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Runtime Agnostic Concurrency with Handlers

Pervasive Parallelism Lunch Talk

Daniel Hillerström

CDT Pervasive Parallelism
The University of Edinburgh, UK

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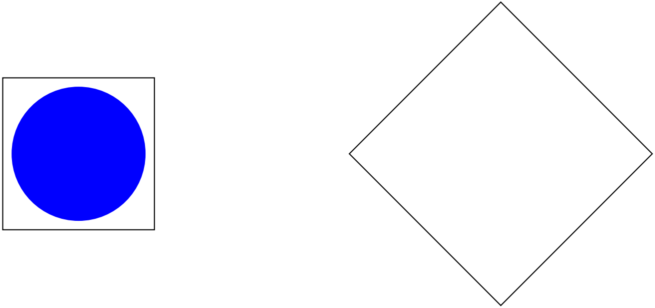
Outline

This talk consists of four parts

1. Motivation
2. Introduction to algebraic effects and their handlers
3. Abstract message-passing concurrency model (Hillerström, 2016)
4. Concurrency model instantiations (joint work with C. Dubach, S. Lindley, and KC Sivaramakrishnan) [work-in-progress]

Setting the stage

In the idealised world: write once, use everywhere (w.r.t some guarantees).



Really, really hard to achieve with different architectures in a parallel setting.

- ● Concurrent program.
- □ Rectangular computer architecture.
- ◇ Diamond computer architecture.

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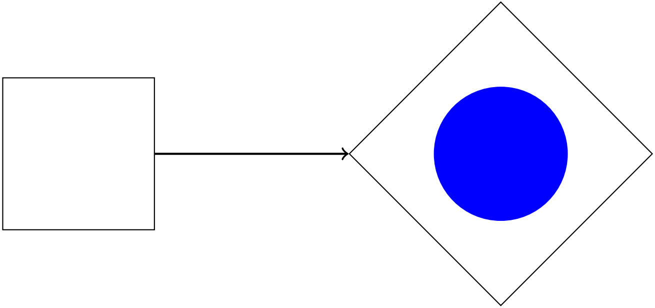

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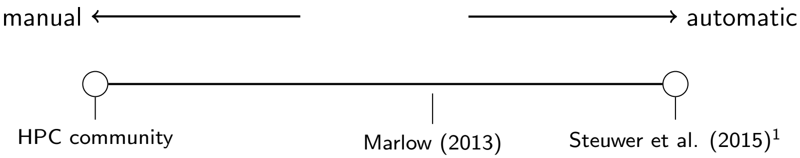
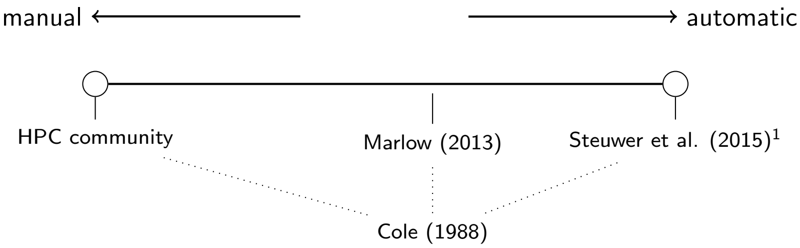
The axis of parallelisation



Lots of promising work in the area of automatic compiler-enabled parallelisation.

[1] Steuwer, Fensch, Lindley, and Dubach

The axis of parallelisation



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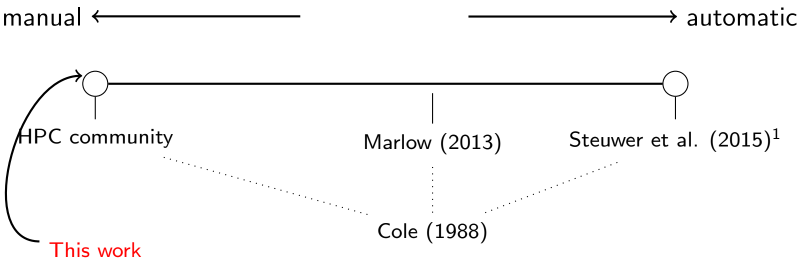

Lots of promising work in the area of automatic compiler-enabled parallelisation.

But my work positions itself in the other extreme.

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Research hypothesis

Research hypothesis

Using algebraic effects and handlers we can decouple the concrete concurrency implementation from the use of concurrency primitives in our programs.

Computational effects

What are some examples of computational effects?

- Printing to standard output (print).
- Interacting with users (input).
- Nondeterminism (choice).
- Concurrency (fork, join, etc.)
- ... many more.

