C++20 Coroutines

What's next?

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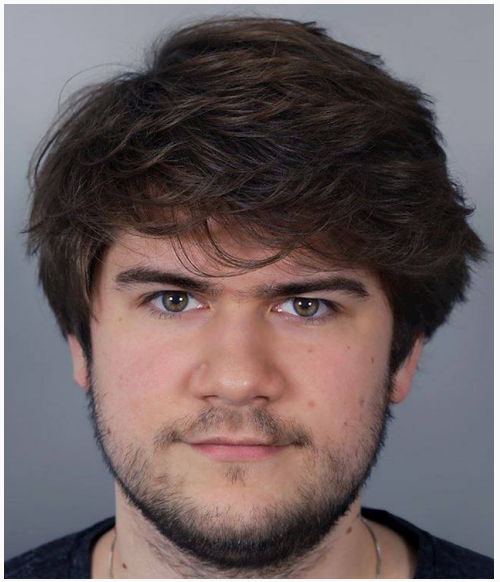
Introduction

Who am I?

Dawid Pilarski

- Senior Software Developer in TomTom
- Member of the ISO/JTC1/SC22/WG21
- Member of the PKN KT **(programming languages)**
- C++ blog writer



Agenda

Quick refresh about the coroutines.

Asynchronous RAII
P1662R0

RVO for the co_await
P1663R0

non tail call optimization
P1713R0

Questions...

Please hold your questions till the end.

Quick refresh about the coroutines.

What are the coroutines?

Subroutine Is a sequence of program instructions that perform a specific task, packaged as a unit.

Function Is a subroutine

Coroutine Is generalization of the function.

What are the coroutines?

Function can be:

- called
- returned from

What are the coroutines?

Coroutine can be:

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- suspended

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Coroutine can be:

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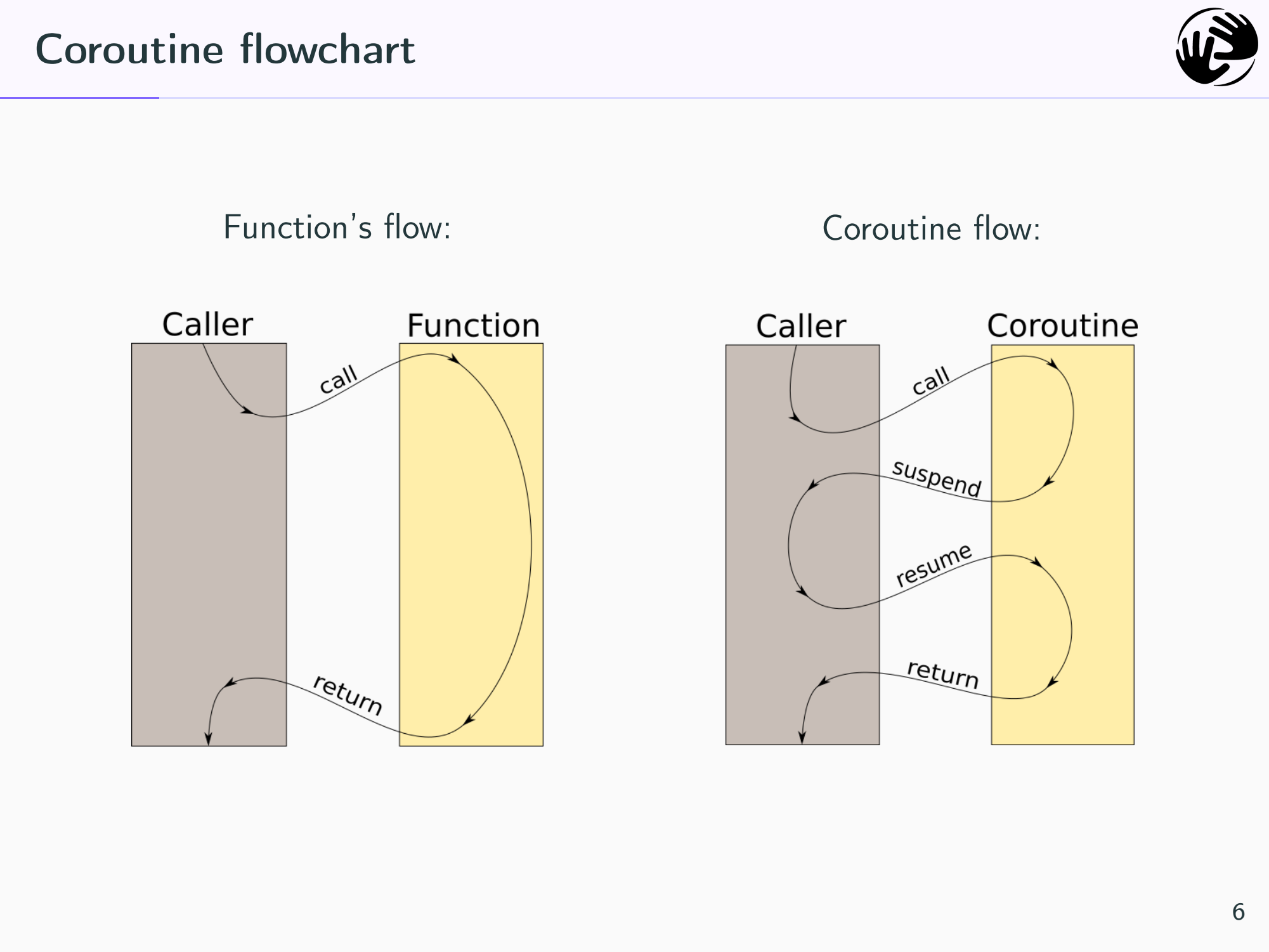
- destroyed

Coroutine flowchart



Function's flow:

Coroutine flow:

How to implement custom coroutine types.

Creating custom coroutine type is not easy:

- C++ provides keywords only.

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This means:

- Implementation of promise_type (~6 functions)
- Implementation of the co_await keyword (~3 functions)

You need to remember to implement on minimum 9 functions.

Coroutine declaration

```
// returned-type   name       arguments
//|-------------| |-------| |--------------|
   generator<int> fibonacci (int from_value);
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- Compiler knows the function is a coroutine by presence of keywords `co_await`, `co_return`, `co_yield`
- If function is a coroutine it's return type must support coroutines.

Promise_type

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promise_type can be:

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- member of the specialization of the coroutine_traits<returned_type>

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- `return_type get_return_object();`
- `void unhandled_exception();`

- `suspension at the beginning`
- `suspension at the end`
- `how to create return_type`
- `handling unhandled exception`

Keywords and promise_type

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- `co_return;`

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- `co_return V;`
- `co_return;`
- `co_yield V;`

- `p.return_value(V);`
- `p.return_void();`
- `co_await p.yield_value();`

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  - `T await_resume()`

Resuming coroutine with coroutine_handle

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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; void resume() const;

  void destroy() 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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template<class Promise>
struct coroutine_handle : coroutine_handle<>
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Why is that useful?

We can:

- hide asynchronous code
- hide state management

Asynchronous RAII

P1662R0

Asynchronous RAII

RAII - Resource Acquisition Is Initialization.

RAII vs. coroutines

How do coroutines differ?

RAII vs. coroutines

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Possible leak when async_read throws

It's not only about proper error handling

Consider following scenario:

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generator<std::string> lines(const path& file_path) {
  ifstream stream(file_path.string());
  std::string line;
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    co_yield line;
  }
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generator example usage

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for(const auto& line : lines("myfile.txt")){
  if(starts_with(line, "string I am looking for"))
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- not all lines from file might be consumed
- proper cleanup needs to be performed anyway on `coroutine_handle::destroy()`

No issue for the given synchronous coroutine

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on destroy

on loop finished

~ifstream()

asynchronous generators

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async_generator<std::string> lines(const path& file_path) {
  auto opened_file = co_await async_open(file_path);
  std::optional<std::string> opt_line;
  while(opt_line = co_await
                   async_read_line(opened_file)){
    co_yield *opt_line;
  }

  co_await async_close(opened_file);
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on early destroy - *no cleanup*

on loop finished

cleanup

Current solution to the problem

```
async_generator<std::string> lines(const path& file_path) {
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  std::optional<std::string> opt_line;
  while(opt_line = co_await
                   async_read_line(opened_file)){
    // remember to resume the coroutine before destroying
    auto cancellation_token = co_yield *opt_line;
    if(cancellation_token) break;
  }

  co_await async_close(opened_file);
}
```

Current solution to the problem

```
async_generator<std::string> lines(const path& file_path) {
  auto opened_file = co_await async_open(file_path);
  std::optional<std::string> opt_line;
  while(opt_line = co_await
                   async_read_line(opened_file)){
    // remember to resume the coroutine before destroying
    auto cancellation_token = co_yield *opt_line;
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Proposed coroutines improvement

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- create special function in the awaiter : `~operator co_await`
- `~operator co_await` gets co-awaited at the end of the scope
- instead of `destroy()` you will invoke `set_done()`

Example

```
async_generator<std::string> lines(const path& file_path) {
  co_await auto opened_file = async_open(file_path);
  std::optional<std::string> opt_line;
  while(opt_line = co_await
                   async_read_line(opened_file)){
    co_yield *opt_line;
  }

  // async_close happens as a part of clean-up
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  - coroutine bodies
  - coroutine type, because we cannot simply destroy the coroutine
- In the space of asynchronous operations we have got no RAII idiom
- With adoption of the proposal above is solved

RVO for the co_await

P1663R0

What is RVO?

RVO - Return Value Optimization.

Allows to avoid unnecessary copy or move construction of the values returned from the function.

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Allows to avoid unnecessary copy or move construction of the values returned from the function.
For example:

```
std::vector<int> foo(){
  return {1,2,3,4,5};
}

// no copy or move construction
// invoked
auto _ = foo();
```

RVO on regular functions

regular function

```
std::vector<int> foo(){
  return {1,2,3,4,5};
}
```

transformed by compiler into:

```
void foo(std::vector<int>* ptr){
  new(ptr) std::vector<int>
           {1,2,3,4,5};
}
```

Why RVO is not possible with co_await

expression

```
co_await task;
```

transformed by compiler into:

```
{
  auto&& awaiter = transform(task);
  if(!awaiter.await_ready()){
    <coroutine suspend>
    awaiter.await_suspend();
    <coroutine resume>;
  }
  awaiter.await_resume();
}
```

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```

How to resolve the issue

1. Remove await_resume function.

