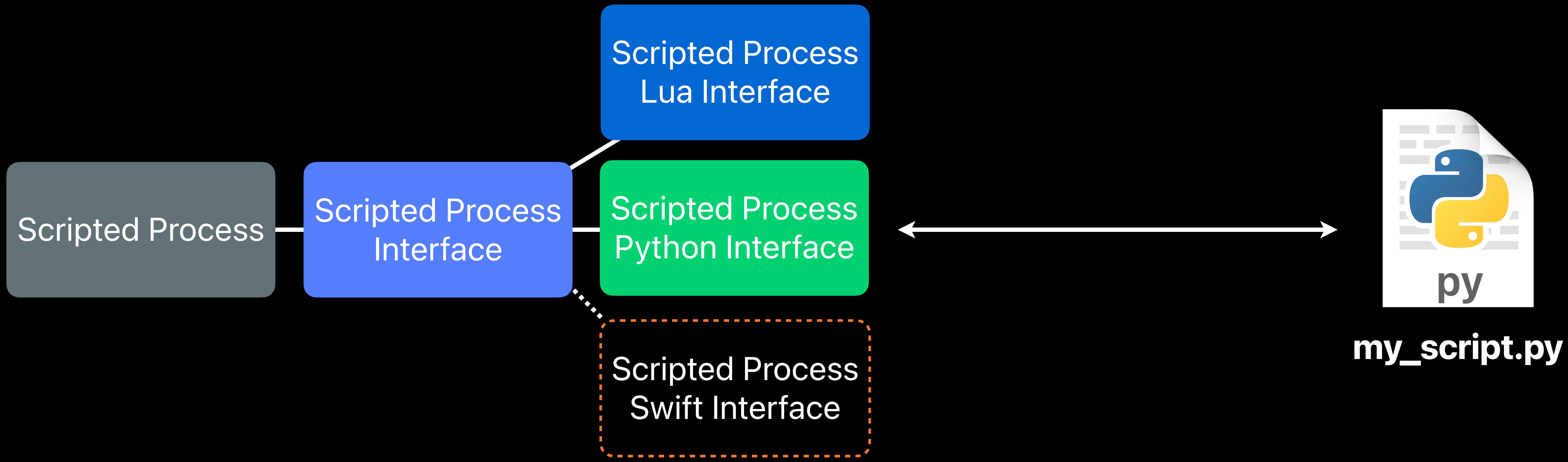


Scripting Interfaces Architecture

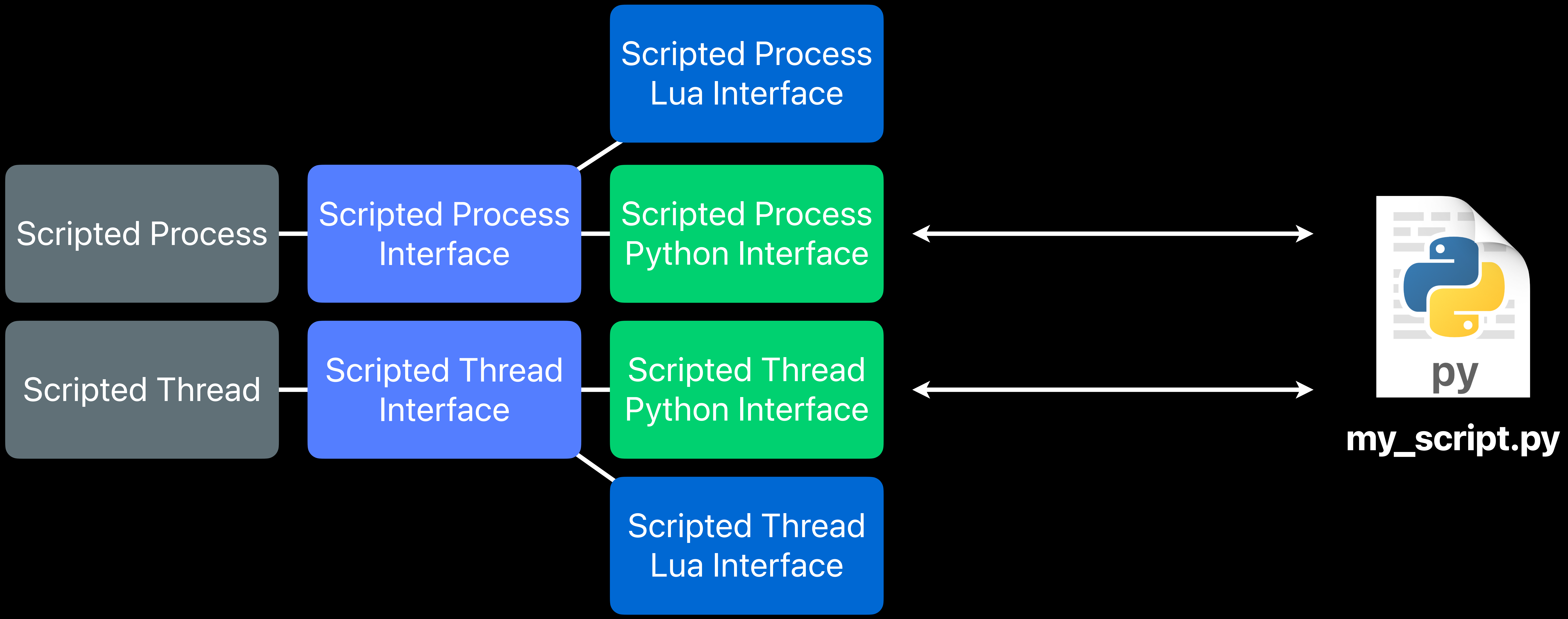


```
Attach();
Launch();
Resume();
GetThreadsInfo();
CreateBreakpoint();
ReadMemoryAtAddress();
WriteMemoryAtAddress();
GetProcessID();
```

