Generators

Introduction to the coroutines.

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Agenda

Coroutine theory - what are the coroutines?

Practical part I - using cppcoro library

Theory - promise_types

Promise_type excercise

Coroutine theory - what are the coroutines?

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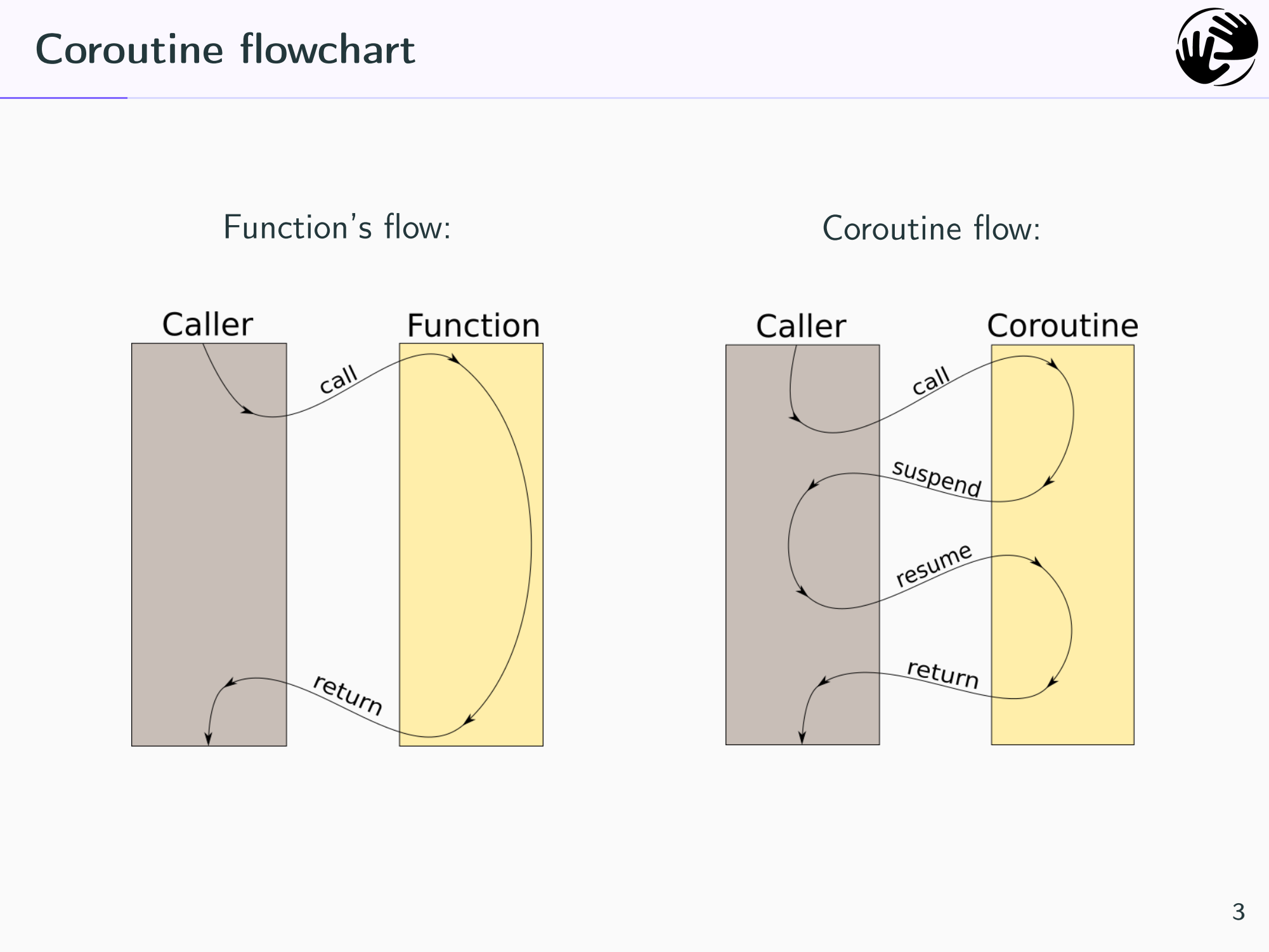
Coroutine flowchart



Function's flow:

Coroutine flow:

What are coroutines for?

Common use cases for the coroutines are:

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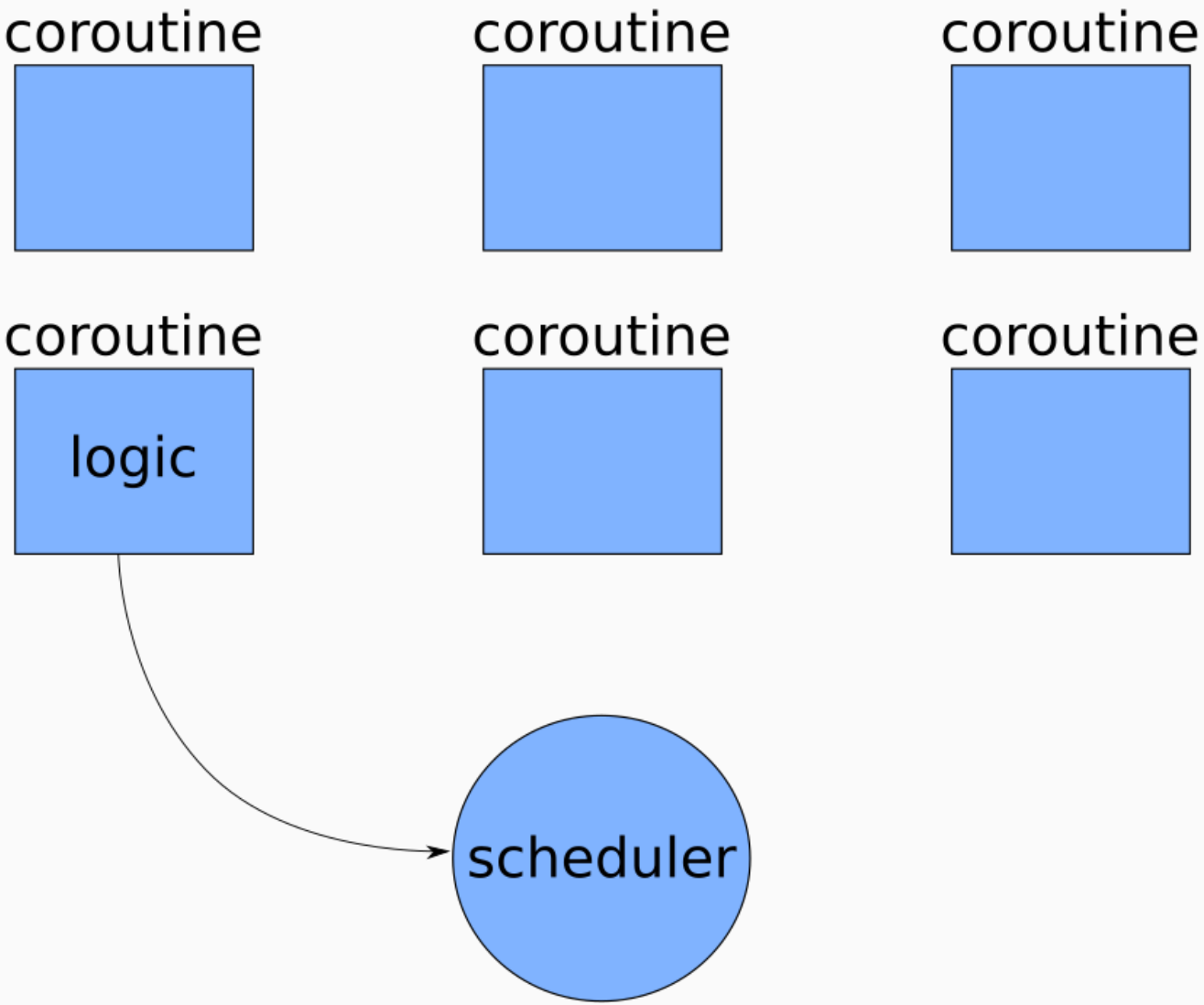
Common use cases for the coroutines are:

- lazy computation of the sequences (generators)
- possibility of introducing asynchronous code with one thread