```
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  auto&& awaiter = transform(task);
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How to resolve the issue

1. Remove await_resume function.
2. await_suspend will create return result

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```

How to resolve the issue

1. Remove await_resume function.
2. await_suspend will create return result
3. Remove await_ready function.

```
{
  auto&& awaiter = transform(event);
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```

How to resolve the issue

1. Remove `await_resume` function.
2. `await_suspend` will create return result
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```
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Extensions to the coroutine_handle

Two additional functions in the coroutine_handle are needed.

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Two additional functions in the coroutine_handle are needed.

- set_value(T)
- set_value_from(std::in_place_construct<Arg&&...>)
- set_exception(exception_ptr)

On coroutine resumption the compiler will generate code to check whether the exception was saved with set_exception and will rethrow it when needed.

Example of the yield_value

```
template <typename T> class task<T>::promise_type{
// ....

  template <typename U> requires ConstructibleFrom<T, U>
  void return_value(U&& value){
    handle.set_value<T>(std::forward<U>(value));
  }

  template <typename... Args>
            requires ConstructibleFrom<T, Args...>
  void return_value(std::in_place_construct<Args&&...>
                    ctor_args){
    handle.set_value_from<T>(ctor_args);
  }

};
```

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};
```

How do compiler know the result of the co_await?

With removal of the await_resume the compiler no longer knows about the co_await returned type.

We will need to guide the compiler. The proposal P1663R0 proposes to add member await_result_type to the Awaiter.

RVO summary

pros

- very simplified awaiter concept

cons

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- removing await_ready makes co_await always suspend the coroutine (even if not needed)

RVO summary

pros

- very simplified awaiter concept
- RVO optimizations
  - no temporary variable created
  - allocated coroutine state is smaller

cons

- removing await_ready makes co_await always suspend the coroutine (even if not needed)
- a need to support RVO manually (with the help of construct_in_place)

non tail call optimization

P1713R0

return value [and|or] return void

right now it's not possible to implement both in the same scope.

- `return_value(T)`
- `return_void()`

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- `return_value(T)`
- `return_void()`

Why would we even need that?

Motivating example: implementation simplifications

```
task<int> foo(){
  co_return 42;
}

task<void> start(){
  std::cout << (co_await foo()) << std::endl;
  // implicit co_return;
}
```

Motivating example: implementation simplifications

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task<int> foo(){
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task<int> foo(){
  co_return 42;
}

task<void> start(){
  std::cout << (co_await foo()) << std::endl;
  // implicit co_return;
}
```

return_value(42);

return_void()

How implementors would like to implement it

```
template <typename T>
struct task<T>::promise_type{
  // ...
  void return_void()
    requires std::is_same<T, void>{}

  template <typename U>
  void return_value(U&& val)
    requires not std::is_same<T, void>{}
}
```

How implementors would like to implement it

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template <typename T>
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}
```

But that's not the way it works.

How implementors have to implement it?

```
template <typename T>
struct task<T>::promise_type{
  //...
  template <typename T>
  void return_value(T&&){
    //...
  }
};
```

How implementors have to implement it?

```
template <typename T>
struct task<T>::promise_type{
  //...
  template <typename T>
  void return_value(T&&){
    //...
  }
};
```

```
template <>
struct task<void>::promise_type{
  //...
  void return_void(){
    //...
  }
};
```

Tail coroutine call

What are tail coroutine calls?

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```
task<int> bar(){
  co_return 42;
}

task<int> foo(){
  co_return co_await bar();
}
```

Tail coroutine call

What are tail coroutine calls?

Find a difference in the pictures

```
task<int> bar(){
  co_return 42;
}

task<int> foo(){
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}
```

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}

task<int> foo(){
  co_return bar();
}
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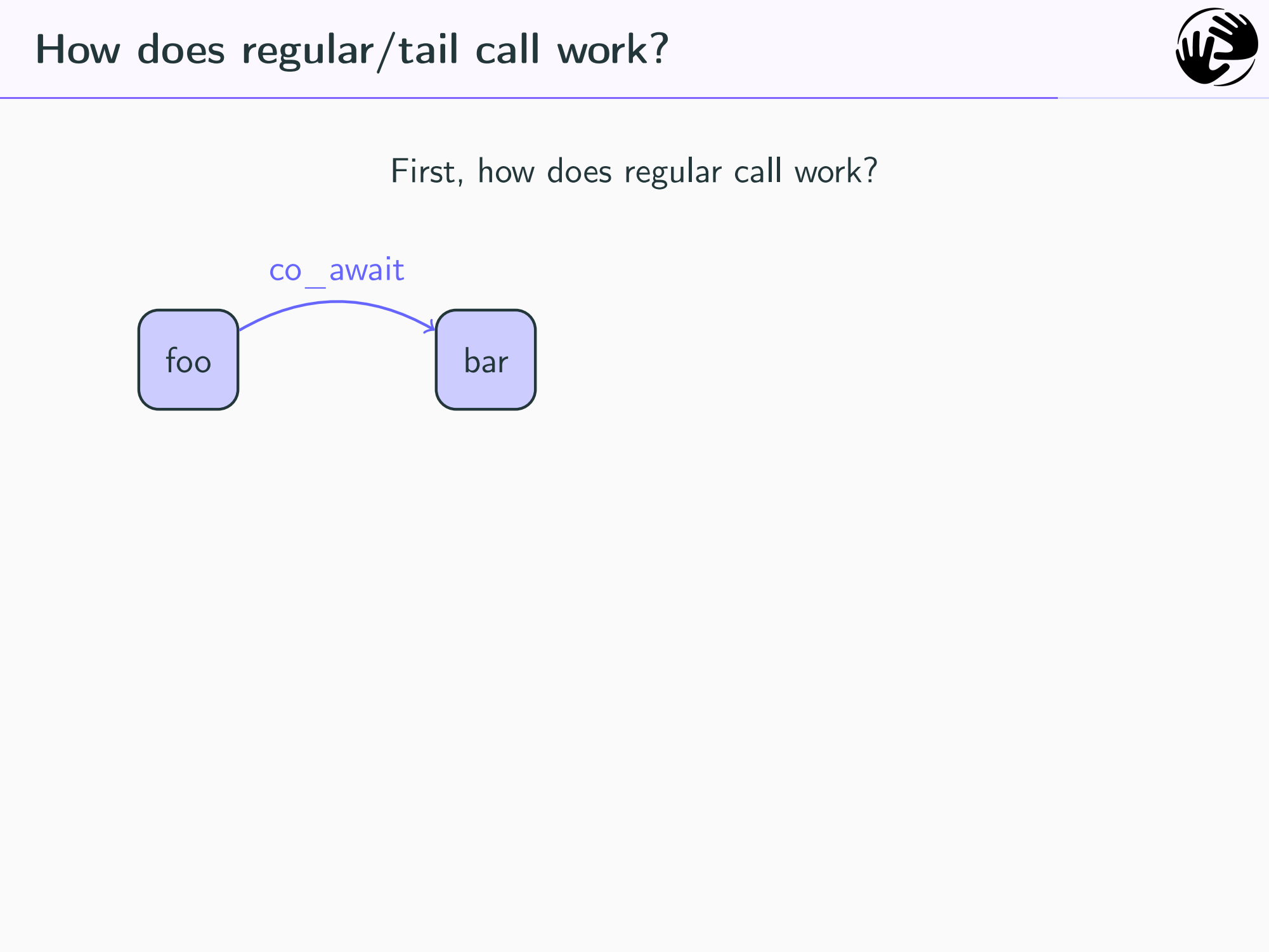
  co_return bar();
}
```

tail call / no tail call

How does regular/tail call work?

First, how does regular call work?

How does regular/tail call work?



