

Proofs as Programs

Exercises in Type Level Programming

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Kosice, 16 Nov. 2023

About the project

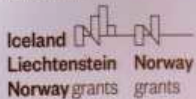
The **Modern Approaches and Tools for Teaching Classes at the University Level in Theoretical Computer Science Courses of Logic, Types, and Semantics** initiative no: **FBR-PDI-025** is funded by Iceland, Liechtenstein and Norway through the EEA Grants and Norway Grants.



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Talk given in context of

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Agenda

- ▶ Propositions as types, proofs as programs.
- ▶ Exercises.
- ▶ What are dependent types.
- ▶ How can we simulate dependent types in Haskell.
- ▶ Exercises.
- ▶ Discussion.

The Curry-Howard-Lambek Correspondence

From Wikipedia

- ▶ Curry 1934 : Types look like axiom schemes for intuitionistic logic.
- ▶ Curry 1958 : Hilbert style deduction systems coincide with the typed fragment of combinatory logic.
- ▶ Howard 1969 : Natural deduction can be directly interpreted in a typed lambda calculus.
- ▶ Lambek 2005 : Lambda calculi are structurally equivalent to Cartesian closed categories.

Propositions as types, Proofs as Programs (Exercises)

`https://github.com/jtkristensen/
exercises-in-type-level-programming/tree/main/
tuke-2023/ProofsAsPrograms`

Lambda Cube (λ_{\rightarrow})

$$t ::= x \mid \lambda x : \tau. t \mid t_1 t_2$$

$$\tau ::= \tau_1 \rightarrow \tau_2$$

$\boxed{\Gamma \vdash t : \tau}$, for closed terms t :

$$\text{Var}_t : \frac{\Gamma(x) = \tau}{\Gamma \vdash x : \tau} \quad \text{Abs}_{t \rightarrow t} : \frac{\Gamma[x \mapsto \tau_1] \vdash t : \tau_2}{\Gamma \vdash \lambda x : \tau_1. t : \tau_1 \rightarrow \tau_2}$$

$$\text{App}_{tt} : \frac{\Gamma \vdash t_1 : \tau_1 \rightarrow \tau_2 \quad \Gamma \vdash t_2 : \tau_1}{\Gamma \vdash t_1 t_2 : \tau_2}$$

Lambda Cube (λ_2)

$t ::= x \mid \lambda x : \tau. t \mid \Lambda X. t \mid t_1 t_2 \mid t[\tau]$

$\tau ::= X \mid \forall X. \tau \mid \tau_1 \rightarrow \tau_2$

$\boxed{\Gamma \vdash t : \tau}$, for closed terms t :

$$\text{Var}_t : \frac{\Gamma(x) = \tau}{\Gamma \vdash x : \tau} \quad \text{Abs}_{t \rightarrow t} : \frac{\Gamma[x \mapsto \tau_1] \vdash t : \tau_2}{\Gamma \vdash \lambda x : \tau_1. t : \tau_1 \rightarrow \tau_2}$$

$$\text{App}_{tt} : \frac{\Gamma \vdash t_1 : \tau_1 \rightarrow \tau_2 \quad \Gamma \vdash t_2 : \tau_1}{\Gamma \vdash t_1 t_2 : \tau_2}$$

$\boxed{\Gamma \vdash t : \tau}$, for closed terms t :

$$\text{Abs}_{\tau \rightarrow t} : \frac{\Gamma \vdash t : \tau}{\Gamma \vdash \Lambda X. t : \forall X. \tau} \quad \text{App}_{t\tau} : \frac{\Gamma \vdash t : \forall X. \tau_1}{\Gamma \vdash t[\tau_2] : \tau_1[\tau_2/X]}$$

Lambda Cube (λ_ω)

$$t ::= x \mid \lambda x : \tau. t \mid t_1 t_2$$

$$\tau ::= X \mid \lambda X : \kappa. \tau \mid \tau_1 \rightarrow \tau_2 \mid \tau_1 \tau_2$$

$$\kappa ::= * \mid \kappa_1 \rightarrow \kappa_2$$

$\boxed{\Gamma \vdash t : \tau}$, for closed terms t :

$$\text{Var}_t : \frac{\Gamma(x) = \tau}{\Gamma \vdash x : \tau} \quad \text{Abs}_{t \rightarrow t} : \frac{\Gamma[x \mapsto \tau_1] \vdash t : \tau_2}{\Gamma \vdash \lambda x : \tau_1. t : \tau_1 \rightarrow \tau_2}$$

$$\text{App}_{tt} : \frac{\Gamma \vdash t_1 : \tau_1 \rightarrow \tau_2 \quad \Gamma \vdash t_2 : \tau_1}{\Gamma \vdash t_1 t_2 : \tau_2}$$

repeat Var_t , $\text{Abs}_{t \rightarrow t}$ and App_{tt} to get Var_τ , $\text{Abs}_{\tau \rightarrow \tau}$ and $\text{App}_{\tau\tau}$.

Lambda Cube (λ_{Π})

$$t ::= x \mid \lambda x : \tau. B \mid t_1 t_2$$

$$\tau ::= \Pi x : A. B \mid \tau \rightarrow \tau$$

$$\kappa ::= * \mid \Pi x : \tau. \kappa$$

$\boxed{\Gamma \vdash t : \tau}$, for closed terms t :

$$\text{Var}_t : \frac{\Gamma(x) = \tau}{\Gamma \vdash x : \tau} \quad \text{Abs}_{t \rightarrow t} : \frac{\Gamma[x \mapsto \tau_1] \vdash t : \tau_2}{\Gamma \vdash \lambda x : \tau_1. t : \tau_1 \rightarrow \tau_2}$$

$$\text{App}_{tt} : \frac{\Gamma \vdash t_1 : \tau_1 \rightarrow \tau_2 \quad \Gamma \vdash t_2 : \tau_1}{\Gamma \vdash t_1 t_2 : \tau_2}$$

$\boxed{\Gamma \vdash t : \tau}$, for closed terms t :

$$\text{Abs}_{t \rightarrow \tau} : \frac{\Gamma \vdash A : \tau \quad \Gamma[x \mapsto A] \vdash B : \sigma \quad \Gamma[x \mapsto A] \vdash B' : B}{\Gamma \vdash \lambda x : A. B' : \Pi x : A. B} \quad (\sigma \in \{\kappa, \tau\})$$

$$\text{App}_{\tau t} : \frac{\Gamma \vdash t_1 : \Pi x : \tau. B \quad \Gamma \vdash t_2 : \tau}{\Gamma \vdash t_1 t_2 : B[t_2/x]}$$

Simulating Dependent types in Haskell (Exercises)

`https://github.com/jtkristensen/
exercises-in-type-level-programming/tree/main/
tuke-2023/NatProperties`

Discussion