Compiling Links Effect Handlers to the OCaml Backend

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Abstract
Algebraic effects and handlers provide a modular abstraction for modelling and controlling computational effects. We present a compiler for the experimental language Links with effect handlers. Our compiler interfaces with the Multicore OCaml backend to take advantage of OCaml’s implementation of efficient handlers.

1. Motivation
Algebraic effects and handlers \cite{7} afford a compelling and modular alternative to monad transformers for controlling computational effects. In previous work, we extended the functional web programming language Links with algebraic effects and handlers \cite{3,4}. Links is a strict ML-like functional language for the web \cite{11}. It has three backends: i) a JavaScript compiler for the client, ii) an interpreter for the server, iii) and an SQL generator for the database. Currently effect handlers are only supported on the server; in future we intend to extend the JavaScript compiler to support them too.

In order to improve performance, and to study efficient compilation of effect handlers in general, we have implemented a Links compiler that targets the Multicore OCaml backend \cite{2}. By taking advantage of the OCaml backend we obtain both native code compilation and access to the OCaml toolchain for free.

Prior work focuses mainly on the design and expressiveness of handlers rather than performance. Nevertheless, several papers do address performance. Kammar et al. \cite{5} take advantage of Haskell’s aggressive fusion optimisations for an efficient Haskell library for handlers, as explained in detail by Wu and Schrijvers \cite{9}. Kiselyov and Ishii \cite{6} also optimise a different Haskell library for handlers, taking advantage of prior work on optimising monadic reflection \cite{8}. Our work differs from these systems in that we compile effect handlers directly, rather than via library.

2. Affine and Multi-shot Effect Handlers
This section provides a short primer to effect handlers in Links. An algebraic effect is given by a signature of abstract operations. For example nondeterminism is an algebraic effect that is given by a nondeterministic choice operation called Choose. In Links, we may use this operation to implement a coin toss:

\[
\text{fun toss() \{ if (do Choose) Heads else Tails \}}
\]

This declares an abstract computation `toss`, which invokes an operation `Choose` using the do construct. The `sig` keyword begins a signature, which reads: `toss` is a computation with effect signature \{Choose:Bool |e\} and return value `Toss`, whose constructors are `Heads` and `Tails`. Links employs row typing to support extensible effect signatures, thus `e` is an effect variable, which can be instantiated with additional operations.

Introduction of another operation causes the effect signature to grow accordingly. For example, if we introduce an exception operation \textbf{Fail} : \textbf{Zero}, then we can model a drunk coin toss:

\[
\text{fun drunkToss() \{ if (do Choose) toss() else switch (do Fail) \{ } \}}
\]

Here \textbf{Zero} is the empty type, and thus the \texttt{switch} pattern matching construct has no clauses. An effect handler instantiates a subset of the operations of an abstract computation. For example, the following handler interprets \texttt{Choose} randomly:

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\text{fun drunkToss() \{ if (do Choose) toss() else switch (do Fail) \{ } \}}
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3. Compiler Infrastructure

We reuse most of the previous Links infrastructure. The Links frontend is type-checked and translated into a small, typed intermediate language in A-normal form (ANF). The Links interpreter implements a generalised CEK machine, which interprets ANF code.

Our compilation strategy is to translate the Links ANF language into the OCaml Lambda language, which is a small, un-typed lambda calculus. The OCaml backend exposes a hierarchy of intermediate representations (IRs), where the top representation is known as Lambda. As shown in Figure 1, the Lambda IR offers two different compilation options: byte code and native code. Therefore by targeting Lambda rather than a lower level IR, we achieve maximum flexibility as a translation into byte code, in principle, enables us to take advantage of custom backends such as js.

There are several semantic differences between Links and OCaml, e.g. Links employs structural typing, whilst OCaml predominantly employs nominal typing. In particular, Links employs row typing for effects, records, and variants, whereas OCaml only supports row typing for the latter. Exhibiting a faithful translation from Links to OCaml amounts to a lot of value boxing. Thus, we target Lambda for greater flexibility and control. We effectively subvert OCaml’s typechecker by targeting Lambda, however the translation is safe as Links programs are already typechecked.

4. Runtime Representation

By using the OCaml backend we naturally inherit the OCaml runtime. OCaml implements effect handlers as heap-managed stack data structures, and as a consequence composition of handlers gives rise to n-element stacks at run-time. For example, the composition randomResult(maybeResult(0)) is represented as a two-element stack. Thus, an invocation of an abstract operation amounts to the following in plain OCaml:

```ocaml
let all_results m = match m () with
| x -> [x]
| effect Choose k ->
  let k' arg = continue (Obj.clone_continuation k) arg
  in k' true @ k' false
```

OCaml provides a unified syntax for pattern-matching on regular, effect, and exception patterns. The keyword effect begins an operation-clause. Essentially, we create a local function k', which wraps the actual continuation k. An invocation of k' passes its argument to a fresh copy of the actual continuation. The continue function is provided by the standard library; given a continuation and a value, it invokes the continuation with that particular value. By default we implement every handler as a multi-shot handler.

5. Optimisations

Table 1 contains the results of a few micro-benchmarks from Kammar et al. [5]. Links Compiler corresponds to this work. While the results are promising, it is rather conservative to implement every handler as multi-shot. We would like to recover the efficiency of affine handlers, but without sacrificing abstraction.

**Handler Resolution** Traversing a large handler stack is likely to be costly. If the handler stack, or part of it, is known statically, then we can instantiate abstract operations at compile time.

**Linearisation** Handlers that use their continuations linearly should be promoted to linear handlers at compile time. We are currently working on applying the existing linear type system of Links to track the linearity of handlers.

### Table 1. Micro-benchmarks (execution times are in milliseconds)

<table>
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References