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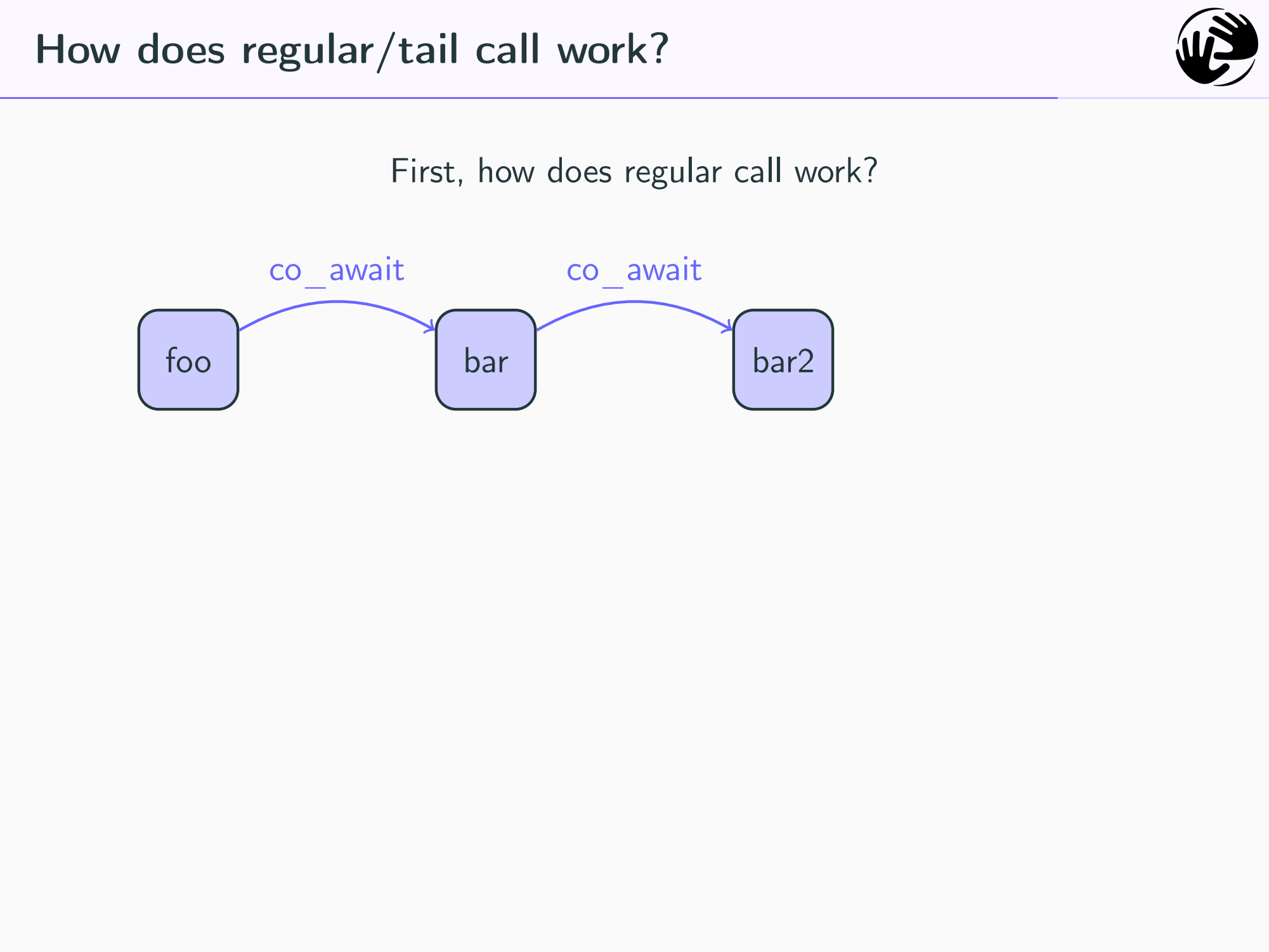

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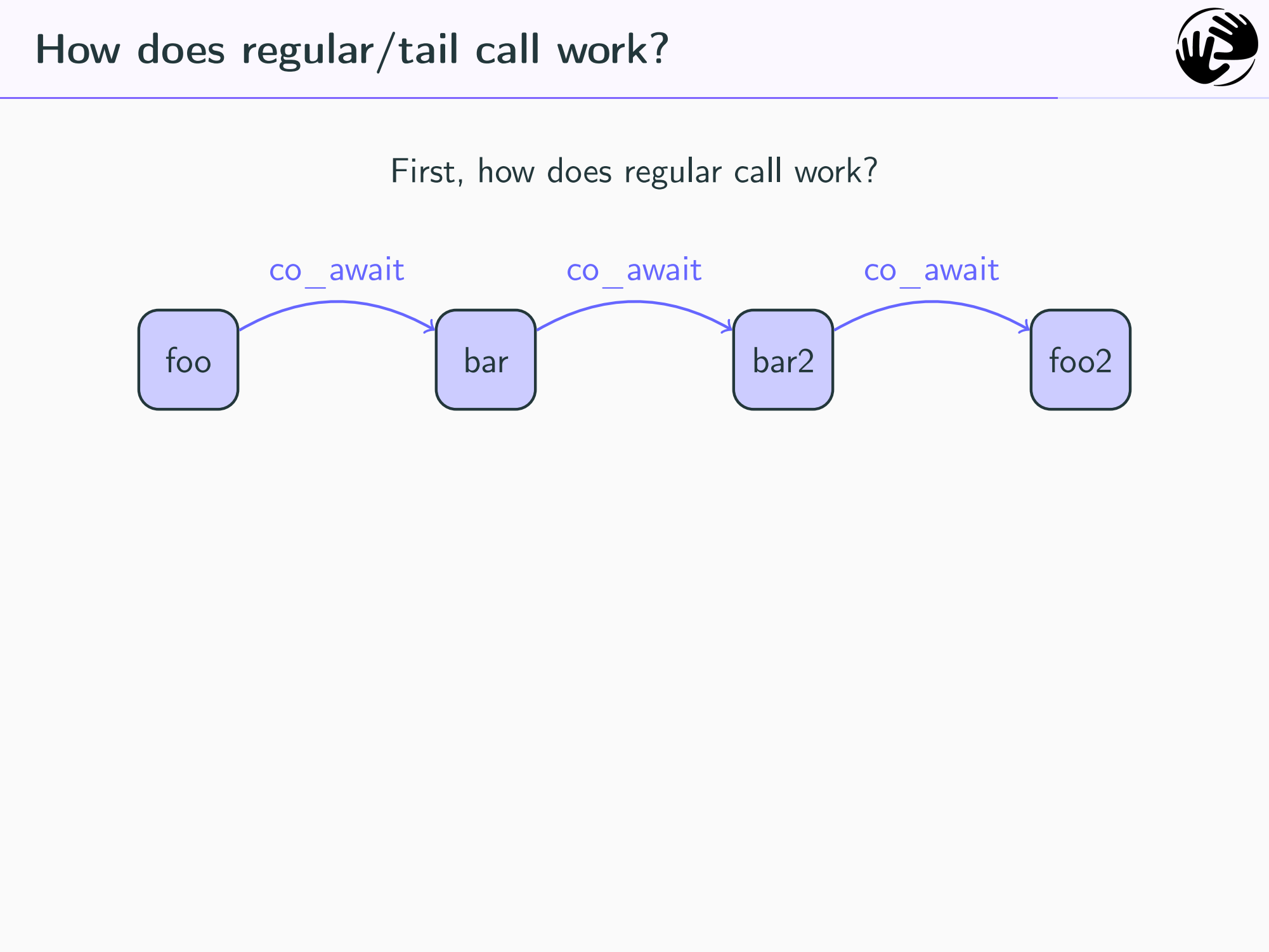

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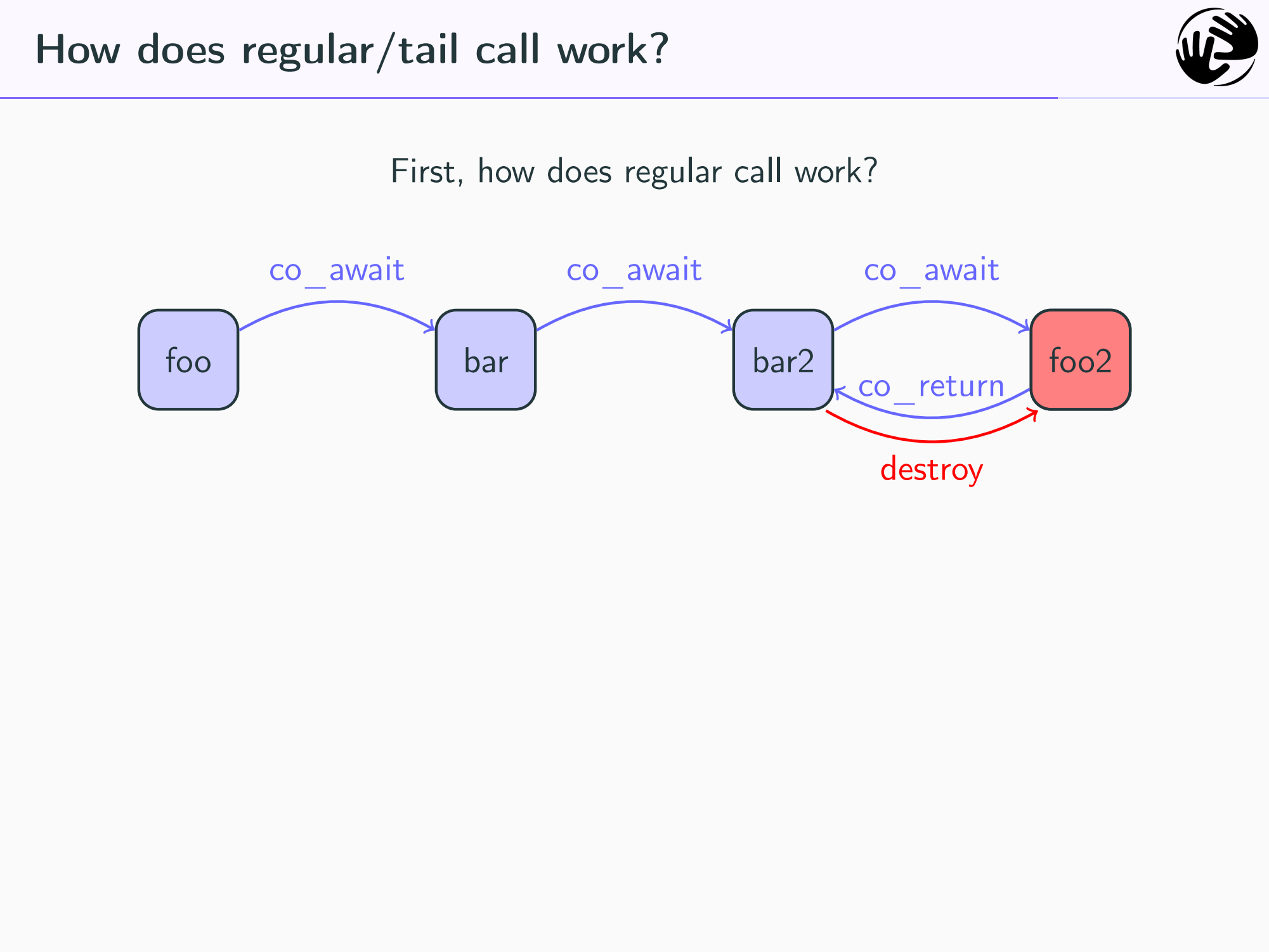