Example coroutines usage



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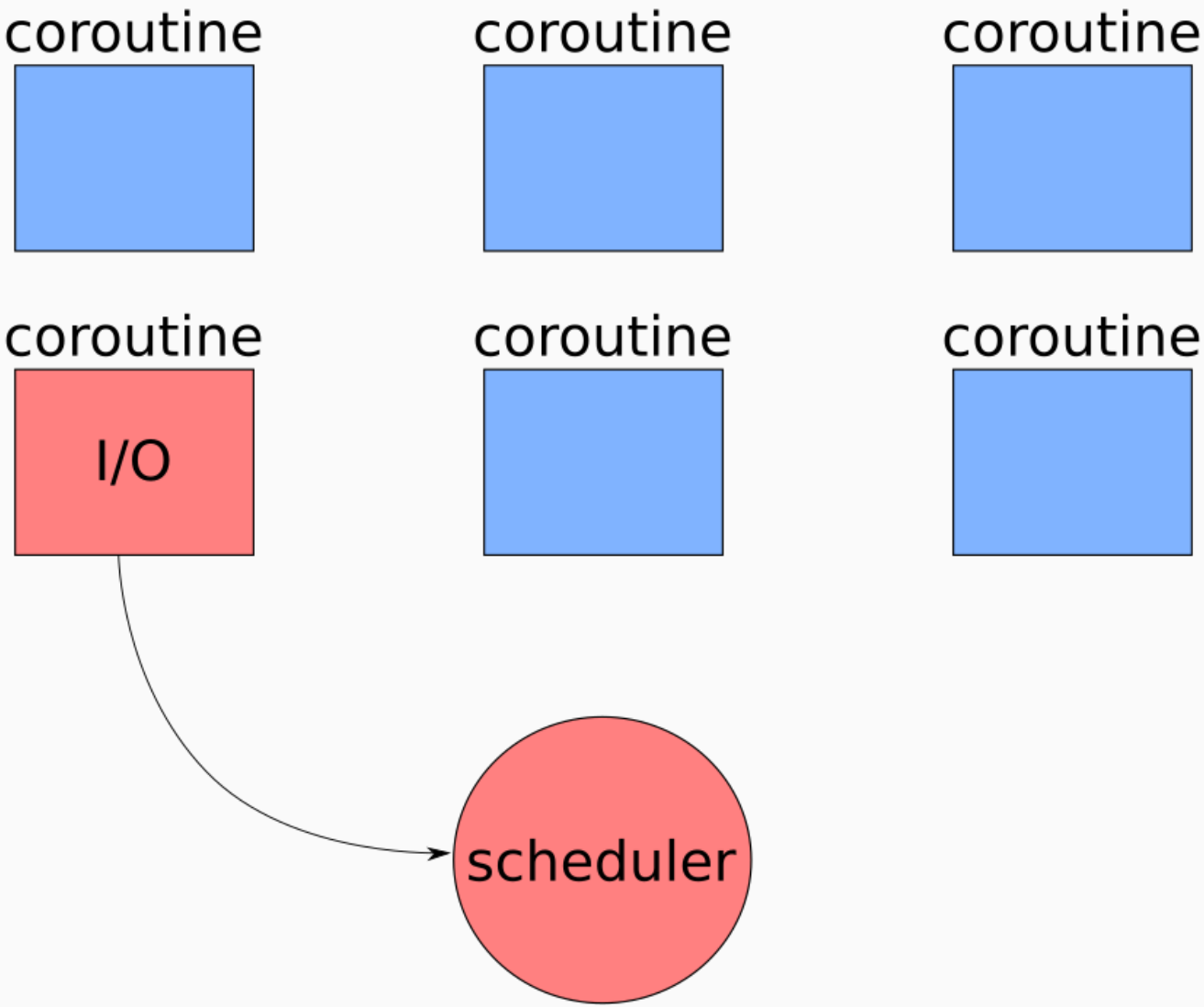

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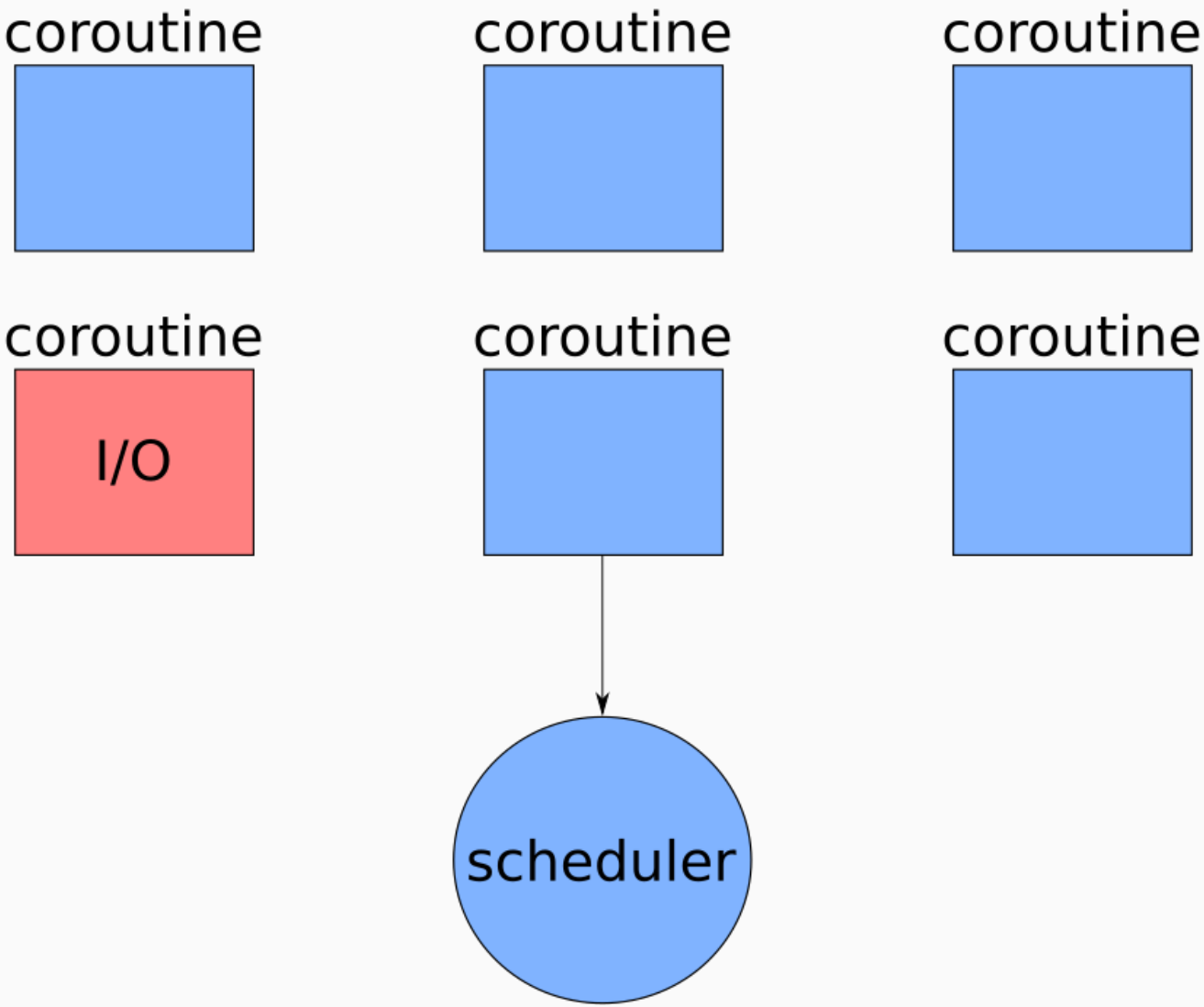