Scripting Interfaces Architecture

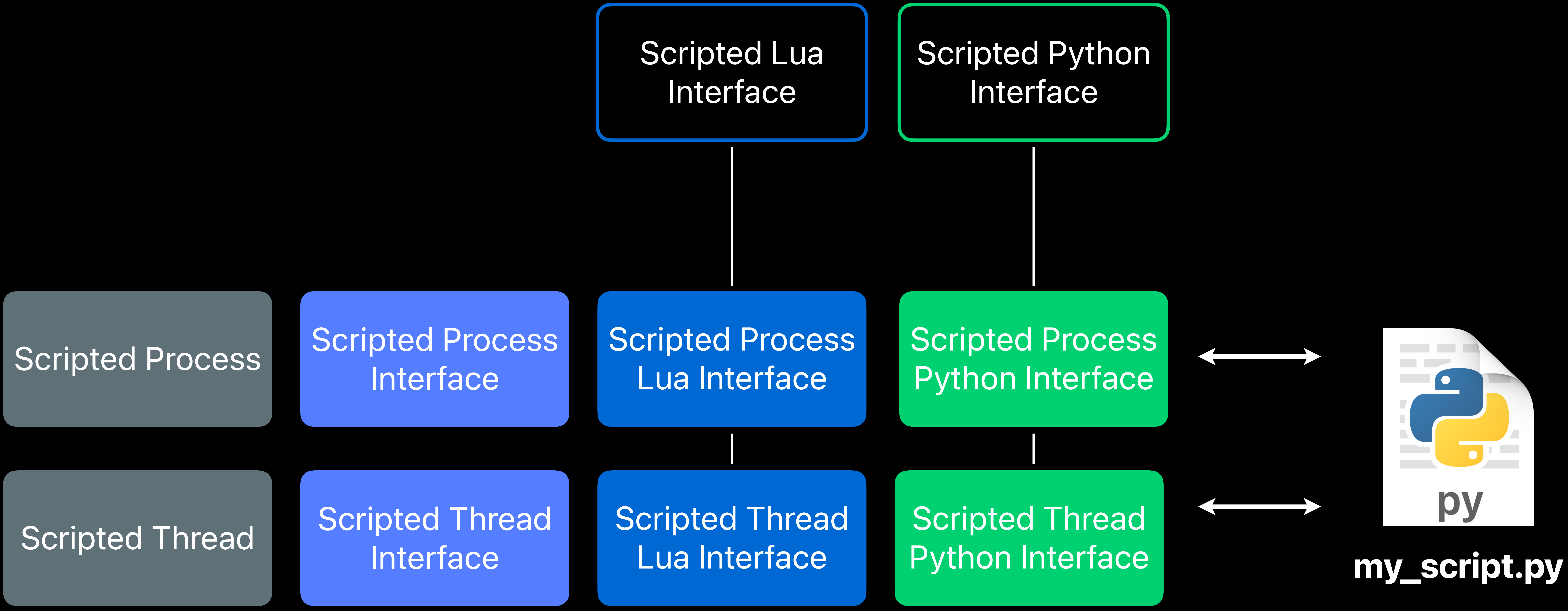

Scripted Process
Scripted Process Interface
Scripted Process Lua Interface
Scripted Process Python Interface
Scripted Process Swift Interface
py
my_script.py

Scripting Interfaces Architecture



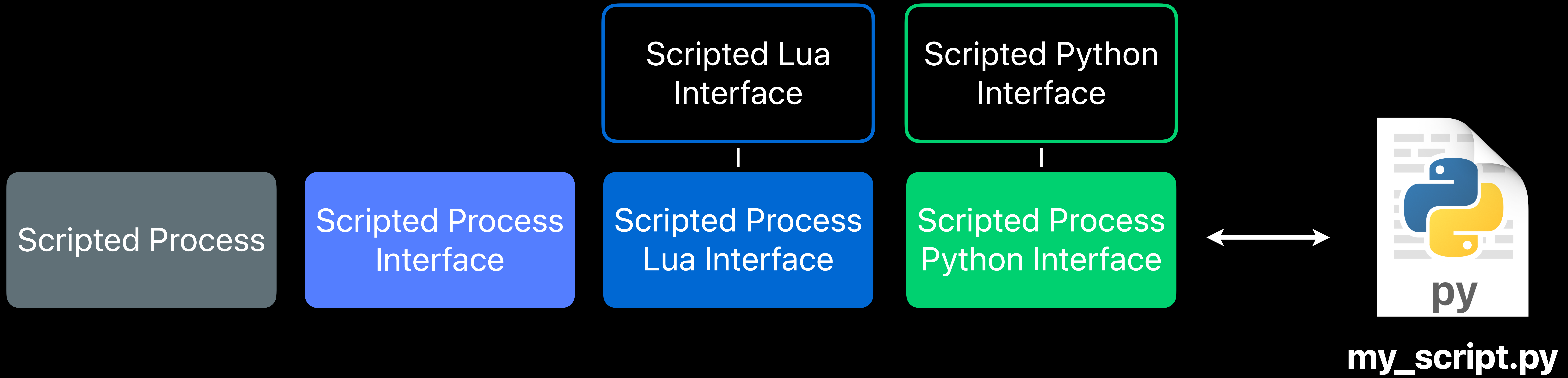
Scripted Process Lua Interface
Scripted Process
Scripted Process Interface
Scripted Process Python Interface
Scripted Thread
Scripted Thread Interface
Scripted Thread Python Interface
Scripted Thread Lua Interface
py
my_script.py