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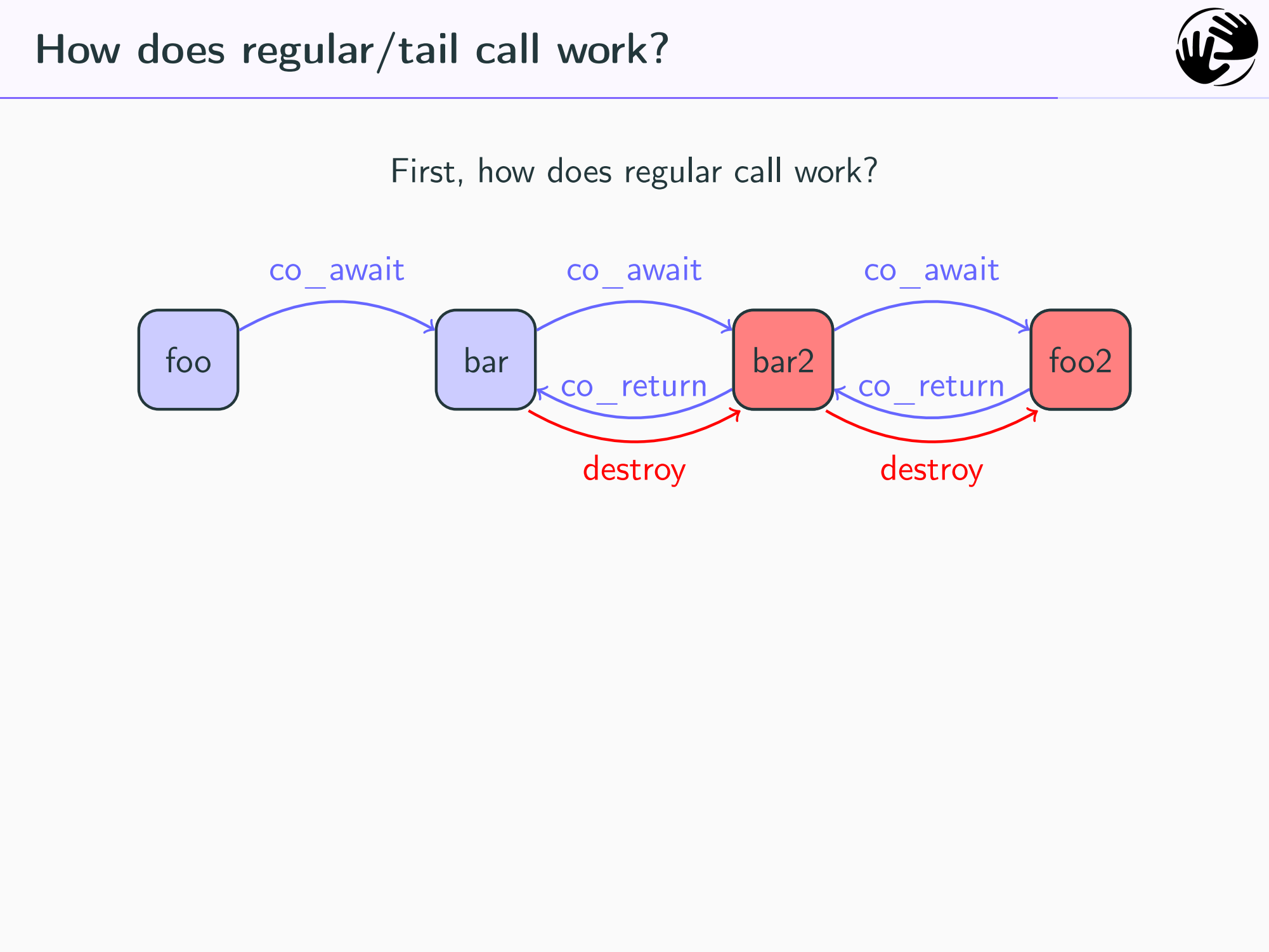

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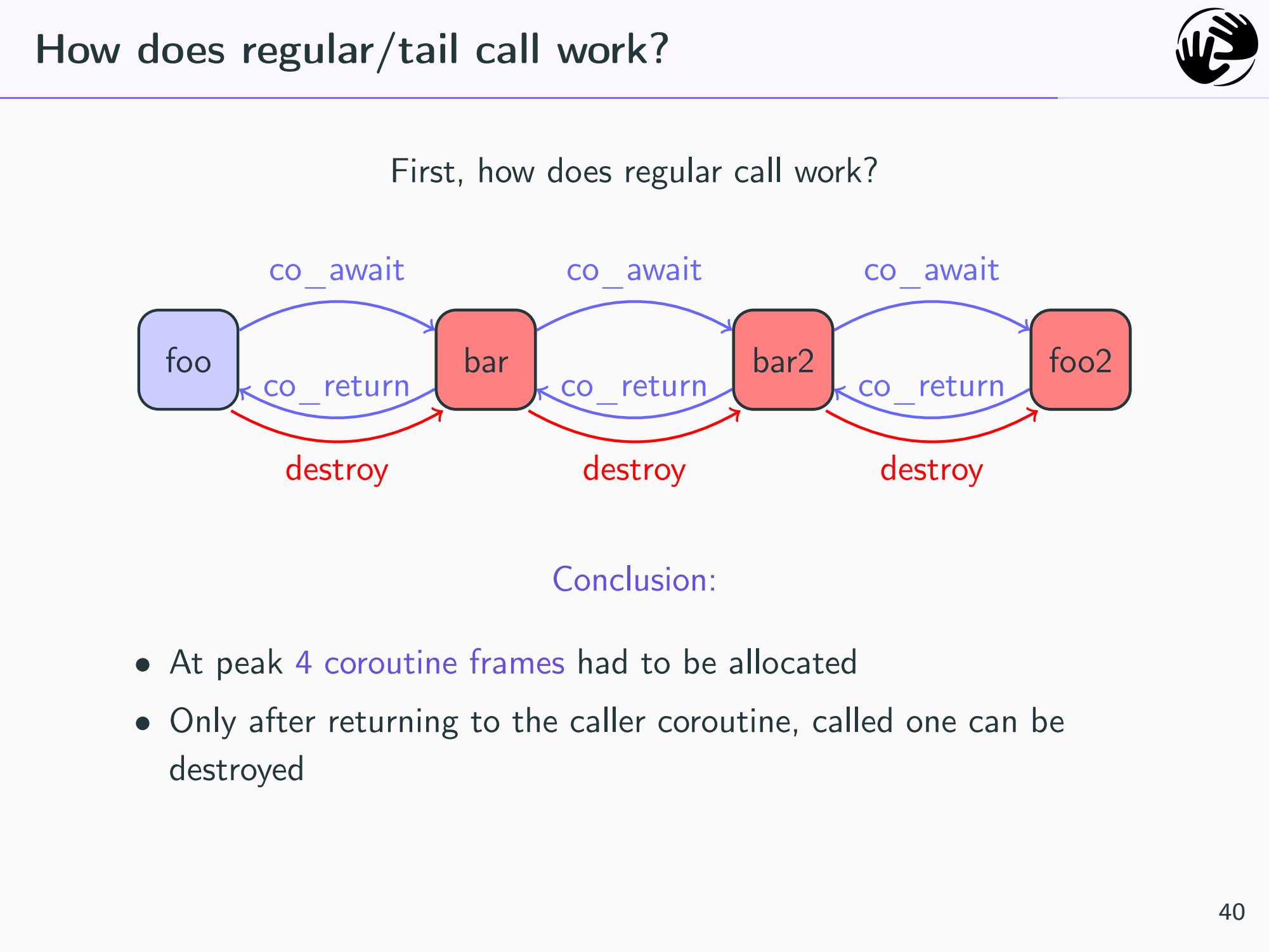

First, how does regular call work?

Conclusion:

- At peak 4 coroutine frames had to be allocated
- Only after returning to the caller coroutine, called one can be destroyed

How does non tail-call work?

In case of non tail-call we first destroy the coroutine and then call another one.