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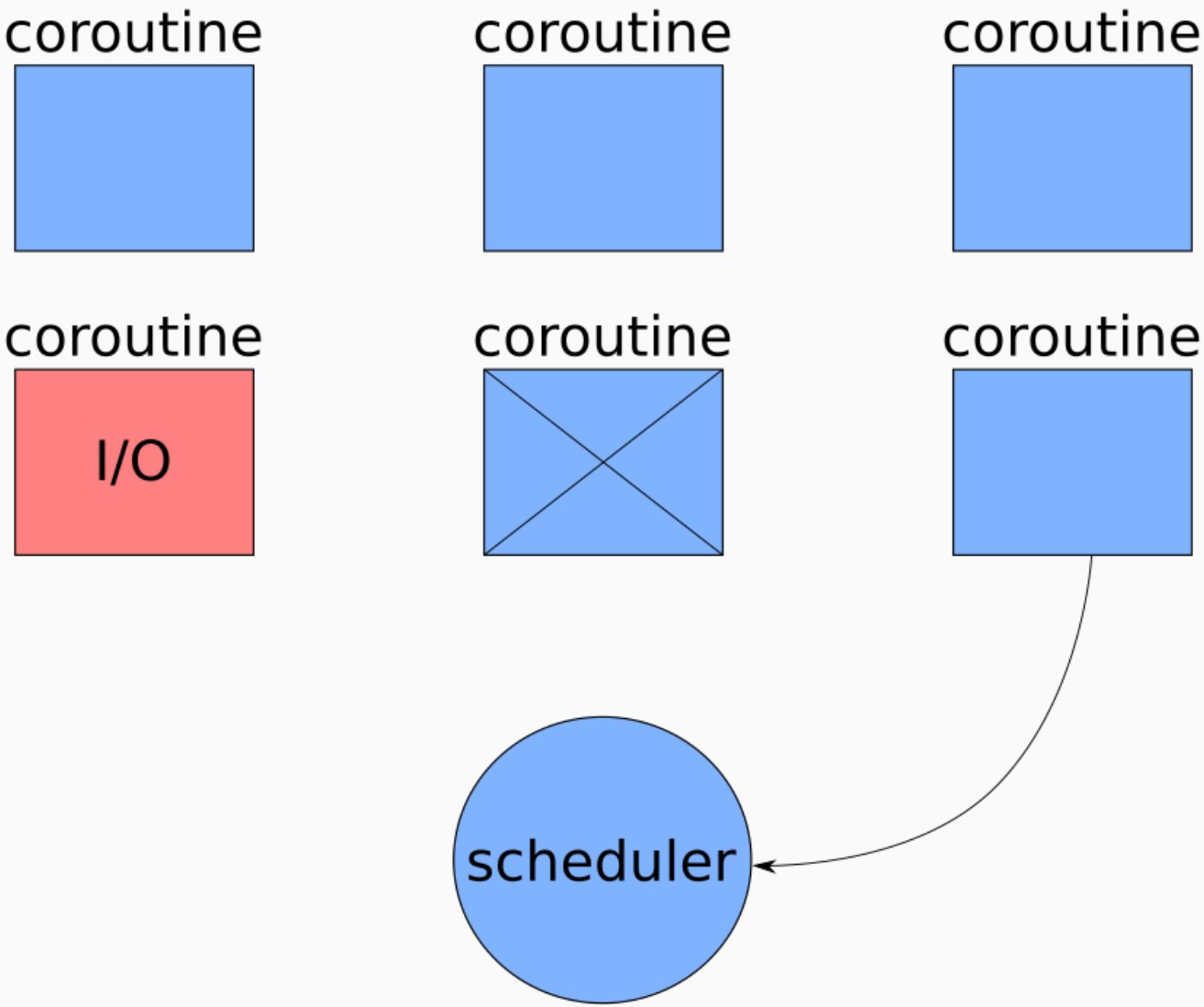

