Introduction to Effect Handler Oriented Programming in C++

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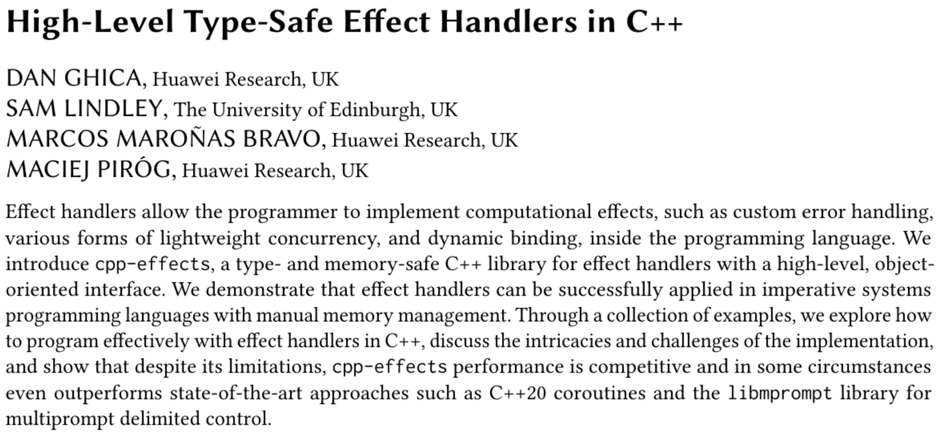
C++Effects: A library for effect handler oriented programming



High-Level Type-Safe Effect Handlers in C++

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Effect handlers allow the programmer to implement computational effects, such as custom error handling, various forms of lightweight concurrency, and dynamic binding, inside the programming language. We introduce `cpp-effects`, a type- and memory-safe C++ library for effect handlers with a high-level, object-oriented interface. We demonstrate that effect handlers can be successfully applied in imperative systems programming languages with manual memory management. Through a collection of examples, we explore how to program effectively with effect handlers in C++, discuss the intricacies and challenges of the implementation, and show that despite its limitations, `cpp-effects` performance is competitive and in some circumstances even outperforms state-of-the-art approaches such as C++20 coroutines and the `libmprompt` library for multiprompt delimited control.

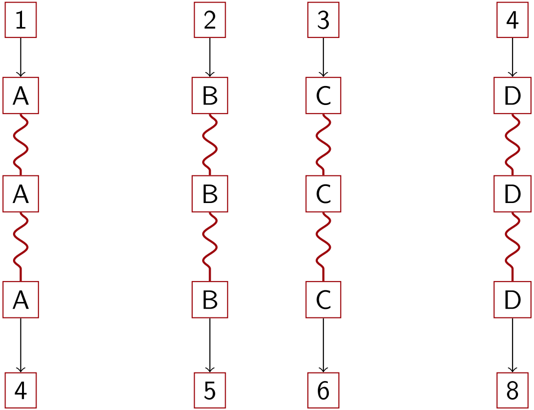
Talk objective

Demonstrate effect handler-oriented programming by example

- Implement a tiny tasking library;
- supporting task-local state;
- and task fault recovery

Example 1: Dynamic binding (1)

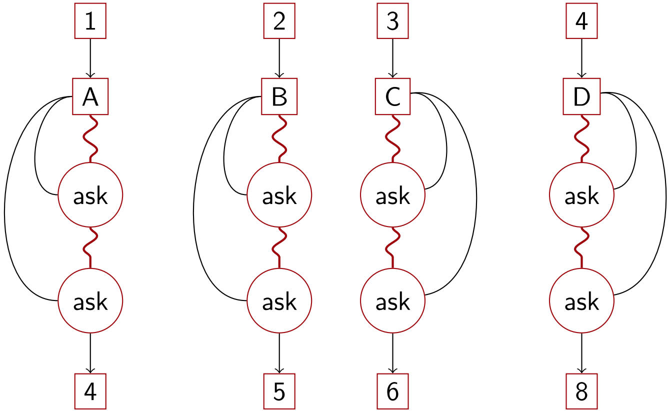
The state passing technique explicitly ‘threads’ the value through the entire computation.



Relevant code: `examples/ex1/state_passing.cpp`

Example 1: Dynamic binding (2)

The environment handler provides a context-dependent variable.



