CS 4110

Programming Languages & Logics

Lecture 19
Continuations

Continuations

In the preceding translations, the control structure of the source language was translated directly into the corresponding control structure in the target language.

For example:

$$\mathcal{T}[\![\lambda x.\, e]\!] = \lambda x.\, \mathcal{T}[\![e]\!]$$
$$\mathcal{T}[\![e_1\; e_2]\!] = \mathcal{T}[\![e_1]\!]\; \mathcal{T}[\![e_2]\!]$$

What can go wrong with this approach?

Continuations

- A snippet of code that represents “the rest of the program”
- Can be used directly by programmers…
- …or in program transformations by a compiler
- Make the control flow of the program explicit
- Also useful for defining the meaning of features like exceptions

Example

Consider the following expression:

$$(\lambda x.\, x)\ ((1 + 2) + 3) + 4$$

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$$(\lambda x.\, x)\ ((1+2)+3)+4$$

If we make all of the continuations explicit, we obtain:

$$k_0 = \lambda v.\, (\lambda x.\, x)\ v$$

Example

Consider the following expression:

$$(\lambda x.\, x)\ ((1+2)+3)+4$$

If we make all of the continuations explicit, we obtain:

$$\begin{aligned} k_0 &= \lambda v.\, (\lambda x.\, x)\ v \\ k_1 &= \lambda a.\, k_0\ (a+4) \end{aligned}$$

Example

Consider the following expression:

$$(\lambda x.\, x)\; ((1 + 2) + 3) + 4$$

If we make all of the continuations explicit, we obtain:

$$\begin{aligned} k_0 &= \lambda v.\, (\lambda x.\, x)\; v \\ k_1 &= \lambda a.\, k_0\; (a + 4) \\ k_2 &= \lambda b.\, k_1\; (b + 3) \end{aligned}$$

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The original expression is equivalent to $k_3\ 1$, or:

$$(\lambda c.\, (\lambda b.\, (\lambda a.\, (\lambda v.\, (\lambda x.\, x)\ v)\ (a + 4))\ (b + 3))\ (c + 2))\ 1$$

Example (Continued)

Recall that let $x = e$ in e' is syntactic sugar for $(\lambda x.\, e')\; e$.

Hence, we can rewrite the expression with continuations more succinctly as

$$\begin{array}{l}
\text{let } c = 1 \text{ in} \\
\text{let } b = c + 2 \text{ in} \\
\text{let } a = b + 3 \text{ in} \\
\text{let } v = a + 4 \text{ in} \\
(\lambda x.\, x)\; v
\end{array}$$

CPS Transformation

We write $\mathcal{CPS}[\![e]\!]\ k = \ldots$ instead of $\mathcal{CPS}[\![e]\!] = \lambda k.\ \ldots$

We assume that the new variables introduced are "fresh."

CPS Transformation

$$\mathcal{CPS}[\![n]\!]\,k = k\,n$$

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CPS Transformation

$$\mathcal{CPS}[\![n]\!]\,k = k\,n$$
$$\mathcal{CPS}[\![e_1 + e_2]\!]\,k = \mathcal{CPS}[\![e_1]\!]\,(\lambda n.\,\mathcal{CPS}[\![e_2]\!]\,(\lambda m.\,k\,(n+m)))$$

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\mathcal{CPS}[\![(e_1, e_2)]\!]\,k &= \mathcal{CPS}[\![e_1]\!]\,(\lambda v.\,\mathcal{CPS}[\![e_2]\!]\,(\lambda w.\,k\,(v, w)))
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\mathcal{CPS}[\![\#2\, e]\!]\, k &= \mathcal{CPS}[\![e]\!]\, (\lambda v.\, k\, (\#2\, v)) \\
\mathcal{CPS}[\![x]\!]\, k &= k\, x \\
\mathcal{CPS}[\![\lambda x.\, e]\!]\, k &= k\, (\lambda x.\, \lambda k'.\, \mathcal{CPS}[\![e]\!]\, k')
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\mathcal{CPS}[\![e_1\;e_2]\!]\,k &= \mathcal{CPS}[\![e_1]\!]\,(\lambda f.\,\mathcal{CPS}[\![e_2]\!]\,(\lambda v.\,f\,v\,k))
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