

# F AE-cps – F AE with Continuation-Passing Style

## 1 INTRODUCTION

F AE-cps is a toy language for the [COSE212](#) course at Korea University. F AE-cps stands for the [F AE](#) language with the **continuation-passing style (CPS)**. Since it has the same syntax and semantics as F AE, it supports the following features:

- **integers**
- **basic arithmetic operators**: addition (+) and multiplication (\*)
- **first-class functions**

This document is the specification of F AE-cps. While it has the same syntax and semantics as F AE, Section 2 and Section 3 repeat the concrete and abstract syntax parts for completeness, respectively. Section 4 redefines the same semantics in a small-step operational (reduction) semantics style rather than a big-step style.

## 2 CONCRETE SYNTAX

The concrete syntax of F AE-cps is written in a variant of the extended Backus–Naur form (EBNF). The notation `<nt>` denotes a nonterminal, and `"t"` denotes a terminal. We use `?` to denote an optional element and `+` (or `*`) to denote one or more (or zero or more) repetitions of the preceding element. We use **butnot** to denote a set difference to exclude some strings from a producible set of strings. We omit some obvious terminals using the ellipsis (`...`) notation.

```
// basic elements
<digit>    ::= "0" | "1" | "2" | ... | "9"
<number>   ::= "-"? <digit>+
<alphabet> ::= "A" | "B" | "C" | ... | "Z" | "a" | "b" | "c" | ... | "z"
<idstart>  ::= <alphabet> | "_"
<idcont>   ::= <alphabet> | "_" | <digit>
<id>       ::= <idstart> <idcont>*

// expressions
<expr>     ::= <number> | <expr> "+" <expr> | <expr> "*" <expr> | <id>
              | "(" <expr> ")" | "{" <expr> "}"
              | <id> "=>" <expr> | <expr> "(" <expr> ")"
```

The precedence and associativity of operators are defined as follows:

Operator	Associativity	Precedence
*	left	1
+	left	2

### 3 ABSTRACT SYNTAX

The abstract syntax of FAE-cps is defined as follows:

Expressions	$\mathbb{E} \ni e ::= n$	(Num)	where	Integers	$n \in \mathbb{Z}$	(BigInt)
	$  e + e$	(Add)		Identifiers	$x \in \mathbb{X}$	(String)
	$  e \times e$	(Mul)				
	$  x$	(Id)				
	$  \lambda x. e$	(Fun)				
	$  e(e)$	(App)				

### 4 SEMANTICS

We use the following notations in the semantics:

Values	$\mathbb{V} \ni v ::= n$	(NumV)
	$  \langle \lambda x. e, \sigma \rangle$	(CloV)
Environments	$\sigma \in \mathbb{X} \xrightarrow{\text{fin}} \mathbb{V}$	(Env)
Continuations	$\mathbb{K} \ni \kappa ::= \square$	(EmptyK)
	$  (\sigma \vdash e) :: \kappa$	(EvalK)
	$  (+) :: \kappa$	(AddK)
	$  (\times) :: \kappa$	(MulK)
	$  (@) :: \kappa$	(AppK)
Value Stacks	$\mathbb{S} \ni s ::= \blacksquare \mid v :: s$	(List[Value])

The small-step operational (reduction) semantics of FAE-cps is defined as follows:

	$\langle \kappa \parallel s \rangle \rightarrow \langle \kappa \parallel s \rangle$	
Num	$\langle (\sigma \vdash n) :: \kappa \parallel s \rangle$	$\rightarrow \langle \kappa \parallel n :: s \rangle$
Add <sub>1</sub>	$\langle (\sigma \vdash e_1 + e_2) :: \kappa \parallel s \rangle$	$\rightarrow \langle (\sigma \vdash e_1) :: (\sigma \vdash e_2) :: (+) :: \kappa \parallel s \rangle$
Add <sub>2</sub>	$\langle (+) :: \kappa \parallel n_2 :: n_1 :: s \rangle$	$\rightarrow \langle \kappa \parallel (n_1 + n_2) :: s \rangle$
Mul <sub>1</sub>	$\langle (\sigma \vdash e_1 \times e_2) :: \kappa \parallel s \rangle$	$\rightarrow \langle (\sigma \vdash e_1) :: (\sigma \vdash e_2) :: (\times) :: \kappa \parallel s \rangle$
Mul <sub>2</sub>	$\langle (\times) :: \kappa \parallel n_2 :: n_1 :: s \rangle$	$\rightarrow \langle \kappa \parallel (n_1 \times n_2) :: s \rangle$
Id	$\langle (\sigma \vdash x) :: \kappa \parallel s \rangle$	$\rightarrow \langle \kappa \parallel \sigma(x) :: s \rangle$
Fun	$\langle (\sigma \vdash \lambda x. e) :: \kappa \parallel s \rangle$	$\rightarrow \langle \kappa \parallel \langle \lambda x. e, \sigma \rangle :: s \rangle$
App <sub>1</sub>	$\langle (\sigma \vdash e_1(e_2)) :: \kappa \parallel s \rangle$	$\rightarrow \langle (\sigma \vdash e_2) :: (\sigma \vdash e_1) :: (@) :: \kappa \parallel s \rangle$
App <sub>2</sub>	$\langle (@) :: \kappa \parallel v_2 :: \langle \lambda x. e, \sigma \rangle :: s \rangle$	$\rightarrow \langle (\sigma[x \mapsto v_2] \vdash e) :: \kappa \parallel s \rangle$

where  $\rightarrow^*$  is the reflexive-transitive closure of  $\rightarrow$  and denotes the repeated reduction:

$$\langle \kappa \parallel s \rangle \rightarrow^* \langle \kappa \parallel s \rangle$$

$$\frac{\langle \kappa \parallel s \rangle \rightarrow^* \langle \kappa' \parallel s' \rangle \quad \langle \kappa' \parallel s' \rangle \rightarrow \langle \kappa'' \parallel s'' \rangle}{\langle \kappa \parallel s \rangle \rightarrow^* \langle \kappa'' \parallel s'' \rangle}$$

The evaluation result of an expression  $e$  is the value  $v$  if

$$\langle (\emptyset \vdash e) :: \square \parallel \blacksquare \rangle \rightarrow^* \langle \square \parallel v :: \blacksquare \rangle$$