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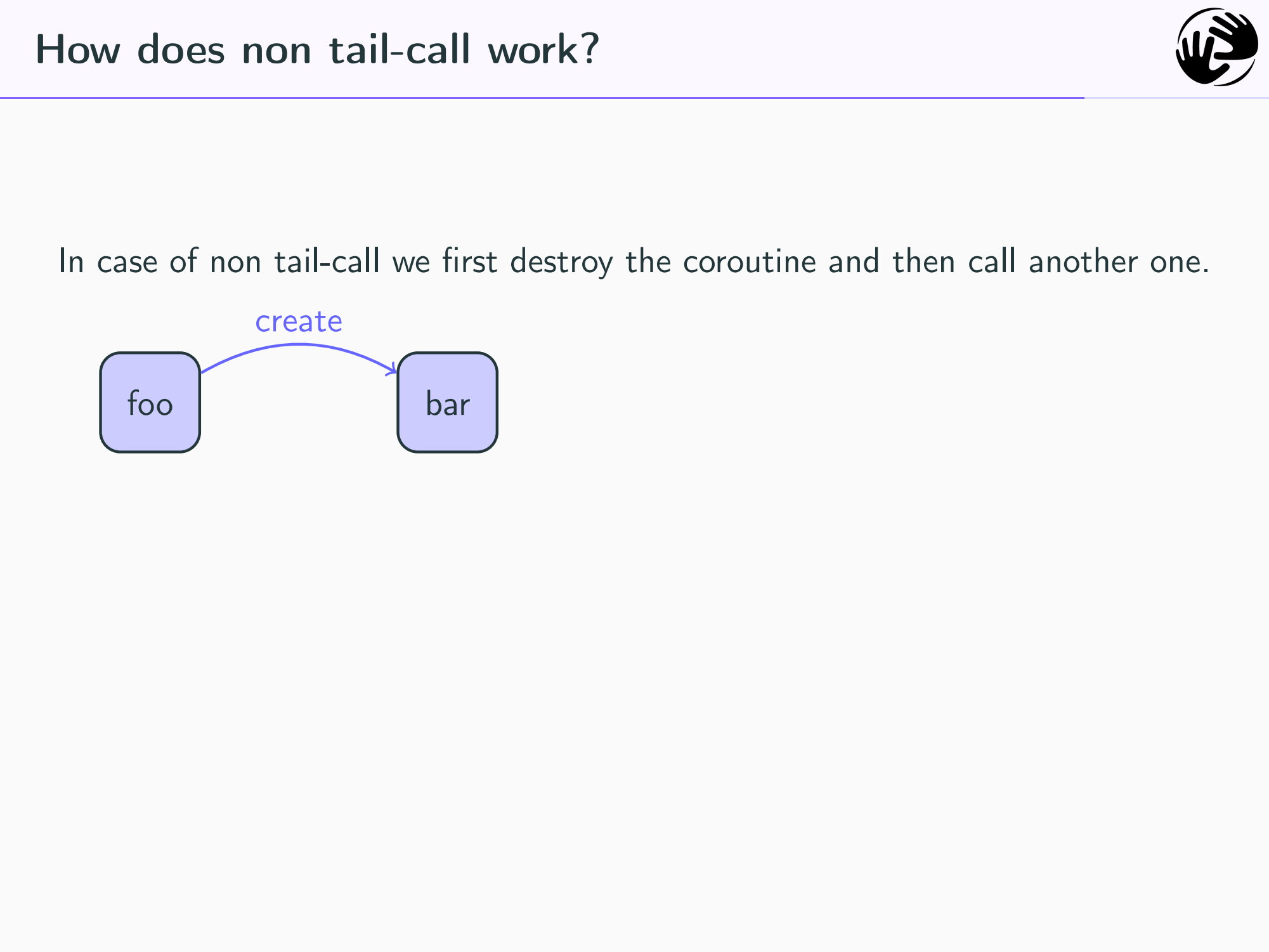

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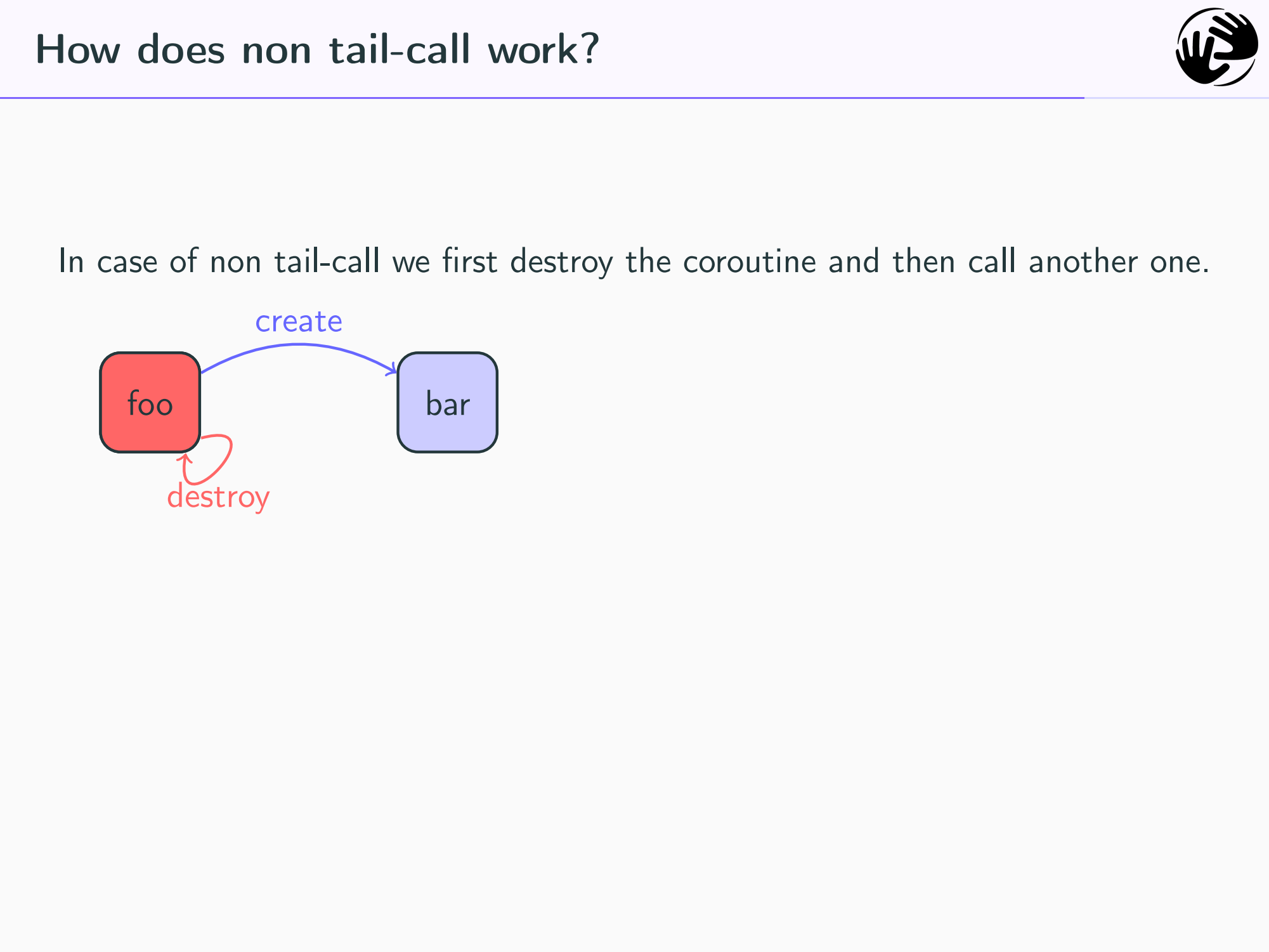

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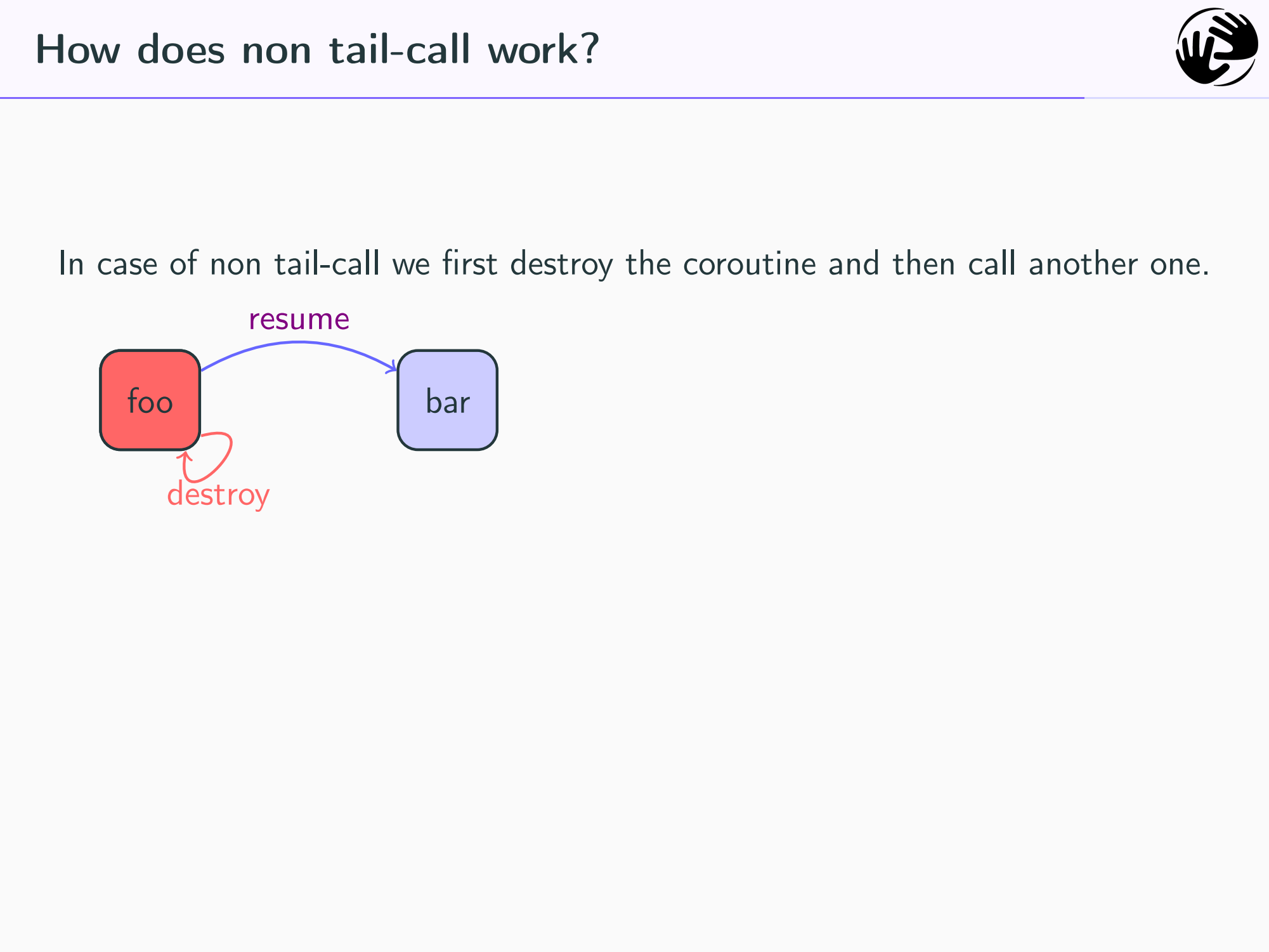