Scripting Interfaces Architecture



Scripted Lua Interface
Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Lua Interface
Scripted Process Python Interface
Scripted Thread
Scripted Thread Interface
Scripted Thread Lua Interface
Scripted Thread Python Interface
py
my_script.py

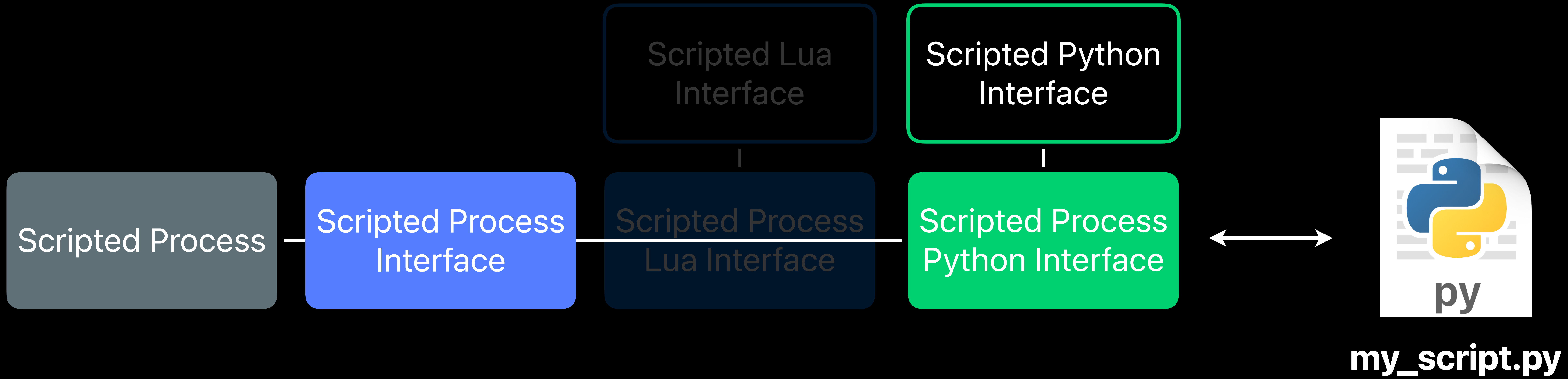
Scripting Python Interface Usage


Scripted Lua Interface
Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Lua Interface
Scripted Process Python Interface
py
my_script.py

1 Import & register the python class

```
(lldb) command script import /tmp/my_scripted_process.py

(lldb) process launch --script-class my_scripted_process.MyScriptedProcess
```

Scripting Python Interface Usage

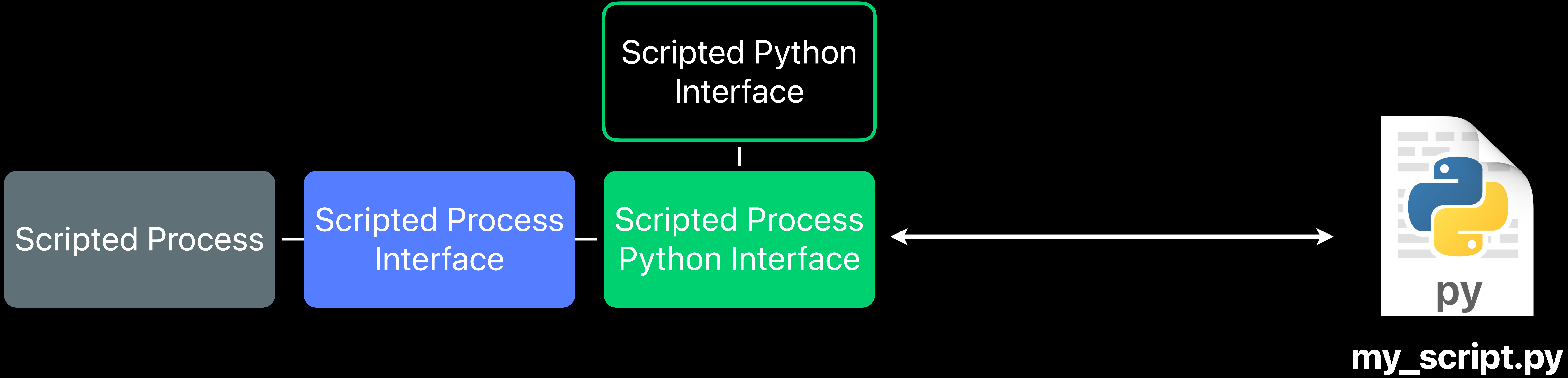


Scripted Lua Interface
Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Lua Interface
Scripted Process Python Interface
py
my_script.py

