The CPS Transform

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Objectives

You should be able to ...

You've seen how to write CPS functions by hand, but we want you to know the mathematical definition.

After today's lecture, you will

- Convert a direct-style function into CPS:
  - Both simple and complex, involving nested continuations.

The CPS Transform, Simple Expressions

Top Level Declaraion To convert a declaration, add a continuation argument to it and then convert the body.

$$C[\![f\ arg\ =\ e)]\!] \Rightarrow f\ arg\ k\ =\ C[\![e]\!]_k$$

Simple Expressions A simple expression in tail position should be passed to a continuation instead of returned.

$$C[\![a]\!]_k \Rightarrow\ k\ a$$

- "Simple" = "No available function calls."
- $f\ a$ is available in $3 + f\ a$, but not in $\lambda x.x + f\ a$.

Try converting these functions ...

```
f x = x
pi1 a b = a
const x = 10
```

Simple Expression Examples

Before:

```
f x = x
pi1 a b = a
const x = 10
```

After:

```
f x k = k x
pi1 a b k = k a
const x k = k 10
```

The CPS Transform, Function Calls

Function Call on Simple Argument To a function call in tail position (where `arg` is simple), pass the current continuation.

$$C[\![f\ arg]\!]_k \Rightarrow\ f\ arg\ k$$

Function Call on Non-simple Argument If `arg` is not simple, we need to convert it first.

$$C[\![f\ arg]\!]_k \Rightarrow\ C[\![arg]\!]_{(\lambda v.f\ v\ k)},\ \text{where } v \text{ is fresh.}$$

Try converting these functions.

```
foo 0 = 0
foo n | n < 0       = foo n
      | otherwise = inc (foo n)
```

Example

```haskell
foo 0 = 0
foo n | n < 0       = foo n
      | otherwise = inc (foo n)
```

```haskell
foo 0 k = k 0
foo n k | n < 0       = foo n k
        | otherwise = foo n (\v -> inc v k)
```

The CPS Transform, Operators

Operator with Two Simple Arguments If both arguments are simple, then the whole thing is simple.

$$C[\![e_1 + e_2]\!]_k \Rightarrow\ k(e_1 + e_2)$$

Operator with One Simple Argument If e_2 is simple, we transform e_1.

$$C[\![e_1 + e_2]\!]_k \Rightarrow\ C[\![e_1]\!]_{(\lambda v -> k(v + e2))} \text{where } v \text{ is fresh.}$$

Operator with No Simple Arguments If both need to be transformed ...

$$C[\![e_1 + e_2]\!]_k \Rightarrow\ C[\![e_1]\!]_{(\lambda v_1 -> C[\![e_2]\!]_{\lambda v_2 -> k(v_1 + v_2)})} \text{where } v_1 \text{ and } v_2 \text{ are fresh.}$$

Notice that we need to nest the continuations!

Examples

```
foo a b = a + b
bar a b = inc a + b
baz a b = a + inc b
quux a b = inc a + inc b
```

Examples

```
foo a b = a + b
bar a b = inc a + b
baz a b = a + inc b
quux a b = inc a + inc b
```

```
foo a b k = k (a + b)
```

Examples

```
foo a b = a + b
bar a b = inc a + b
baz a b = a + inc b
quux a b = inc a + inc b
```

```
foo a b k = k (a + b)
bar a b k = inc a (\v -> k (v + b))
```

Examples

```
foo a b = a + b
bar a b = inc a + b
baz a b = a + inc b
quux a b = inc a + inc b
```

```
foo a b k = k (a + b)
bar a b k = inc a (\v -> k (v + b))
baz a b k = inc b (\v -> k (a + v))
```

Examples

```
foo a b = a + b
bar a b = inc a + b
baz a b = a + inc b
quux a b = inc a + inc b
```

```
foo a b k = k (a + b)
bar a b k = inc a (\v -> k (v + b))
baz a b k = inc b (\v -> k (a + v))
quux a b k = inc a (\v1 -> inc b (\v2 -> k (v1 + v2)))
```

References

[DF90] Olivier Danvy and Andrzej Filinski. "Abstracting control". In: *Proceedings of the 1990 ACM conference on LISP ...* (1990), pp. 151–160. ISSN: 1098-6596. DOI: http://doi.acm.org.ezp-prod1.hul.harvard.edu/10.1145/91556.91622.

[DF92] Oliver Danvy and Andrzex Filinski. "Representing Control: a Study of the CPS Transformation". In: *Mathematical Structures in Computer Science* 2.04 (1992), p. 361. ISSN: 0960-1295. DOI: 10.1017/S0960129500001535.

[Rey93] John C. Reynolds. "The discoveries of continuations". In: *LISP and Symbolic Computation* 6.3 (Nov. 1993), pp. 233–247. ISSN: 1573-0557. DOI: 10.1007/BF01019459. URL: https://doi.org/10.1007/BF01019459.