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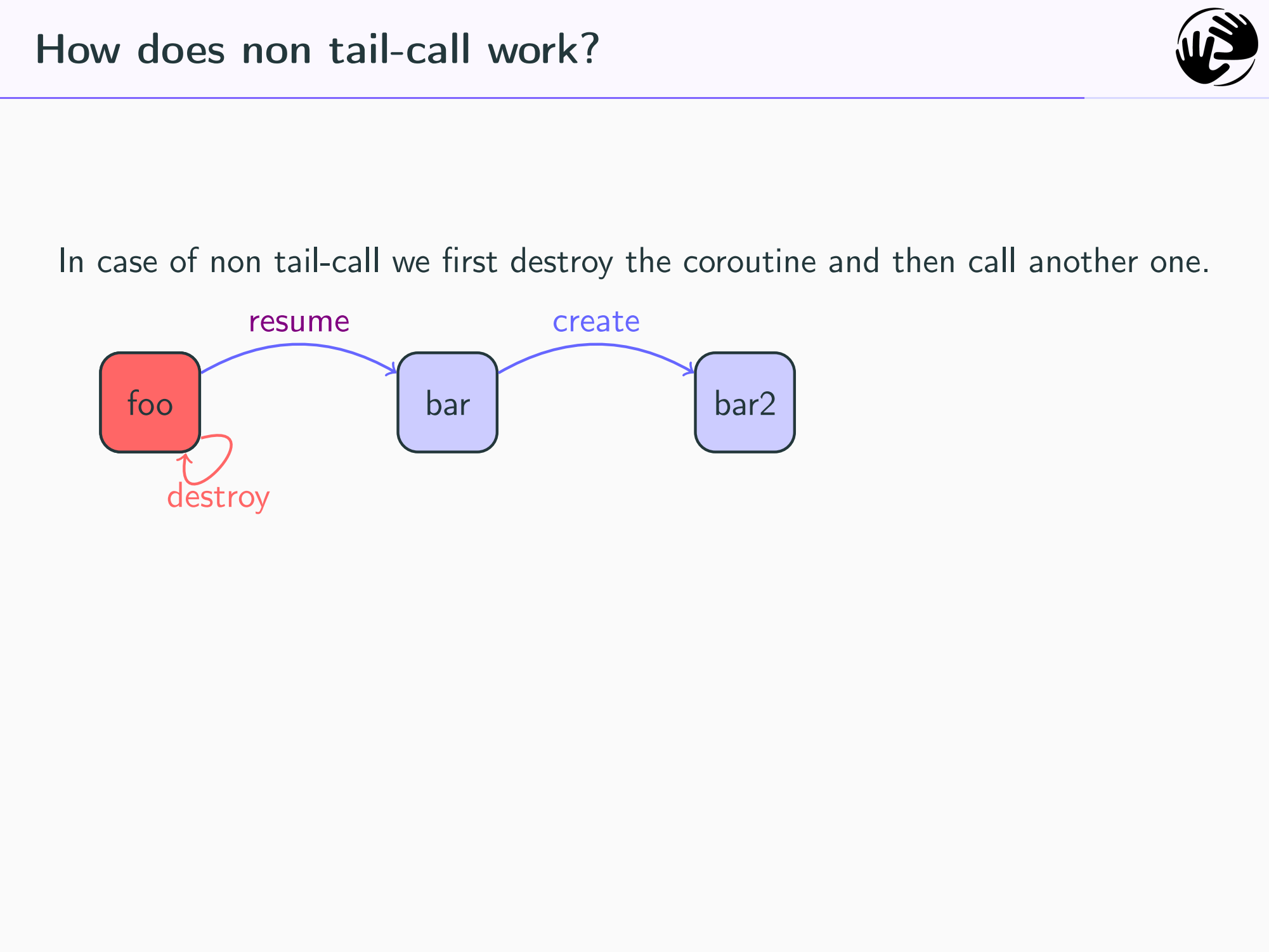

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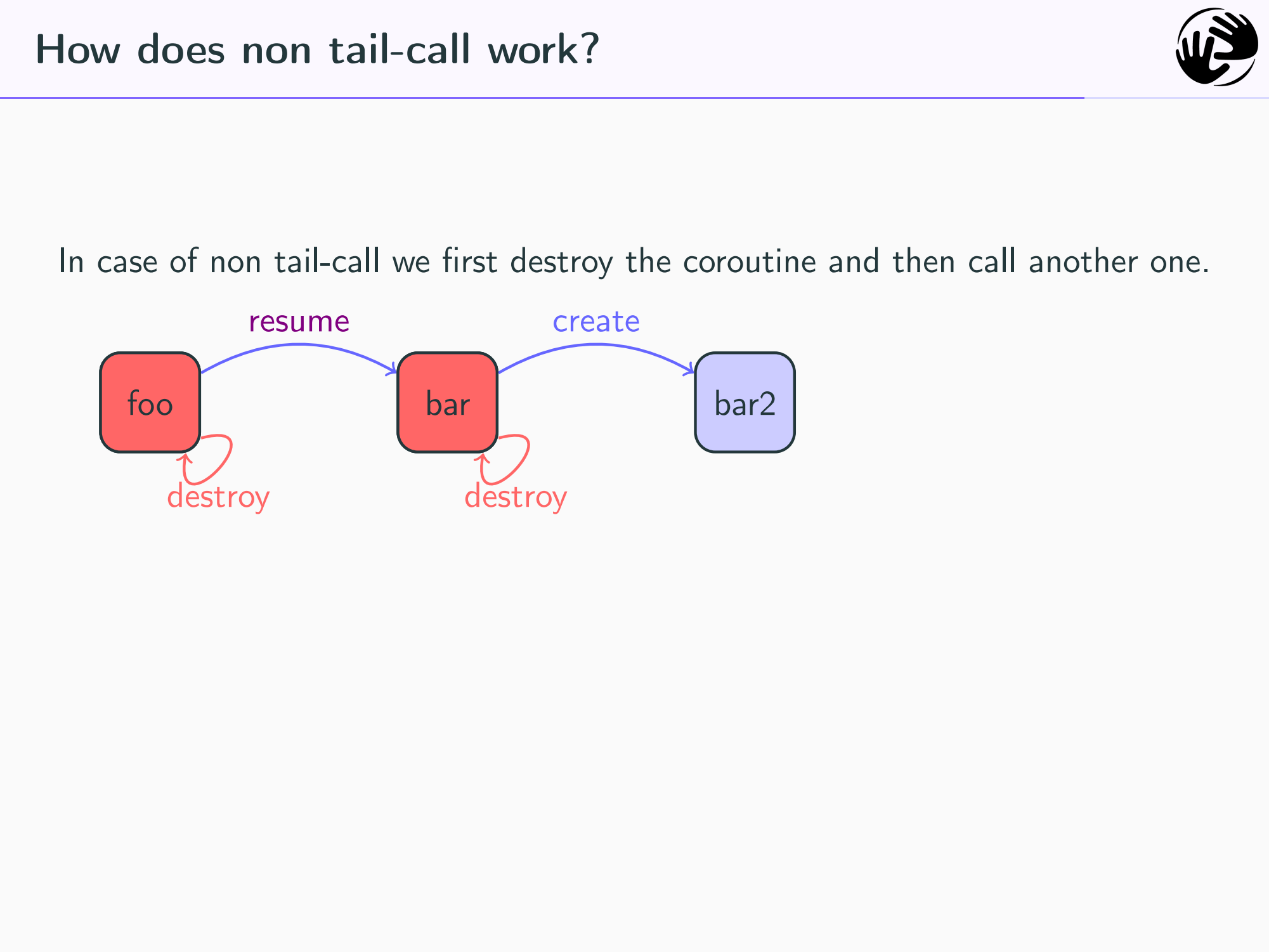