1. Import & register the python class

2. Create the interfaces

Scripting Python Interface Usage



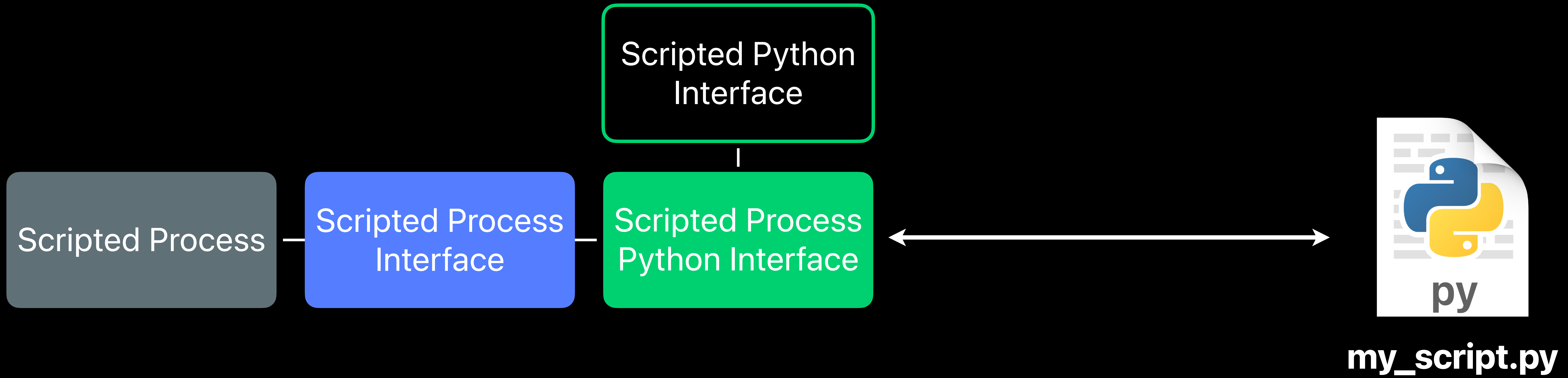
Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Python Interface
py
my_script.py

1. Import & register the python class
2. Create the interfaces
3. Instantiate the script object

“Classes are callable. […] The arguments of the call are passed […] to __init__() to initialize the new instance.”

The Python Documentation website, Data Model, 3.2.8.8. Classes

Scripting Python Interface Usage

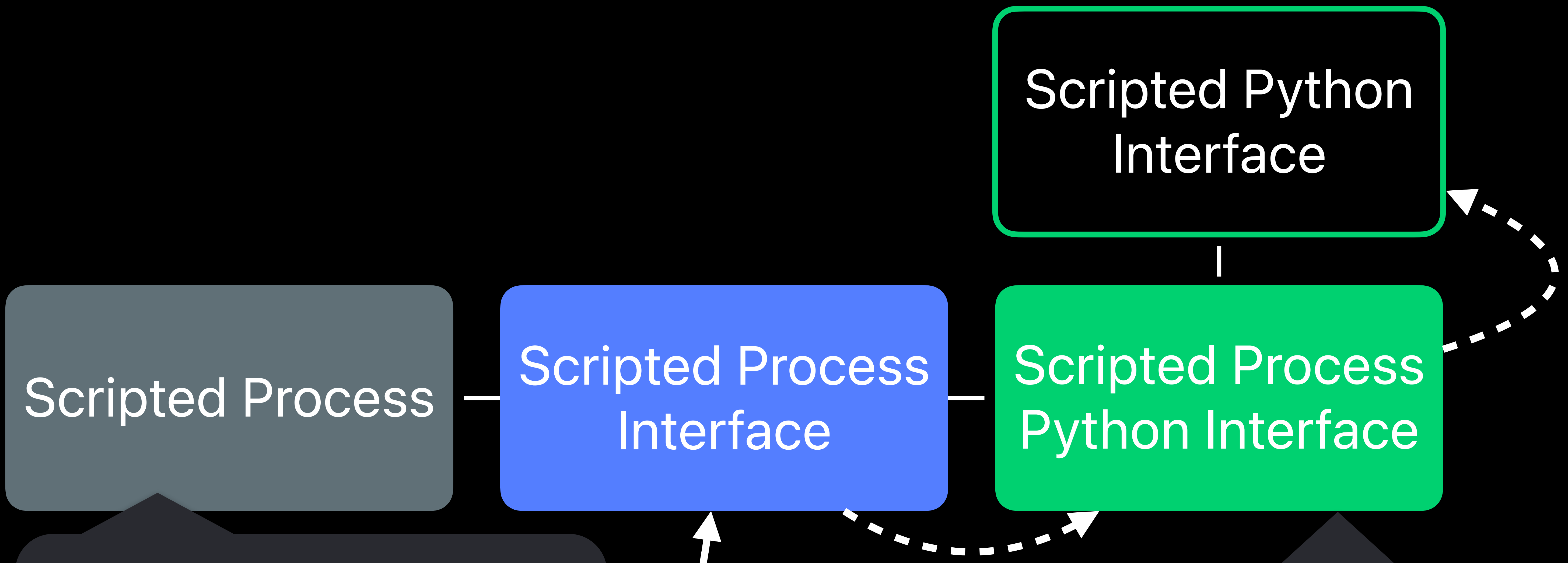

Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Python Interface
py
my_script.py