In short: computational effects are *pervasive*.

Nowadays, monads are the defacto abstraction for controlling effects (Moggi, 1991; Wadler 1992).

Algebraic effects (Plotkin and Power, 2001) combined with effect handlers (Plotkin and Pretnar, 2013) provide a modular alternative to monads.

Algebraic effects

Definition (Algebraic effect)

An algebraic effect is a collection of *abstract* operations. For example, we may think of

```
effect Incr : int -> int
effect Decr : int -> int
```

as describing an algebraic effect with two operations `Incr` and `Decr`. Essentially, an algebraic effect is an interface.

A silly example *abstract* computation:

```
let fortytwo () =
  let i = perform (Incr 42) in
  Printf.printf "%d\n" i;
  Printf.printf "%d\n" (perform (Decr i))
```

Handlers

From the previous slide

```
let fortytwo () =
  let i = perform (Incr 42) in
  Printf.printf "%d\n" i;
  Printf.printf "%d\n" (perform (Decr i))
```

Definition (Handler)

A handler is a *modular* interpreter over abstract computations.

Example interpretation of `Incr` and `Decr`:

```
let incr_decr m =
  match m () with
  | v -> v
  | effect (Incr i) comp -> continue comp (i+1)
  | effect (Decr i) comp -> continue comp (i-1)
```

To interpret `fortytwo` we apply `incr_decr`:

```
# incr_decr fortytwo;;
43
42
```

Implementations of algebraic effects and handlers

Programming languages with support for effect handlers

- *Eff* by Bauer and Pretnar (2015).
- Multicore OCaml by Dolan, White, Sivaramakrishnan, Yallop, and Madhavapeddy (2015).
- Links[2] by Hillerström and Lindley (2016)[3].
- Shonky by McBride (2016).
- Frank by Lindley, McBride, and McLaughlin (2017)[4].

Some embeddings in other programming languages

- Haskell library by Kiselyov, Sabry, and Swords (2013).
- Haskell library by Kammar, Lindley, and Oury (2013).
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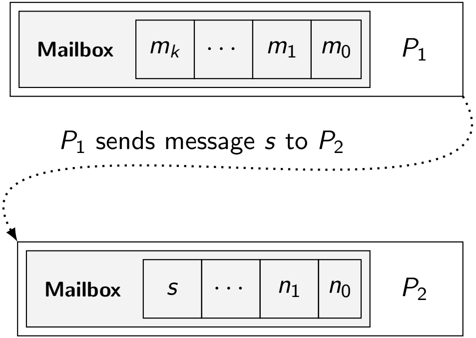
Modelling message-passing concurrency

We are interesting in modelling a message-passing concurrency model.



Concurrency ingredients

Some *abstract* type `pid` that classifies process identifiers.

Three abstract operations for managing processes:

- `Spawn : (unit -> unit) -> pid` — for process creation.
- `Yield : unit` — for context switching.
- `Self : pid` — for self-referral.

Two operations for managing communication among processes:

- `Send : (pid * m) -> unit` — for sending a message of type `m`.
- `Recv : pid -> m option` — for receiving a message of type `m`.

An example abstract concurrent computation

This computation fits on a single slide:

```
let rec fib n parent () =
  let rec recv self =
    match perform (Recv self) with
    | None -> yield (); recv ()
    | Some msg -> msg
  in
  let send pid msg =
    perform (Send (pid, msg)); yield ()
  in
  if n < 2
  then send parent n
  else let self = perform Self in
       let _    = perform (Spawn (fib (n-1) self)) in
       let _    = perform (Spawn (fib (n-2) self)) in
       send parent ((recv self) + (recv self))
```

Scheduling

A handler for `Spawn` and `Yield` is a *scheduler* for processes. Consider the following code[5]:

```
let roundrobin f () =
  ...
  let rec spawn f =
    match f () with
    | () -> dequeue ()
    | effect (Spawn f) comp ->
       let child_pid = fresh_pid () in
       enqueue (fun () -> continue comp child_pid);
       spawn f
    | effect Yield comp      ->
       enqueue (fun () -> continue comp ()); dequeue ()
  in
  spawn f
```

[5] Adapted from Bauer and Pretnar (2015)

Communication

A mailbox can be represented as a mapping from `pid` to queues of `msg`.

```
let communication f =
  ...
  match f () with
  | v -> v
  | effect (Send (pid, msg)) k ->
     put pid msg;
     continue k ()
  | effect (Recv pid) k ->
     let msg = lookup pid in
     continue k msg
```

Model instantiation

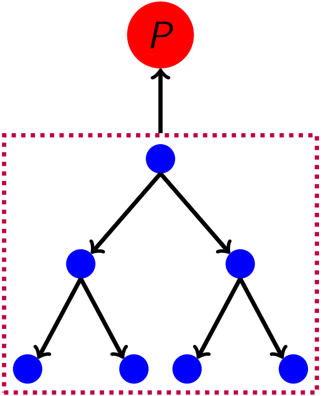
Let `type pid = int`. Now, we make a single-threaded instantiation of our concurrency model:

```
communication (roundrobin (fun () -> fib 7 (self ())))
```

Computes the value 8.