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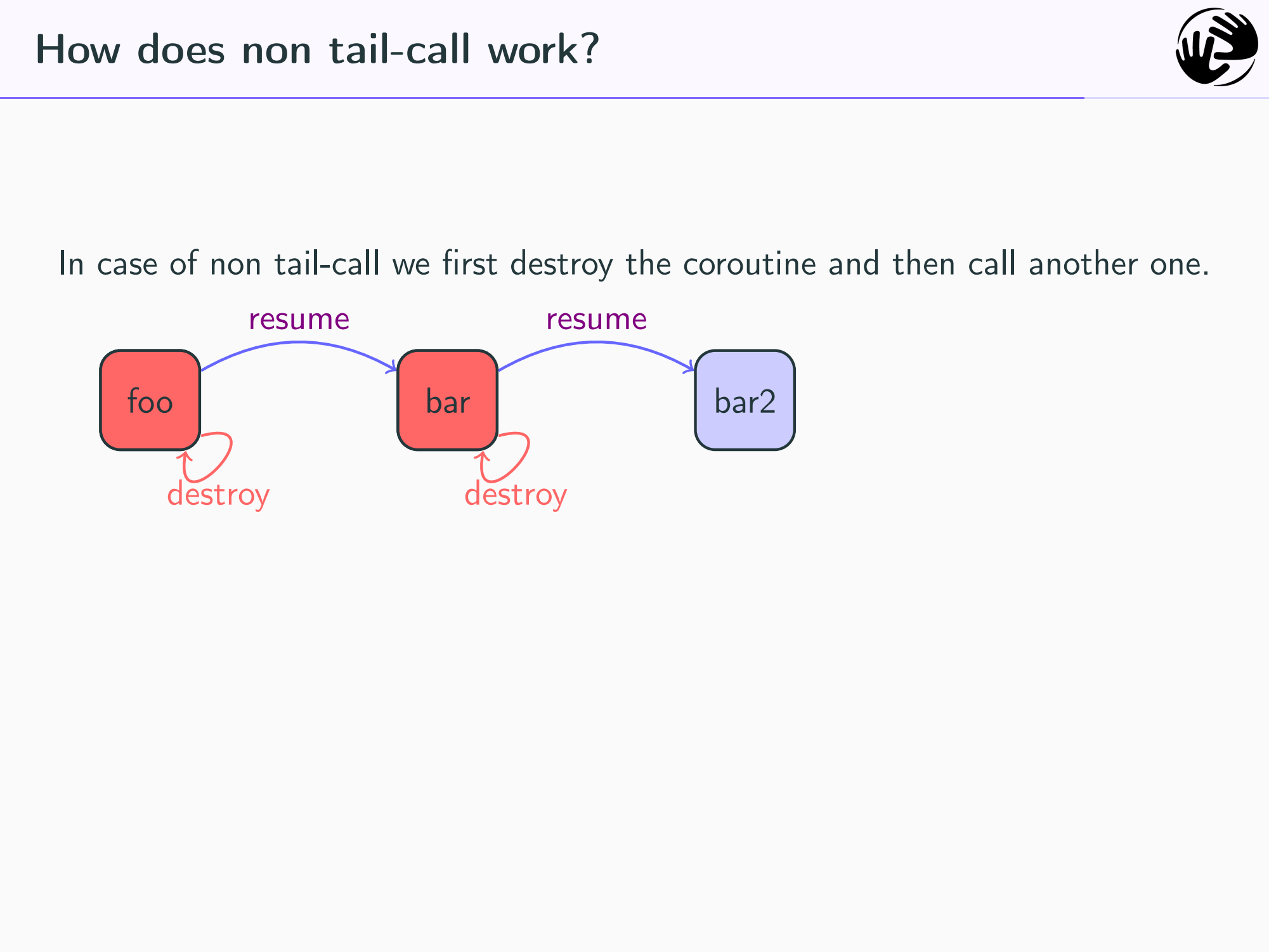

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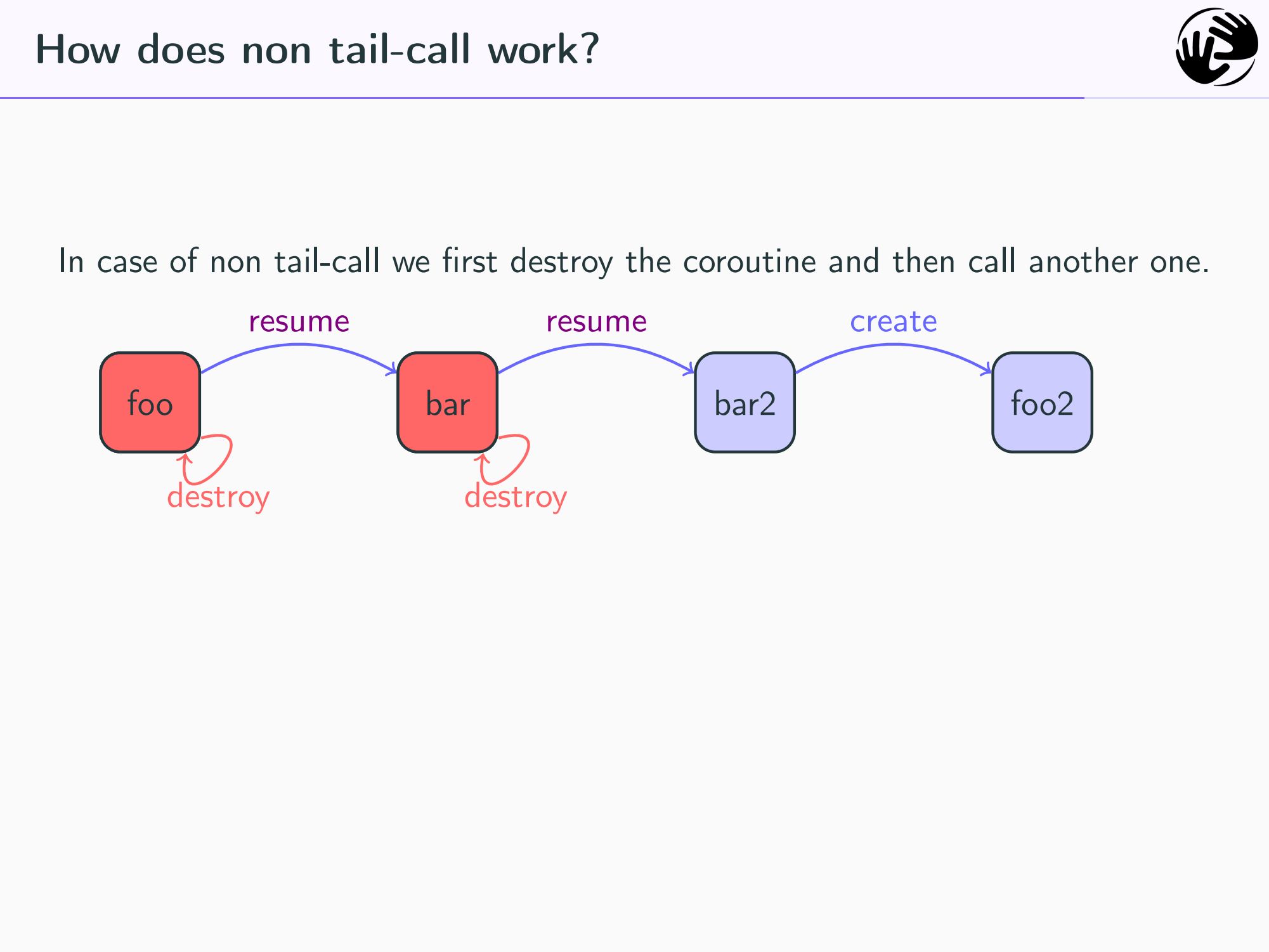

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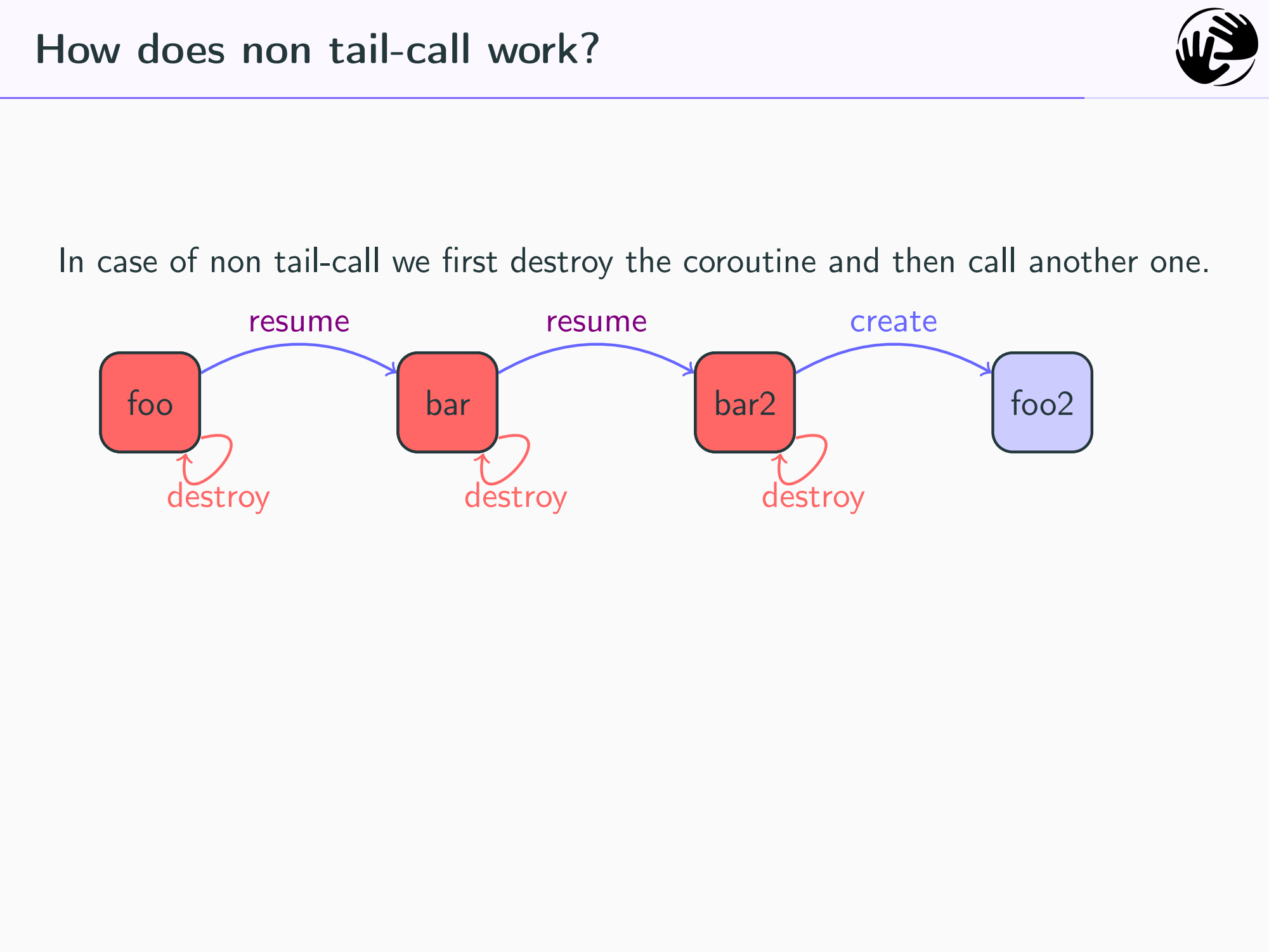

