Semantics of Functional Programming

Lecture III: The Scott Model of **PCF**

Chuang, Tyng-Ruey
`trc.iis.sinica.edu.tw`

Institute of Information Science, Academia Sinica

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Interpretation of types and contexts

Definition 1

Every type σ in **PCF** associates with a domain D_σ as follows:

1. $[\![\mathtt{nat}]\!] := \mathbb{N}_\perp$, and
2. $[\![\tau \to \sigma]\!] := [\![\sigma]\!]^{[\![\tau]\!]}$.

Definition 2

For each context $\Gamma = x_1 : \sigma_1, x_2 : \sigma_2, \ldots, x_n : \sigma_n$, the associated domain is defined as

$$[\![\Gamma]\!] := [\![\sigma_1]\!] \times [\![\sigma_2]\!] \times \cdots \times [\![\sigma_n]\!]$$

and the associated domain of the empty context is $1 = \{*\}$.

Every judgement of this form $\Gamma \vdash \mathsf{M} : \tau$ will be interpreted as a function

$$[\![\Gamma \vdash \mathsf{M} : \tau]\!] : [\![\Gamma]\!] \to [\![\tau]\!].$$

Interpretation of simply type lambda calculus and natural numbers

$$[\![x_1 : \sigma_1, \ldots, x_n : \sigma_n \vdash x_i : \sigma_i]\!] := \pi_i \quad \text{for } i = 1 \ldots n$$

$$[\![\Gamma \vdash \lambda x.\, \mathsf{M} : \sigma \to \tau]\!] := \Lambda [\![\Gamma, x : \sigma \vdash \mathsf{M} : \tau]\!]$$

$$[\![\Gamma \vdash \mathsf{M}\ \mathsf{N} : \tau]\!] = ev \circ \langle [\![\Gamma \vdash \mathsf{M} : \sigma \to \tau]\!], [\![\Gamma \vdash \mathsf{N} : \sigma]\!] \rangle$$

$$[\![\Gamma \vdash \mathtt{zero} : \mathtt{nat}]\!](\vec{d}) := 0$$

$$[\![\Gamma \vdash \mathtt{suc}\ \mathsf{M} : \mathtt{nat}]\!] := S \circ [\![\Gamma \vdash \mathsf{M} : \mathtt{nat}]\!]$$

Interpretation of general recursion and if-zero test

$$[\![\Gamma \vdash \mathtt{Y}x.\,\mathsf{M} : \sigma]\!] := \mu \circ \Lambda[\![\Gamma, x : \sigma \vdash \mathsf{M} : \sigma]\!]$$

$$\begin{aligned} &[\![\Gamma \vdash \mathtt{ifz}(\mathsf{M}; \mathsf{M}_0; \mathsf{M}_1) : \tau]\!] \\ &:= \mathit{ifz}_\tau \circ \langle\, [\![\Gamma \vdash \mathsf{M} : \mathtt{nat}]\!], [\![\Gamma \vdash \mathsf{M}_0 : \tau]\!], \Lambda[\![\Gamma, x : \mathtt{nat} \vdash \mathsf{M}_1 : \tau]\!] \,\rangle \end{aligned}$$

where S and ifz_τ are defined by

$$S(n) := \begin{cases} \bot & \text{if } d = \bot \\ n+1 & \text{otherwise.} \end{cases} \qquad \mathit{ifz}_\tau(n, x, f) := \begin{cases} \bot & \text{if } n = \bot, \\ x & \text{if } n = 0, \\ f(m) & \text{if } n = m+1. \end{cases}$$

In particular, every program $\mathsf{M} : \tau$ associates with a function from 1 to $[\![\tau]\!]$, and thus determines a unique element $[\![\mathsf{M}]\!](*)$ of $[\![\tau]\!]$.

Convention

For brevity, we write $[\![\mathsf{M}]\!]$ instead of $[\![\vdash \mathsf{M} : \tau]\!](*)$ for every program M of type τ

Theorem 3

For every judgement $\Gamma \vdash \mathsf{M} : \tau$, the associated function

$$[\![\Gamma \vdash \mathsf{M} : \tau]\!] : [\![\Gamma]\!] \to [\![\tau]\!]$$

is Scott continuous.