Relevant code: `examples/ex1/env.hpp` and `examples/ex1/env_main.cpp`

The programmer's perspective on effect handlers

Related familiar programming abstractions

- Coroutines
- Generators
- Lightweight threads
- Resumable exceptions
- First-class continuations

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Executive summary

*Effect handlers offer a modern interface for highly **composable** and **customisable** programming with non-local control flow. Effect handlers subsume all classic ad-hoc control abstractions.*

A new programming paradigm

Procedure-oriented programming

Imperative steps organised as logical sub-routines

Object-oriented programming

Encapsulation of data and behaviour in objects

Function-oriented programming

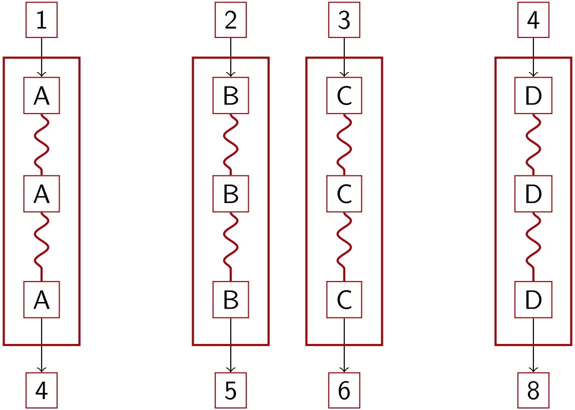
Abstraction through higher-order functions

Effect handler-oriented programming

Interaction with the execution context via continuations

Example 2: Lightweight threads

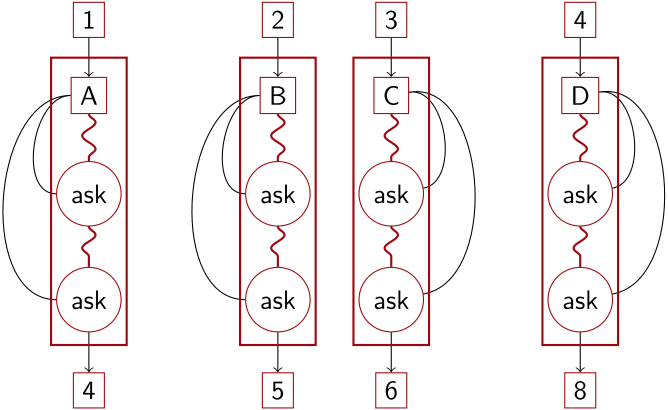
The scheduler handler reifies each task computation as a first-class object.



Relevant code: `examples/ex2/lwt.hpp` and `examples/ex2/lwt_main.cpp`

Example 3: Task-local state

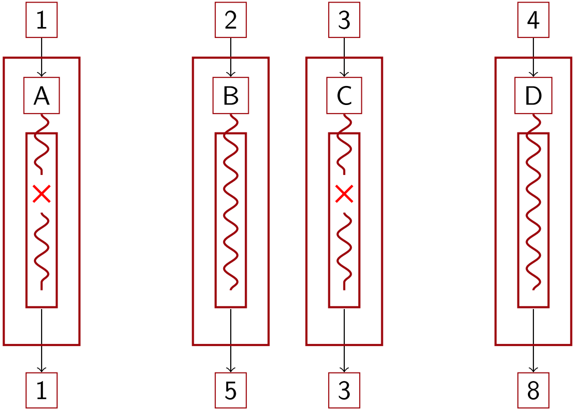
We obtain task-local state by composing the scheduler and environment handlers.



Relevant code: `examples/ex3/lwtenv_main.cpp`

Example 4: Transactional state

We add transactional state by composing yet another handler.



Relevant code: `examples/ex4/rollback.hpp` and `examples/ex4/rollback_main.cpp`

Summary

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- Effect handlers offer modular and composable control
- Common control abstractions are implementable as libraries
- Separation of interface and implementation through continuations
- Extend functionality by composing fine-grained and agnostic handlers

References

Plotkin, Gordon D. and Matija Pretnar (2013). “Handling Algebraic Effects”. In: *Logical Methods in Computer Science* 9.4.

Hillerström, Daniel (2021). “Foundations for Programming and Implementing Effect Handlers”. PhD thesis. The University of Edinburgh, Scotland, UK.

Ghica, Dan et al. (2022). “High-Level Type-Safe Effect Handlers in C++”. In: *Proc. ACM Program. Lang.* 6.OOPSLA, pp. 1–30.