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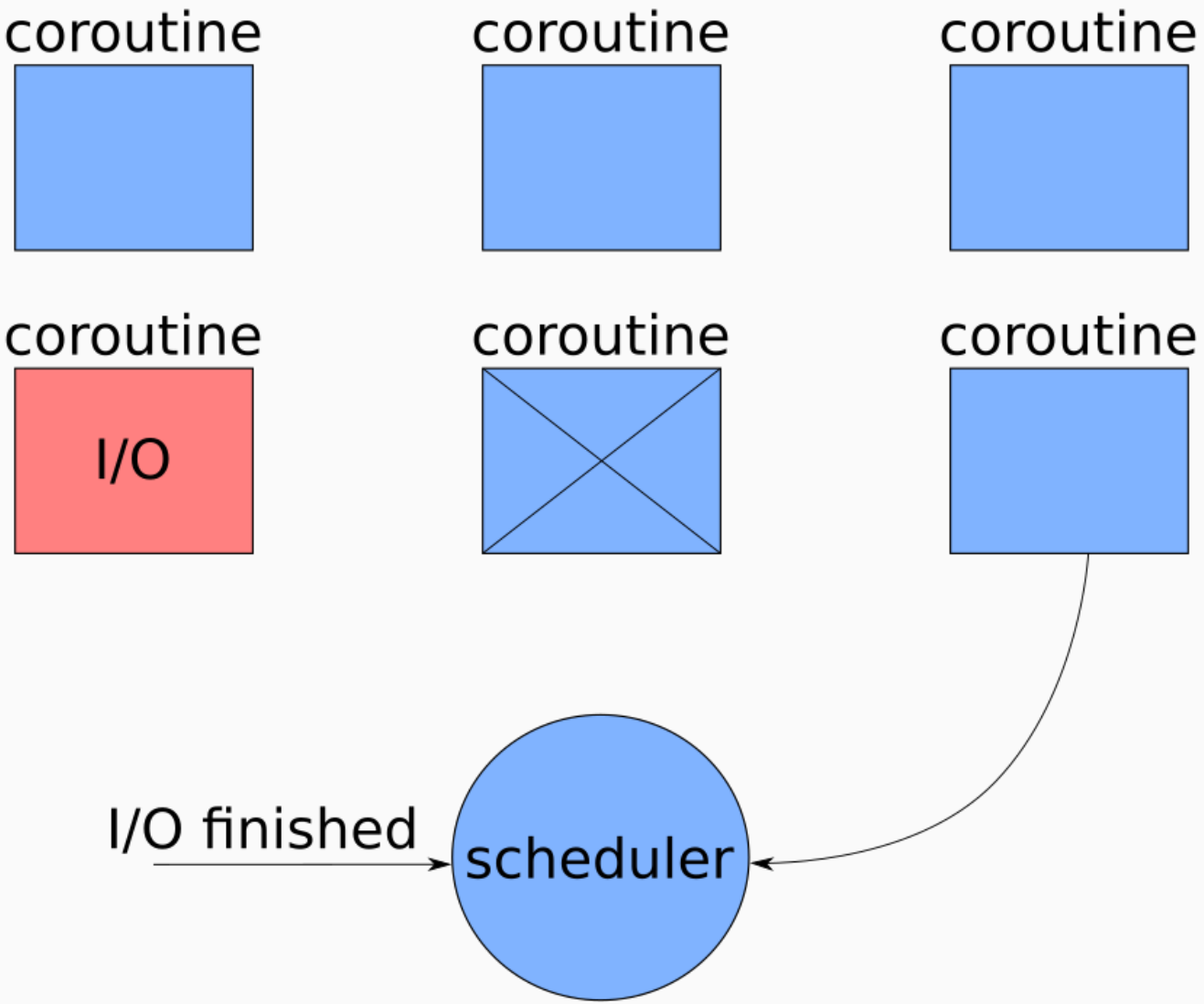