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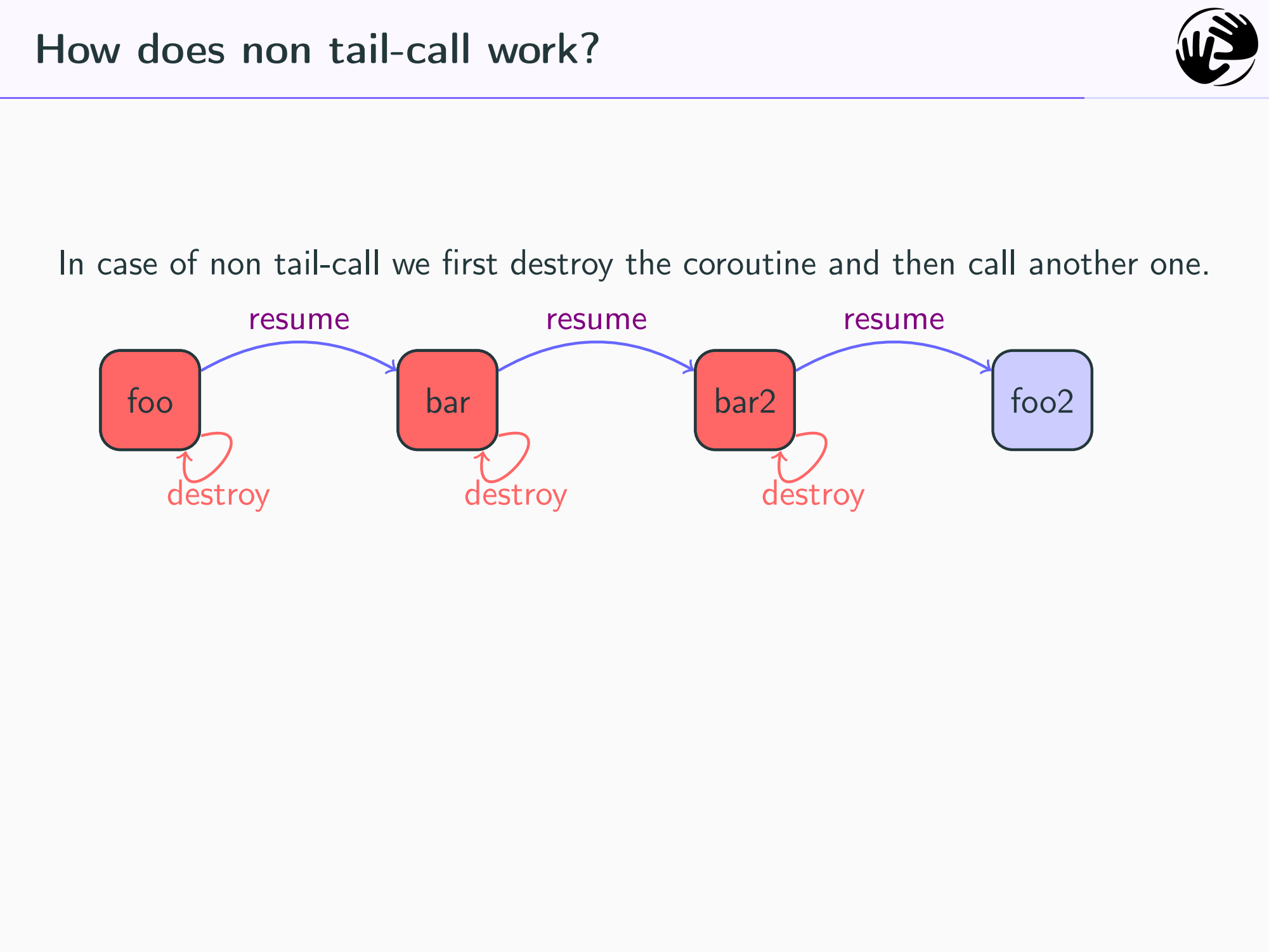

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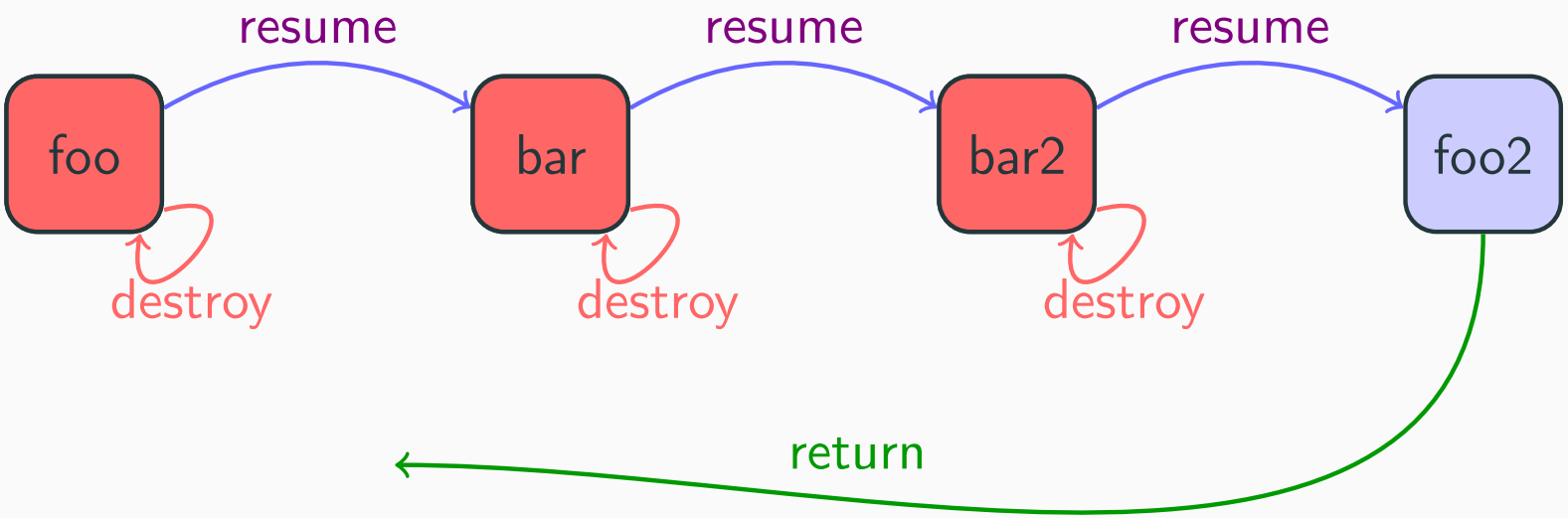

At most 2 frames were allocated.

Tail call is implementable.

Tail call is implementable.

But only for non-void co_returning types.

Why it's not implementable for task<void> types.

```
task<void> display_text(string text){
  // ...
  co_return;
}

task<void> display_file(path file){
  auto content = co_await read_file(file);
  co_return display_text(content);
}
```

Why it's not implementable for task<void> types.

```
task<void> display_text(string text){
  // ...
  co_return;      ⟵ p.return_void();
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```
task<void> display_file(path file){
  auto content = co_await read_file(file);
  co_return display_text(content);
}
```

→ p.return_value(display_text(content))

Why it's not implementable for task<void> types.

```
template <>
struct task<void>::promise_type{
  //...

  void return_void(){}




};
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    // ...
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  //...

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  void return_value(task<void>&&){
    // ...
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```

Both cannot apear in the same scope!

Summary

After accepting this change we will able to:

- simplify implementations of `promise_types` for some cases.

Summary

After accepting this change we will able to:

- simplify implementations of `promise_types` for some cases.
- make it possible for some types to support non tail coroutines calls

Thank you for your attention!

Special thank you! goes to:

- Gor Nishanov
- Lewis Baker

for creating C++ coroutines

Summary

Bibliography and further reading

- Lewis Baker's Assymetric transfer blog
- newest C++ draft
- My blog - blog.panicsoftware.com
- coroutines proposals
- James McNellis - "Introduction to the C++ Coroutines"
- Gor Nishanov - any video about the coroutines
- Toby Allsopp - "Coroutines: what can't they do?"

Questions?

Questions?

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this	https://github.com/dawidpilarski/CodeDive-coroutines