1. Import & register the python class

2. Create the interfaces

3. Call the script methods

Scripting Python Interface Usage

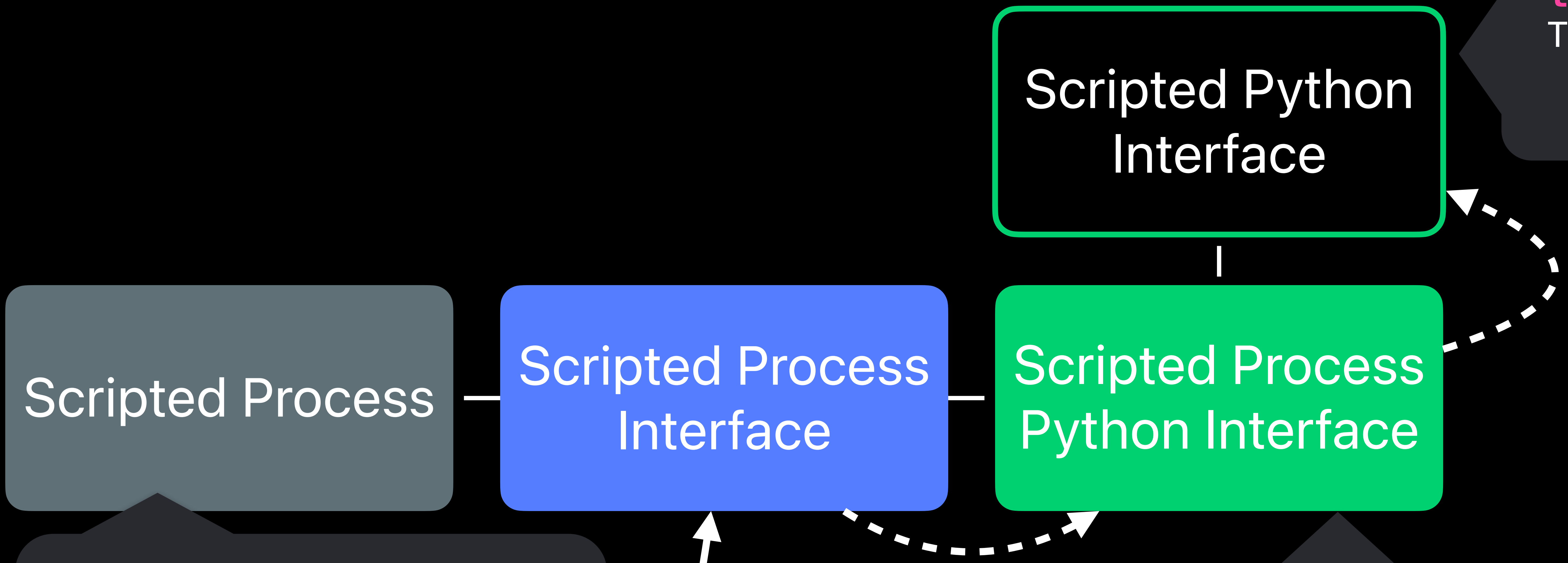

Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Python Interface

- Attach()
- Launch()
- Resume()
- GetThreadsInfo()
- CreateBreakpoint()
- ReadMemoryAtAddress()
- WriteMemoryAtAddress()
- GetProcessID()

```
Data ReadMemoryAtAddress(size_t addr,
                             size_t size,
                               bool &error) {
  Data data = Dispatch<Data>("read_memory_at_address",
                              error, addr, size);

  if (error)
    return {};

  return data;
}
```

my_script.py

ScriptedPythonInterface::Dispatch


Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Python Interface

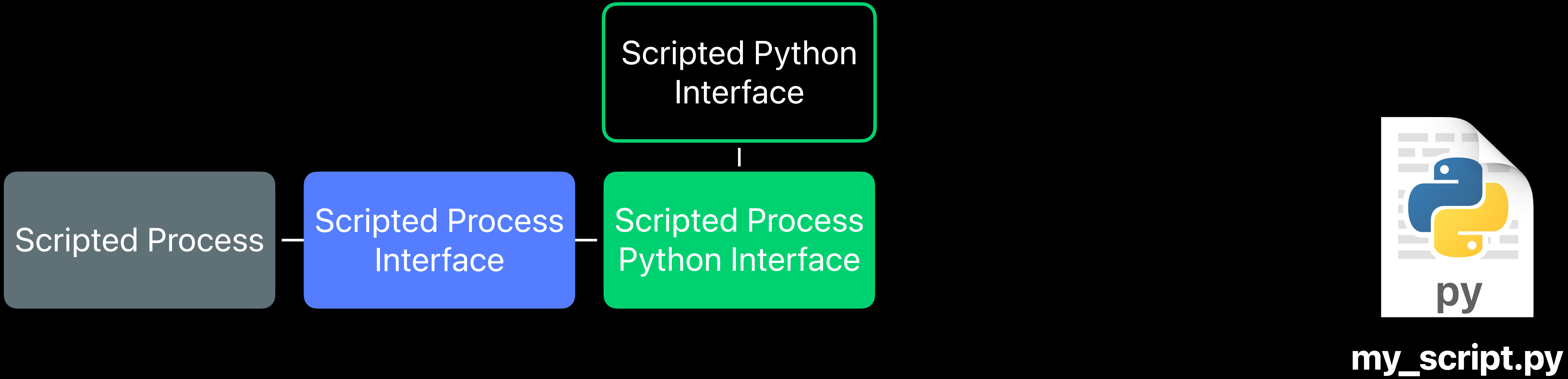
```
template <typename T, typename... Args>
T Dispatch(llvm::StringRef method_name,
                  bool &error,
                        Args &&...args);
```

```
Attach()
Launch()
Resume()
GetThreadsInfo()
CreateBreakpoint()
ReadMemoryAtAddress()
WriteMemoryAtAddress()
GetProcessID()
```

```
Data ReadMemoryAtAddress(size_t addr,
                              size_t size,
                                  bool &error) {
  Data data = Dispatch<Data>("read_memory_at_address",
                                  error, addr, size);

  if (error)
    return {};

  return data;
}
```

my_script.py

ScriptedPythonInterface::Dispatch



Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Python Interface
py
my_script.py