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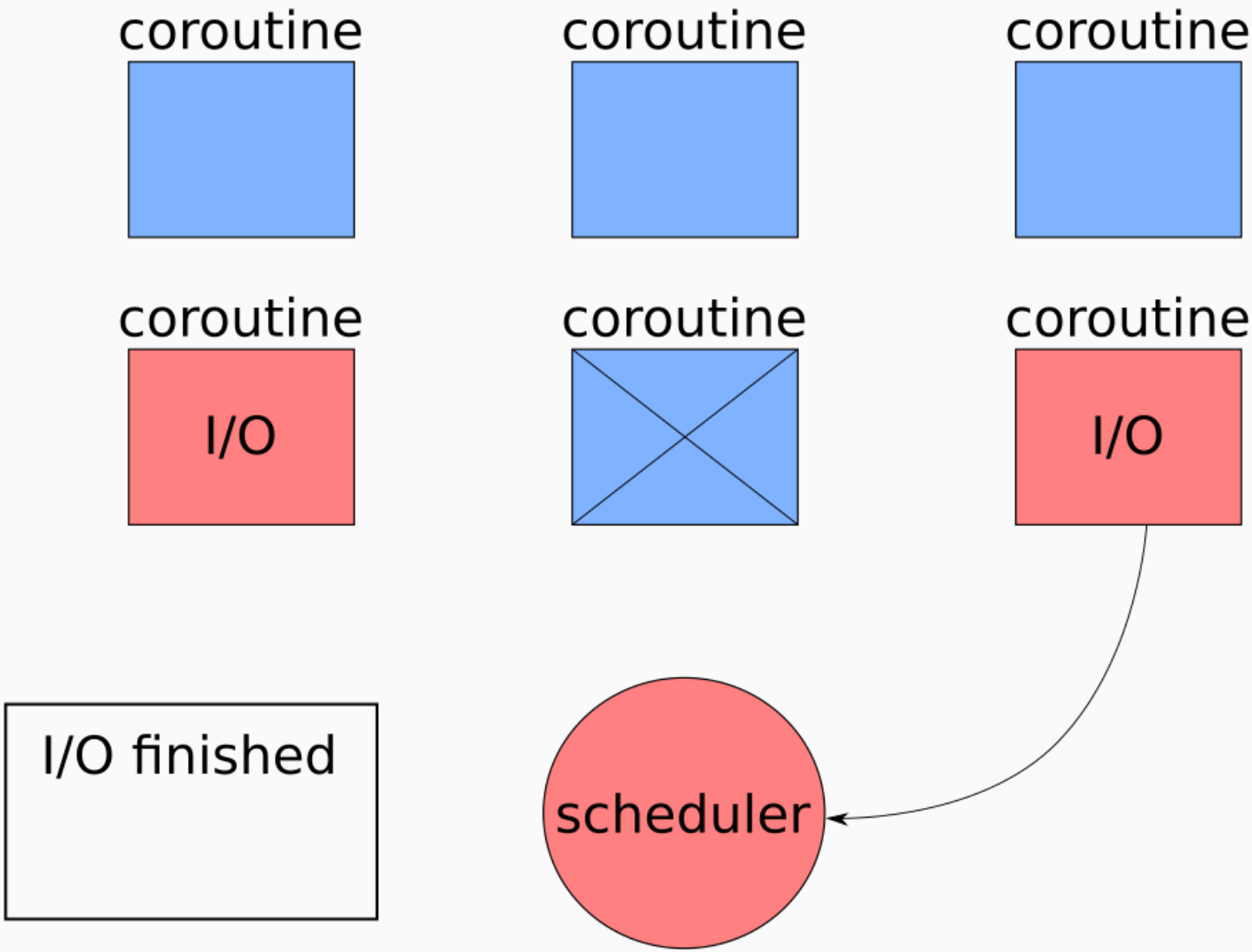

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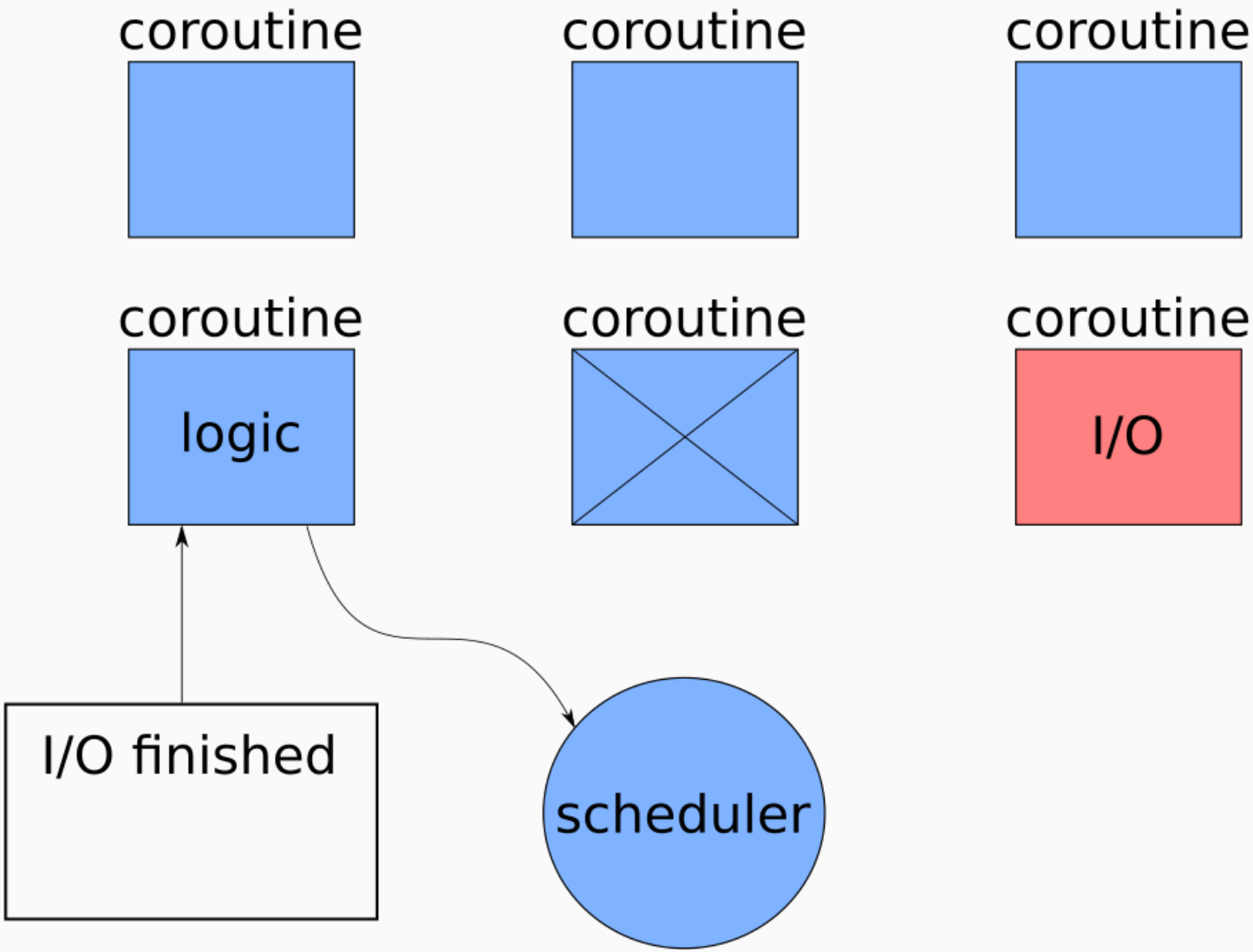

