Delimited Control

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Constraining Control

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@inproceedings{Friedman1985ConstrainingControl,
  author    = {Daniel P. Friedman and Christopher T. Haynes},
  title     = {Constraining Control},
  booktitle = {POPL},
  year      = {1985},
  pages     = {245-254},
}

@article{Haynes1987EmbeddingContinuations,
  author    = {Christopher T. Haynes and Daniel P. Friedman},
  title     = {Embedding Continuations in Procedural Objects},
  journal   = {ACM Trans. Program. Lang. Syst.},
  volume    = {9},
  number    = {4},
  year      = {1987},
  pages     = {582-598},
}
```

Summary

Haynes and Friedman show how to extend continuations and call/cc by first capturing the continuation provided by call/cc in another lambda, which they call a "continuation object (cob)", before passing the cob to call/cc's argument. Capturing the continuation in a cob allows greater flexibility because additional operations can be performed before the continuation is invoked. Haynes and Friedman present several useful programs that utilize both cobs and call/cc variations implemented using cobs, with each program building on the previous one.

First, cobs are used to implement fluid environments (dynamic binding), which are used to implement dynamic domains, which are finally used to implement `dynamic-wind`. The `dynamic-wind` operator is used when a programmer wants to guarantee that certain operations are executed when a specified block of code is entered or exited. One application of `dynamic-wind` is to ensure that file streams are always properly closed when they are no longer needed.

Analysis

The primary conclusion of the paper is that continuations provided by call/cc must be properly harnessed and constrained in order to be useful. In the paper, cobs are used to accomplish this. However, the programs presented in the paper are rather inelegant and inefficient. The authors allude to this when they say that the paper "emphasized semantics, while ignoring some security and efficiency issues." The more general problem seems to be that call/cc is "too powerful" because most applications do not need the entire remainder of the program. A better control operator should give the programmer finer-grained access to the program's context.

The Theory and Practice of First-Class Prompts

```
@inproceedings{Felleisen1998Prompts,
  author    = {Matthias Felleisen},
  title     = {The Theory and Practice of First-Class Prompts},
  booktitle = {POPL},
  year      = {1988},
  pages     = {180-190},
}
```

Summary

It has been previously argued that call/cc does not give the programmer complete control over the program because it aborts the current continuation when the captured continuation is invoked [2]. To address this, Felleisen introduces the $\mathcal{F}$ operator [1], which is a variation of call/cc. $\mathcal{F}$ differs from call/cc in two ways. The first is that call/cc implicitly installs a copy of the captured context while $\mathcal{F}$ does not. Secondly, unlike call/cc, the continuations captured by $\mathcal{F}$ do not abort the current continuation when invoked. This gives the programmer finer-grained control over the continuation because continuations can be invoked as many times as necessary, as well as composed. Replacing call/cc with $\mathcal{F}$ also simplifies a calculus like Felleisen's λ_v–C calculus, which formalizes such control operators.

The problem with the λ_v–C calculus is that an evaluator based on the calculus does not obey operational equivalence. To address this problem, Felleisen adds a first-class prompt (#) operator to the calculus that delimits the extent of the continuation captured by the $\mathcal{F}$ operator. With the prompt, expressions that are equal in the calculus behave equivalently in all contexts. Felleisen then derives an abstract machine from the new calculus, and also presents several programming applications of prompts, including a much simpler implementation of the `dynamic-wind` operator of Haynes and Friedman. Having first-class prompts in the language gives the programmer finer-grained control because 1) control operators can only capture context up to the nearest prompt delimiter, and 2) control actions can only erase context up to the nearest prompt delimiter.

Analysis

It seems that the initial motivation for adding first-class prompts to the calculus was to fix operational equivalence, and it wasn't realized until afterwards that prompts are a useful programming construct in their own right. The primary benefit of the $\mathcal{F}$ and prompt operators is that control can be constrained, but another benefit (compared to an operator like call/cc) is that captured continuations can be composed. Perhaps this is implied (because an invocation of a continuation in the abstract machine is just a stack append) but this does not seem to be explicitly stated in the paper.

This is also an instance where studying a formal model of a language revealed an alternative ($\mathcal{F}$) to an existing construct (call/cc), as well as uncovered a new construct (prompts).

Control Delimiters and Their Hierarchies

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@article{Sitaram1990Hierarchies,
  author    = {Dorai Sitaram and Matthias Felleisen},
  title     = {Control Delimiters and Their Hierarchies},
  journal   = {Lisp and Symbolic Computation},
  volume    = {3},
  number    = {1},
  year      = {1990},
  pages     = {67-99},
}
```

Summary

A problem with Felleisen's $\mathcal{F}$ and `prompt` operators is that multiple uses of the operators in a program may interfere with each other. This interference affects not only the correct behavior of a program, but is also a security issue because user-defined control operators may conflict with built-in constructs, thus crossing a programming language's abstraction boundary. After discussing $\mathcal{F}$ and `prompt` (called `control` and `run` this paper) and their relation to `call/cc`, as well as presenting several programming applications of `control` and `run`, Sitaram and Felleisen suggest that the interference problem can be addressed by installing a hierarchy of control operators. Specifically, each `control` and `run` is assigned a "level" and a `run` delimits all `control` applications at or above its level. Therefore, operators with a higher level have less access to the program context. In this way, a language can protect its abstractions while still providing the programmer with general `control` and `run` operators; it simply gives the programmer-level control operators a higher level. The authors add the qualification that their proposed scheme may not be ideal in every situation, but that any hierarchy of control operators would be beneficial in enhancing the robustness and security of a language.

Abstracting Control

```
@inproceedings{Danvy1990AbstractingControl,
  author    = {Olivier Danvy and Andrzej Filinski},
  title     = {Abstracting Control},
  booktitle = {LISP and Functional Programming},
  year      = {1990},
  pages     = {151-160},
}
```


Summary

Danvy and Filinski show that a hierarchy of delimited contexts can be achieved by repeatedly iterating the standard CPS transformation on a programming language (to get what they call "extended CPS"). They introduce the `shift` and `reset` operators, which provide the programmer access to the program context. `shift` and `reset` are comparable to the `control` and `prompt` operators of Felleisen and Sitaram. Danvy and Filinski's approach differs from that of Felleisen in that the continuation captured by `shift` can be determined statically, while `control` captures a continuation up to the nearest dynamic `prompt`. This allows the continuation captured by `shift` to be formally specified as a function, rather than a series of dynamic continuation frames.

The authors present a denotational semantics of a language that includes `shift` and `reset`, as well as several applications of those control operators. One such application is implementing the CPS transformation metacircularly using the `shift` and `reset` operators themselves. This implementation also improves the efficiency of the CPS conversion because it folds in several optimizations that were previously performed after the conversion.

References

1. Felleisen, M., Friedman, D. P., Duba, B. F., and Merrill, J. Beyond continuations. Tech. rep., Indiana University, 1987.
2. Felleisen, M., Friedman, D. P., Kohlbecker, E. E., and Duba, B. F. A syntactic theory of sequential control. *Theor. Comput. Sci. 52* (1987), 205–237.