Continuation Passing Style for Effect Handlers

Mateusz Urbańczyk

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Abstract

We provide an implementation of algebraic effects and handlers by doing continuation passing style transformation of the functional programming language Freak, which is based on the existing Links language [9].

1 Introduction

In this article we present experimental programming language Freak, which is an implementation of Continuation Passing Style for Effect Handlers paper [9], with the addition of a few basic constructs. We start by presenting the related work, then discuss syntax and operational semantics. Basic usage guide for playing with the language is provided, as well as implementation details and examples. We conclude by stating what are the possible augmentations, that are intended to be made in the future.

2 State of the art

Except from Links language [9], on which the implementation is based, there are currently many other alternatives available. One may take a look at Frank [12], which provides a support for multihandlers, Koka [11], Helium [5] or Eff [2]. Except from separate languages, many libraries arose for existing ones like Haskell, Idris, Scala or Multicore OCaml.

As can be seen in the J. Yallop repository [6], algebraic effects and handlers are now trending branch in the programming languages theory.

3 Syntax

The syntax for the calculus is shown below. *nat* n represents an integer n, $V \oplus W$ and $V \approx W$ are respectively binary and relational operators, where we support basic arithmetic and comparison operations. **if** V **then** M **else** N is a standard branching statement. The other constructs are just as in Links, with

slight syntax modifications. Actual programs in Freak can be found in section 7 Examples

$$\begin{aligned}\langle \textit{Values } V,\ W\rangle ::= {} & x \mid \textit{nat } n \\ & \mid \backslash x : A \to M \mid \textbf{rec } g\ x \to M \\ & \mid V \oplus W \mid V \approx W \\ & \mid \langle\rangle \mid \{\ell = V; W\} \mid [\ell\ V]^R\end{aligned}$$

$$\begin{aligned}\langle \textit{Computations } M,\ N\rangle ::= {} & V\ W \\ & \mid \textbf{if } V \textbf{ then } M \textbf{ else } N \\ & \mid \textbf{let } \{\ell = x; y\} = V \textbf{ in } N \\ & \mid \textbf{case } V\{\ell\ x \to M; y \to N\} \mid \textbf{absurd } V \\ & \mid \textbf{return } V \mid \textbf{let } x \leftarrow M \textbf{ in } N \\ & \mid \textbf{do } \ell\ V \mid \textbf{handle } M \textbf{ with } \{H\}\end{aligned}$$

$$\langle \textit{Handlers } H\rangle ::= \textbf{return } x \to M \mid \ell\ p\ r \to M, H$$

$$\langle \textit{Binary operators } \oplus\rangle ::= + \mid \text{-} \mid * \mid /$$

$$\langle \textit{Relational operators } \approx\rangle ::= < \mid \leqslant \mid > \mid \geqslant \mid == \mid !=$$

4 Operational semantics

The source language's dynamics have been described extensively by providing small-step operational semantics, continuation passing style transformation [9] as well as abstract machine [7], which was proved to coincide with CPS translation. That being said, Freak introduces new basic constructs to the language, for which we shall define the semantics.

Extension of the evaluation contexts:

$$\mathcal{E} ::= \mathcal{E} \oplus W \mid V \oplus \mathcal{E} \mid \textbf{if } \mathcal{E} \textbf{ then } M \textbf{ else } N$$

Small-step operational semantics:

$$\begin{aligned}&\textbf{if } \textit{nat } n \textbf{ then } M \textbf{ else } N \rightsquigarrow M && \text{if } n \neq 0 \\ &\textbf{if } \textit{nat } n \textbf{ then } M \textbf{ else } N \rightsquigarrow N && \text{if } n = 0\end{aligned}$$

$$\begin{aligned}&\textit{nat } n \oplus \textit{nat } n' \rightsquigarrow n'' && \text{if } n'' = n \oplus n' \\ &\textit{nat } n \approx \textit{nat } n' \rightsquigarrow 1 && \text{if } n \approx n' \\ &\textit{nat } n \approx \textit{nat } n' \rightsquigarrow 0 && \text{if } n \not\approx n'\end{aligned}$$

5 Usage guide

All commands are available within `src` directory.

5.1 Build and install

- Install dependencies: `make install`
- Compile: `make build`
- Link to PATH: `sudo make link`
- Remove artiacts: `make clean`

After compiling and linking program to PATH, one may evaluate program as follows: `freak programs/choicesList.fk`. The actual code is described in subsection 7.1 Choice

5.2 Running tests

Test cases are available here, they include both inline and file-based tests. For more details about writing tests, one may refer to *HUnit documentation* [10].

- Run tests: `make tests`
- Run code linter: `make lint`
- Compile, run linter and tests: `make check`

6 Implementation

The Freak implementation is available here. While the paper provided a good overview of the language and the translation, the lower-level details were omitted. Therefore, the actual CPS implementation is based on A. Appel [1], which provides a translation for a simplified ML calculus.