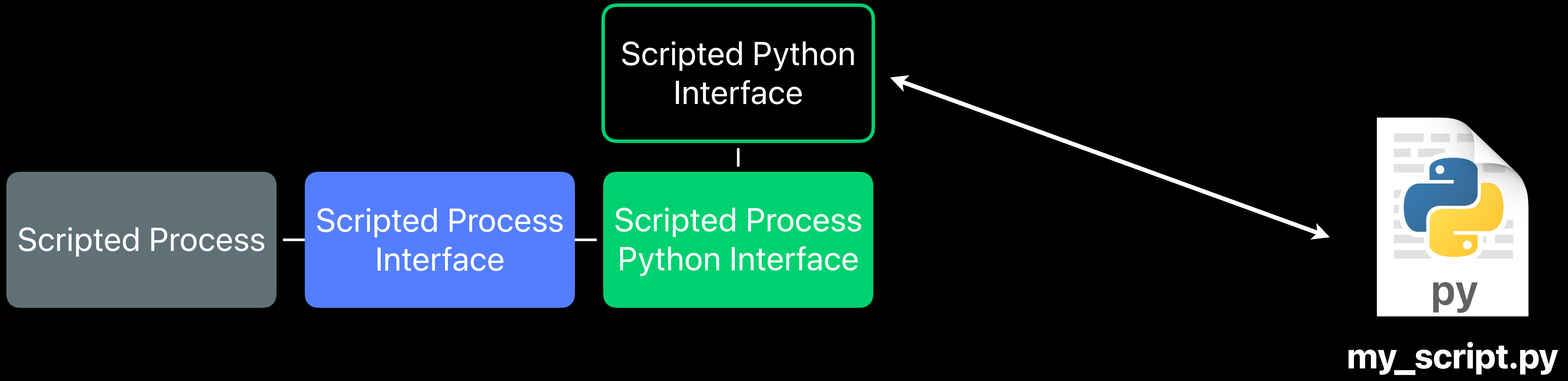
1 Import & register the python class

2 Create the interfaces

3 Call the script methods

A Resolve method object

ScriptedPythonInterface::Dispatch

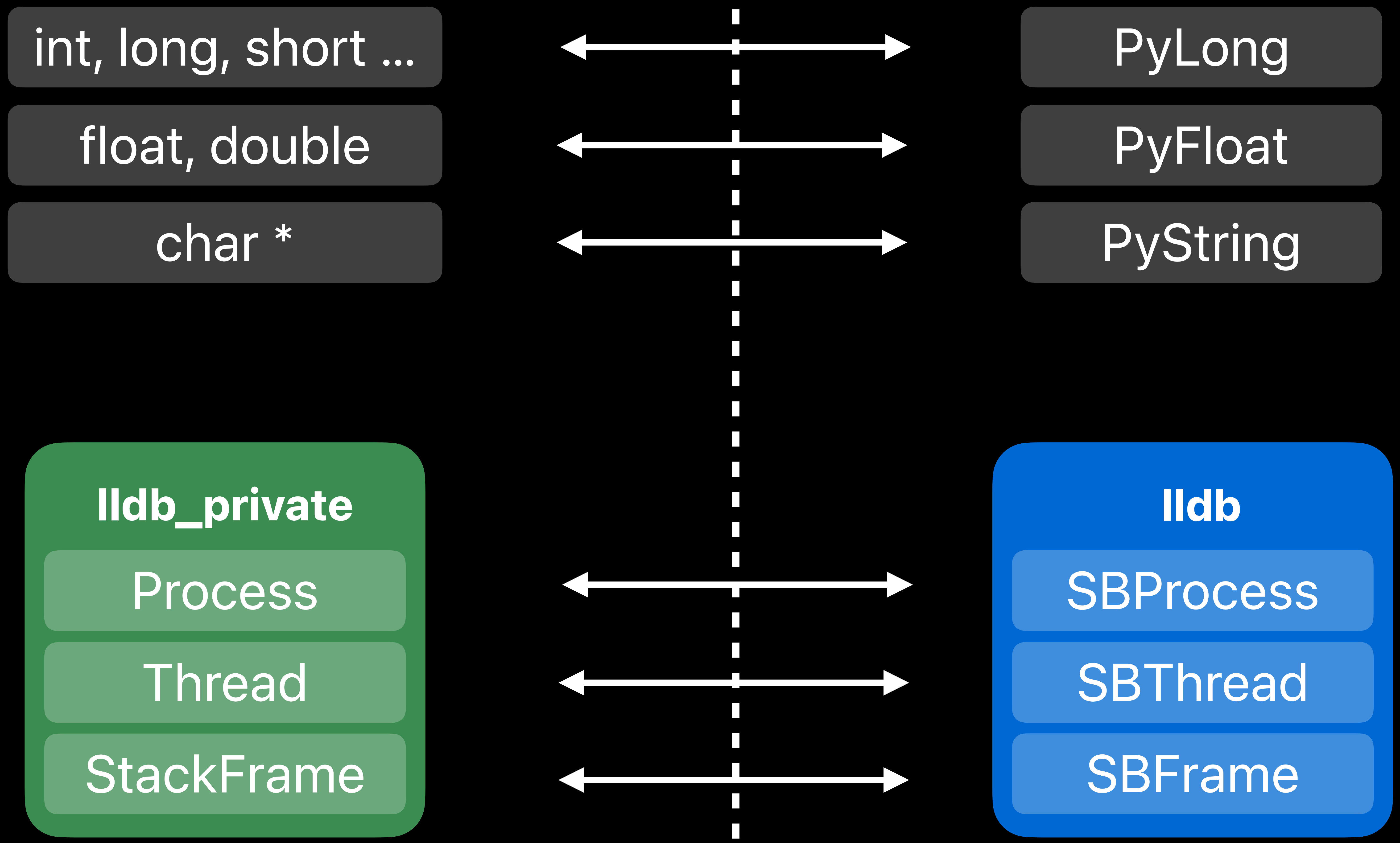


Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Python Interface
py
my_script.py

1. Import & register the python class
2. Create the interfaces
3. Call the script methods

A. Resolve method object

B. Transform arguments & make call



int, long, short … ↔ PyLong

float, double ↔ PyFloat

char * ↔ PyString

lldb_private

- Process