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Imagine you want to suspend a function:

```
int foo(){
  int a = 1;

  co_yield a++;
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}
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issues:

- on suspension variables needs to be saved somewhere
- coroutine needs to know where it suspended last time

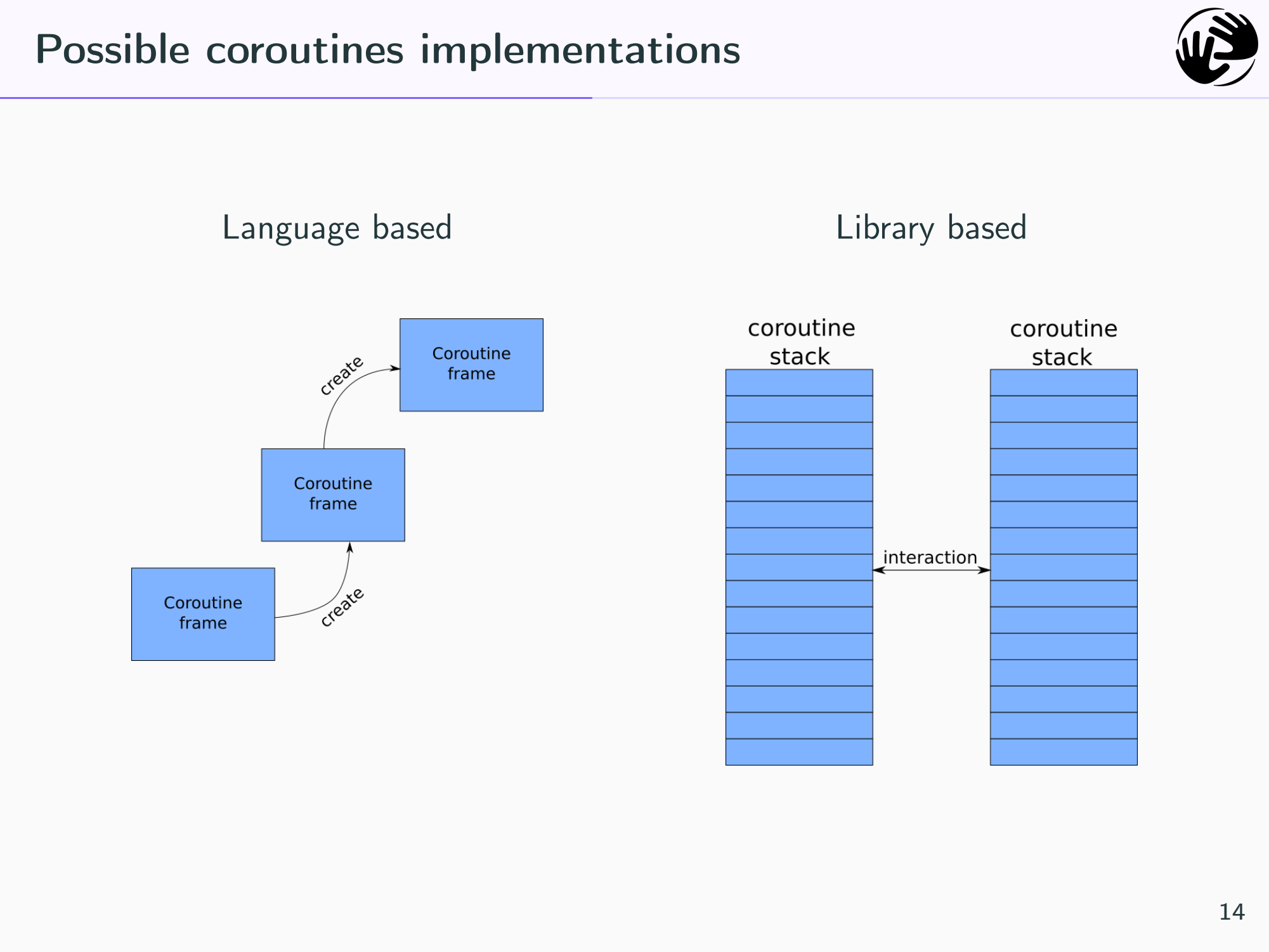
How to achieve that?