Abstract Syntax Tree structure is defined just as syntax is. The core data structure, into which the source program is transformed, is defined as follows:

```
data ContComp
    = CPSApp CValue [CValue]
    | CPSFix Var [Var] ContComp ContComp
    | CPSBinOp BinaryOp CValue CValue Var ContComp
    | CPSValue CValue
    | CPSLet Var CValue ContComp
    | CPSSplit Label Var Var CValue ContComp
    | CPSCase CValue Label Var ContComp Var ContComp
    | CPSIf CValue ContComp ContComp
    | CPSAbsurd CValue
```

The translation is based on the curried first-order translation. For improving the performance of the evaluation, uncurried higher-order translation should be adopted, so that administrative redexes are contracted and proper tail-recursion is obtained. The final answer is represented as a `DValue`, where the meaning of the coproduct is as one would expect:

```
type Label = String

data DValue
    = DNum Integer
    | DLambda Env FuncRecord
    | DUnit
    | DPair DValue DValue
    | DLabel Label
```

6.1 Type inference

The type system as of this day is not implemented, as the focus has been put on CPS transformation. Further work is required here, especially considering the fact that a huge advantage of algebraic effects is that they are explicitly defined in the type of a computation.

6.2 Source code structure

The source code is divided into a number of modules, each with a different responsibility.

```
AST.hs          - AST data structures
CPS.hs          - CPS translation
Eval.hs         - Evaluation of the target calculus
Freak.hs        - API for the language
Main.hs         - Main module running evaluator on given filename
Parser.hs       - Parser and lexer
Tests.hs        - Tests module
Typechecker.hs  - -- suspended --
Types.hs        - Common types definition
programs/       - Exemplary programs used in tests
```

7 Examples

In this section we present a few examples to show the capabilities of the language. The ideas have been based on [3], and thus will not be described in great details. More exemplary programs in Freak language can be found here.

7.1 Choice

The first example will be based on modelling (nondeterministic) choice in the program. We will make two decisions, which will affect the computation result:

```
let c1 <- do Choice () in
let c2 <- do Choice () in
let x <- if c1 then return 10 else return 20 in
let y <- if c2 then return 0 else return 5 in
    return x - y
```

With that in hand, we may want to define effect handlers:

```
handle ... with {
    Choice p r ->
        let t <- r 1 in
        let f <- r 0 in
        <PLACEHOLDER> |
    return x -> return x
}
```

where in the `<PLACEHOLDER>` we can define on what to do with the computation. For example, min-max strategy for picking the minimum value:

```
if t < f then return t else return f
```

where the code evaluates to `5`. Another example is a handler that collects all possible results, which can be achieved by putting `return (t, f)` in the `<PLACEHOLDER>`, which evaluates to `((10, 5), (20, 15))`.

7.2 Exceptions

Exceptions are simply algebraic effect handlers which drop the resumption.

```
handle
    if x == 0 then do ZeroDivisionError ()
              else return 1/x
with {
    ZeroDivisionError p r -> return 42 |
    return x -> return x
}
```

Where we imagine that x variable has been bound previously.

7.3 Side effects

The complexity of the programs and their performance usually comes from side effects. Algebraic effects allow us to define code in a declarative manner, and hence neatly tame the side effects that they produce. This gives us a lot of flexibility in the actual meaning without duplicating the code. Let's consider the following very basic code snippet:

```
let x <- do Fetch () in
-- operate on x
```

The code is dependent on a context in which it is executed, which here is the handler that defines the behaviour of the algebraic `Fetch` effect. In the imperative, or even functional approach, we would need to provide the interface for fetching the data by doing dependency injection or even embedding the operation directly. Here we are just stating what operation we are performing, leaving the interpretation up to the execution context, which could do the fetching or mock the external resource.

These implications are straightforward when looking from a categorical standpoint and models of algebraic theories, nevertheless are very exciting for programming use cases. The current Freak implementation does not yet support I/O.

8 Future work

The Freak language is experimental and a lot of possible enhancements could be adopted. Here we provide a list of the proposed directions in which further work could be done.

8.1 Alternative evaluation

The Links language also provides small-step operational semantics and an abstract machine [7]. Implementing another way of evaluation could serve as a way to empirically assert correctness, as opposed to formally.

8.2 Make the language more usable

While the language is Turing-complete, for convenient usage it requires more basic constructs and syntactic sugar for common patterns that would ease the programming.

8.3 Multiple instances of algebraic effect

The Freak language is limited to a single instance of an effect. We would need to support cases where many instances of the algebraic effects, with the same

handler code, could be instantiated. The current state of the art introduces a concept of resources and instances, as in Eff [3], or instance variables, as in Helium [4].

8.4 Selective CPS

Other languages, like Koka [11], or even the core of the Links, are performing selective CPS translation, which reduces the overhead on code that does not perform algebraic effects. Our current translation is fully embedded in the CPS.

8.5 Exceptions as separate constructs

Exceptions are a trivial example of algebraic effect where the resumption is discarded, and as described in §4.5 [9], they can be modeled as a separate construct to improve performance.

8.6 Shallow handlers

Shallow and deep handlers while being able to simulate each other up to administrative reductions, have a very different meaning from a theoretical point of view. Implementing them as defined by Lindley et al. [8] could be another way of enhancing Freak.

References

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