- Thread
- StackFrame

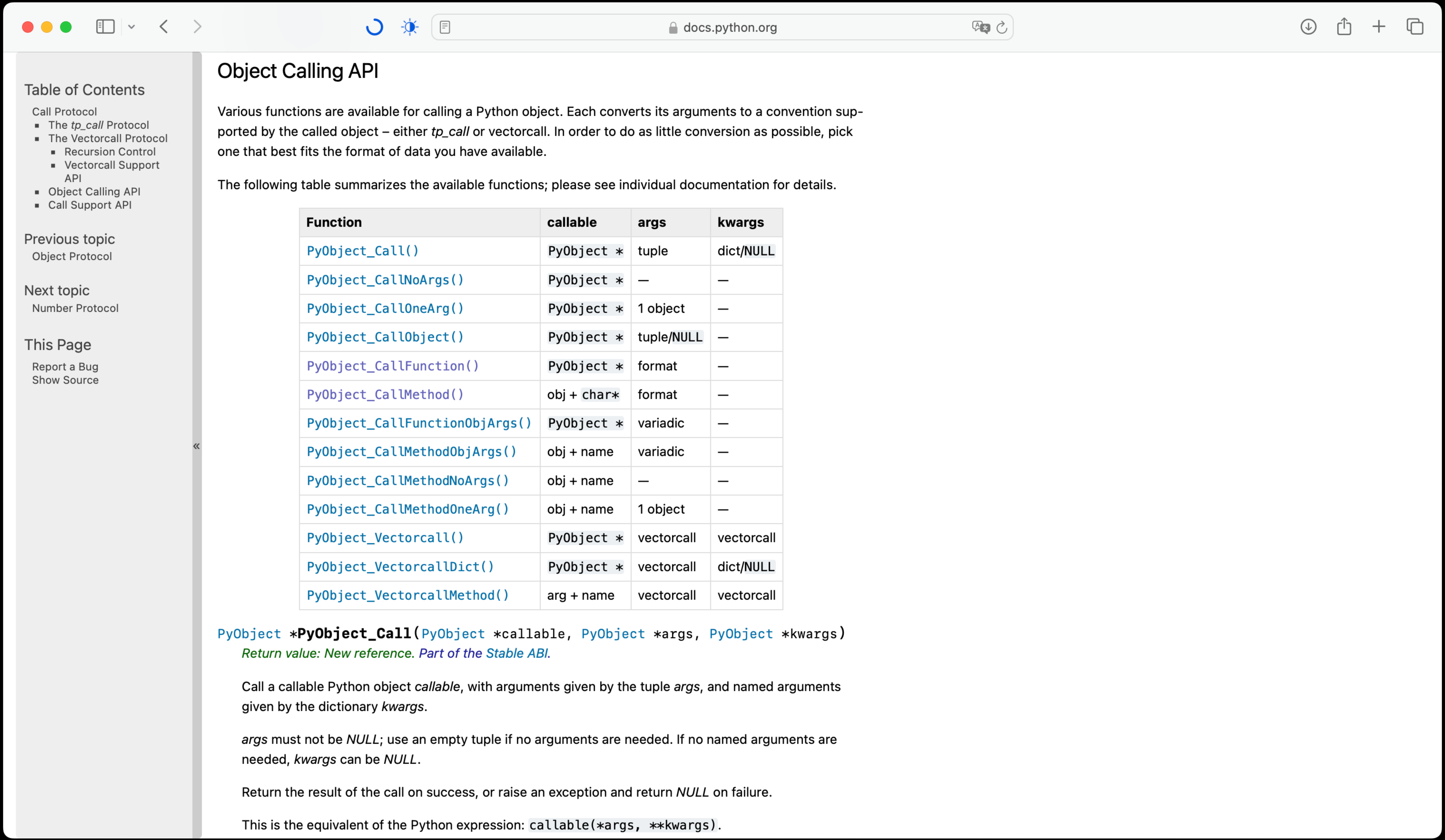
lldb

- SBProcess
- SBThread
- SBFrame

Process ↔ SBProcess

Thread ↔ SBThread

StackFrame ↔ SBFrame



Object Calling API

Various functions are available for calling a Python object. Each converts its arguments to a convention supported by the called object – either *tp_call* or vectorcall. In order to do as little conversion as possible, pick one that best fits the format of data you have available.

The following table summarizes the available functions; please see individual documentation for details.