```
struct foo_state{
  int a=1;
  int recent_point=0;
};

int foo(foo_state* state){
  if(state.recent_point == 0) goto recent_point_0;
  if(state.recent_point == 1) goto recent_point_1;
  if(state.recent_point == 2) goto recent_point_2;

  recent_point_0:
  return state.a++;
  recent_point_1:
  return state.a++;
  recent_point_2:
  return state.a++;
}
```

Possible coroutines implementations



Language based

Library based

Closer look into Boost.Fiber

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built-in coroutines

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built-in coroutines

- Need to allocate the frame for the Coroutine
- Can be suspended only from the top level functions
- Minimal memory allocation
- Easy to optimize by compilers

Coroutine declarations

Same as functions

```
// returned-type   name       arguments
//|-------------| |-------| |--------------|
   generator<int> fibonacci (int from_value);
```

Whether the function is a coroutine depends on it's definition.

3 new keywords

`co_return`
: Returning (or not) value and finishing the coroutine

`co_yield`
: Returning intermediate value from the coroutine

`co_await`
: Awaiting completion of the "task"

Practical part I - using cppcoro library

generators - Fibonacci sequence

```cpp
cppcoro::generator<unsigned long long> fibonacci_gen() {
  std::array arr{0ull, 1ull};
  unsigned long long result=0;

  do {
    co_yield result;
    arr[0] = arr[1];
    arr[1] = result;
    result = arr[0] + arr[1];
  } while (result >= arr[1]);
}
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other (for now only msvc)

- mutexes
- file I/O operations
- networking operations

Theory - promise_types

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- promise_type is strongly connected with coroutine's returned type
  - it can be a member of the returned type
    `returned_type::promise_type`
  - it can be defined as
    `std::coroutine_traits<returned_type>::promise_type`

coroutine body

Each time we write coroutine, compiler modifies it's body into following form:

```
{
  promise_type promise;
  auto&& return_object = promise.get_return_object();
  co_await promise.initial_suspend();

  try{
    //our coroutine_body
  }catch(...) {
    promise.unhandled_exception();
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promise_type extensions

We can extend the coroutine body with:

- (mandatory) support for returning void or returning value
- custom memory allocation algorithm (custom `operator new`)
- (optional) support for yielding intermediate values

co_return - support for returning from coroutine

`co_return`

Usage:

without expression:

```
co_return
```

with void expression:

```
co_return <void expression>
```

Translated to:

```
<expression>;
promise.return_void();
goto final_suspend;
```

co_return - support for returning from coroutine

`co_return`

Usage:

with non-void expression:

```
co_return <expression>
```

Translated to:

```
promise.return_value(<expression>);
goto final_suspend;
```

co_yield - support for returning intermediate values

`co_yield`

Usage:

```
co_yield <non-void expression>
```

Translated to:

```
co_await promise.
         yield_value(<expression>)
```

co_await shortly

`co_await std::experimental::suspend_always{}` -
suspends the coroutine

`co_await std::experimental::suspend_never{}` -
does nothing

Ok, ok but how do I even resume the coroutine?

The low-level interface to the type-erased coroutine is `coroutine_handle` object.

```
template<> struct coroutine_handle<void> {
  constexpr coroutine_handle() noexcept;
  constexpr coroutine_handle(nullptr_t) noexcept;
  coroutine_handle& operator=(nullptr_t) noexcept;

  constexpr void* address() const noexcept;
  constexpr static coroutine_handle from_address(void* addr);

  constexpr explicit operator bool() const noexcept;
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  void operator()() const;
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And how do I get the coroutine_handle object?

`coroutine_handles` are specialized for `promise_type`

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Promise_type excercise

promise_type excercise - generator

type for generating sequences

requirements:

- synchronous (no support for multithreading + no support for co_await).
- next method should return the value and resume the coroutine.

Thank you!

Questions?

recommended lecture:

- Lewiss Baker blog
- My blog
- "programista" magazine
- current C++ standard draft
- coroutine channel on cpplang slack

recommended videos:

- Gor Nishanov
  "C++ Coroutines: Under the covers"
- Toby Allsopp
  "Coroutines: what can't they do"
- James McNellis
  "Introduction to C++ Coroutines"