This instantiation is an implementation of *cooperative multitasking*.

Instantiation: Cooperative multitasking



- Actual system process.
- Abstract concurrent computation.
- Concurrency handler(s).

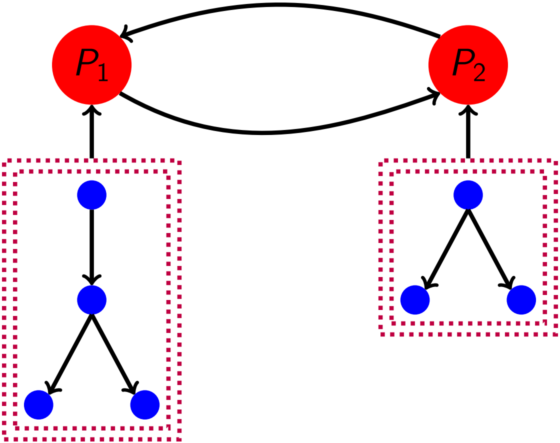
Observation: Model and implementation are decoupled

Observation

The abstract concurrent computations are implemented independently of our choice of model instantiation.

Can we instantiate our model with, perhaps, a parallel runtime such as MPI?

Instantiation: Ring scheduling



Actual system process.

Abstract concurrent computation.

Concurrency handler(s).

Not quite a free lunch

The change of implementation does not come for free

- Must change the initialisation of the application (our main function).
- Must implement new handlers that take advantage of the new runtime.

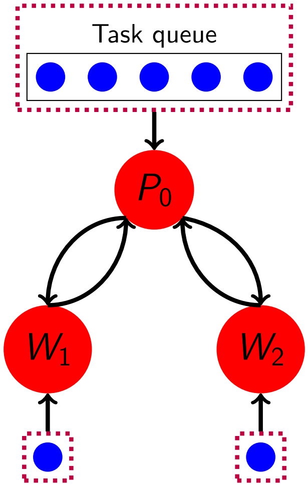
But the main parts of our program are left untouched. We may even reuse previous handlers.

Encapsulation of runtime specific parts inside of handlers

Let `type pid = int * int`.
Observation: calls to MPI routines only occur inside of handlers!

```
let mpihandler m () =
 ...
 let spawn f =
  match f () with
  | v  -> dequeue ()
  | effect (Spawn f) k -> (* Send task to neighbour *)
    let pid = fresh_pid neighbour in
    let _  = Mpi.send (Task (f,pid)) neighbour 1 Mpi.
   comm_world in
    continue k pid
  | effect (Send (pid,msg)) k -> (* Local or remote send? *)
    let _ = Mpi.send (Result (msg, pid)) neighbour 2 Mpi.
   comm_world in
    continue k ()
```

Instantiation: Single master, multiple workers



- Actual system process.
- Abstract concurrent computation.
- Concurrency handler(s).

Future work

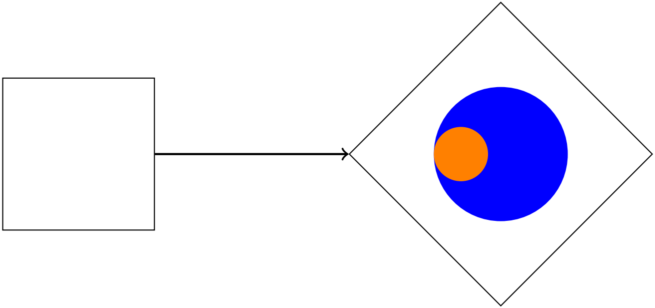
Next steps

- Measure/generate some performance figures
- Application to irregular parallel programs

Future, future work

- Serialisation of continuations
- Mixed-mode parallel programming

Summary



In summary

- Algebraic effects and their handlers provide a modular abstraction for controlling computational effects.
- Concurrency arises as "just" another natural controllable effect.
- Instantiate your concurrency model with your favourite implementation.
- Potential for *unleashing* and *taming* parallelism within abstract computations.

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