Function	callable	args	kwargs
`PyObject_Call()`	`PyObject *`	tuple	dict/`NULL`
`PyObject_CallNoArgs()`	`PyObject *`	—	—
`PyObject_CallOneArg()`	`PyObject *`	1 object	—
`PyObject_CallObject()`	`PyObject *`	tuple/`NULL`	—
`PyObject_CallFunction()`	`PyObject *`	format	—
`PyObject_CallMethod()`	obj + `char*`	format	—
`PyObject_CallFunctionObjArgs()`	`PyObject *`	variadic	—
`PyObject_CallMethodObjArgs()`	obj + name	variadic	—
`PyObject_CallMethodNoArgs()`	obj + name	—	—
`PyObject_CallMethodOneArg()`	obj + name	1 object	—
`PyObject_Vectorcall()`	`PyObject *`	vectorcall	vectorcall
`PyObject_VectorcallDict()`	`PyObject *`	vectorcall	dict/`NULL`
`PyObject_VectorcallMethod()`	arg + name	vectorcall	vectorcall

```
PyObject *PyObject_Call(PyObject *callable, PyObject *args, PyObject *kwargs)
```

Return value: New reference. Part of the Stable ABI.

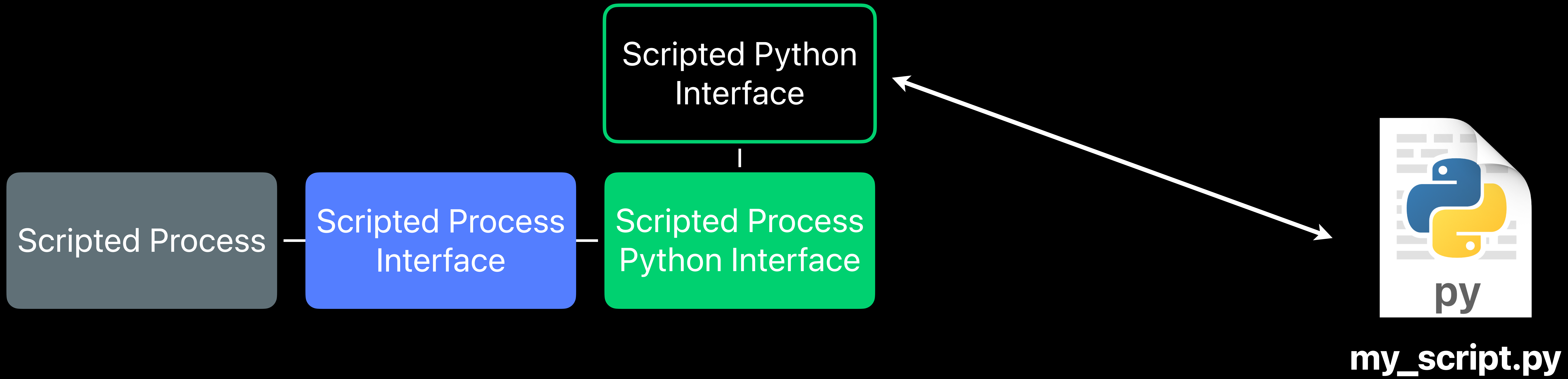
Call a callable Python object *callable*, with arguments given by the tuple *args*, and named arguments given by the dictionary *kwargs*.

args must not be *NULL*; use an empty tuple if no arguments are needed. If no named arguments are needed, *kwargs* can be *NULL*.

Return the result of the call on success, or raise an exception and return *NULL* on failure.

This is the equivalent of the Python expression: `callable(*args, **kwargs)`.

ScriptedPythonInterface::Dispatch


Scripted Python Interface
Scripted Process
Scripted Process Interface
Scripted Process Python Interface
py
my_script.py

1. Import & register the python class
2. Create the interfaces
3. Call the script methods

A. Resolve method object
B. Transform arguments & make call
C. Reverse transform arguments & return type

Conclusion

Conclusion

Reduced boilerplate code with scripting extensions base class

Conclusion

Reduced boilerplate code with scripting extensions base class

Used the base class to keep documentation up-to-date

Conclusion

Reduced boilerplate code with scripting extensions base class

Used the base class to keep documentation up-to-date

Built a unified, robust and generic infrastructure to interface with scripting extensions

Conclusion

Reduced boilerplate code with scripting extensions base class

Used the base class to keep documentation up-to-date

Built a unified, robust and generic infrastructure to interface with scripting extensions

Still more work to come …

Scripting Templates

```
(lldb) scripting template list
Available scripted extensions:
  Name: ScriptedProcessPythonInterface
  Language: Python
  Description: Mock process state
  Command Interpreter Usages:
    process attach -C <script-name> [-k key -v value ...]
    process launch -C <script-name> [-k key -v value ...]
  API Usages:
    SBAttachInfo.SetScriptedProcessClassName
    SBAttachInfo.SetScriptedProcessDictionary
    SBTarget.Attach
    SBLaunchInfo.SetScriptedProcessClassName
    SBLaunchInfo.SetScriptedProcessDictionary
    SBTarget.Launch
```

Call to action 📢

Data Formatters

Custom Commands

~~Scripted Thread Plans~~

Watchpoint Commands

~~Target Stop Hooks~~

~~Scripted Processes~~

Breakpoint Commands

~~Operating System Plugins~~

Q & A

Simplifying, Consolidating & Documenting LLDB's Scripting Functionalities

Ismail Bennani

EuroLLVM 2024 | Apple Inc | April 11th 2024