

System F with exceptions

Sylvain Lebresne

Logical, INRIA and PPS, Université Paris 7

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1 Introduction

2 Presenting F_X

- The terms side
- The types side

3 A realisability model of F_X

4 Conclusion and perspectives

What are exceptions ?

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- What about exceptions in type theoretical settings?

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- with (raise_{cbn}) , not confluent.

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And we want to be able to type such a value.

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- A subtyping relation noted $\leq$.
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- With new type constructions to type it.
- All the typing and subtyping rules of F_η are unchanged. We only add rules.
- Justified by a realisability model.

F_X syntax

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where $\varepsilon \in \mathcal{E}$.

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We also define a notion of value:

$$V ::= \lambda x. M \mid 0 \mid S \mid S N \mid \text{Rec} \mid \text{Rec } M \mid \text{Rec } M N \mid \text{eval}$$

Reduction in F_X (1/2)

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 (\lambda x. M) N & > M\{x := N\} \\
 (\text{raise } \varepsilon) M & > \text{raise } \varepsilon \\
 \text{try}(\text{raise } \varepsilon) \text{ with } \varepsilon \mapsto N & > N \\
 \text{try}(\text{raise } \varepsilon') \text{ with } \varepsilon \mapsto N & > \text{raise } \varepsilon' \\
 \text{try } V \text{ with } \varepsilon \mapsto N & > V
 \end{array}$$

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$(\lambda x. M) N$	$>$	$M\{x := N\}$
$(\text{raise } \varepsilon) M$	$>$	$\text{raise } \varepsilon$
$\text{try}(\text{raise } \varepsilon) \text{ with } \varepsilon \mapsto N$	$>$	N
$\text{try}(\text{raise } \varepsilon') \text{ with } \varepsilon \mapsto N$	$>$	$\text{raise } \varepsilon'$
$\text{try } V \text{ with } \varepsilon \mapsto N$	$>$	V
$\text{Rec } X \ Y \ 0$	$>$	X
$\text{Rec } X \ Y \ (S \ N)$	$>$	$Y \ N \ (\text{Rec } X \ Y \ N)$
$\text{Rec } X \ Y \ (\text{raise } \varepsilon)$	$>$	$\text{raise } \varepsilon$

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Easily defined with Rec and by using an accumulator.

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Types of F_X

The syntax for the types of F_X is given by:

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Terms of $A \uplus \Delta$ are the ones caught by a try.

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What type to give to S (`raise  $\varepsilon$`) ?

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What type to give to $S(\text{raise } \varepsilon)$?

The type $\mathbb{N} \uplus \{\varepsilon\}$ is of course not appropriate.

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$$f : (A \rightarrow B) \uplus \{\varepsilon\}$$

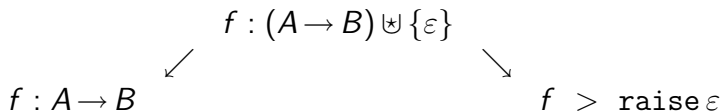
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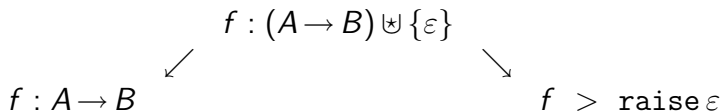
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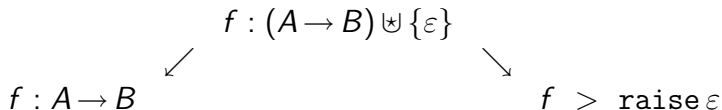
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What about $(A \rightarrow B) \uplus \Delta$?



But f is not allowed by typing to be applied to a term of A
 Type construction $A \uplus \Delta$ doesn't deal well with arrow types.

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Another way to see it,

- a term of $A \uplus \Delta$ may raise an exception at top-level.
- a term of A^Δ may raise an exception in some evaluation context (of A).

Remark: A^Δ is a broader type than $A \uplus \Delta$.

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and finally:

$$S(\text{raise } \varepsilon) : \mathbb{N}^{\{\varepsilon\}}$$

Typing rules of *F_X*

$$\frac{(x : A) \in \Gamma}{\Gamma \vdash x : A} \text{ (ax)}$$

$$\frac{\Gamma, x : A \vdash M : B}{\Gamma \vdash \lambda x. M : A \rightarrow B} \text{ (abs)}$$

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$$\overline{\Gamma \vdash 0 : \mathbb{N}} \text{ (zero)}$$

$$\overline{\Gamma \vdash S : \mathbb{N} \rightarrow \mathbb{N}} \text{ (succ)}$$

$$\overline{\Gamma \vdash \text{Rec} : \forall \alpha. \alpha \rightarrow (\mathbb{N} \rightarrow \alpha \rightarrow \alpha) \rightarrow \mathbb{N} \rightarrow \alpha} \text{ (rec)}$$

Typing rules of *F_X* continued

$$\frac{}{\Gamma \vdash \text{raise } \varepsilon : \emptyset \star \{\varepsilon\}} \text{ (raise)} \qquad \emptyset \equiv \forall \alpha. \alpha$$

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$$\frac{\Gamma \vdash M : A \star \{\varepsilon\} \quad \Gamma \vdash N : A}{\Gamma \vdash \text{try } M \text{ with } \varepsilon \mapsto N : A} \quad (\text{try})$$

Typing rules of *F_X* continued

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$$\frac{}{\Gamma \vdash \text{eval} : \mathbb{N}^\Delta \rightarrow \mathbb{N} \star \Delta} \text{ (eval)}$$

First subtyping rules: F_η

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$$\frac{A \leq B \quad \alpha \notin FV(A)}{A \leq \forall \alpha. B} \text{ (f-gen)} \qquad \frac{}{\forall \alpha. A \leq A\{\alpha := B\}} \text{ (f-inst)}$$

$$\frac{\alpha \notin FV(A)}{\forall \alpha. (A \rightarrow B) \leq A \rightarrow \forall \alpha. B} \text{ (f-arr)}$$

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$$\overline{\forall \alpha. (A \uplus \Delta) \leq (\forall \alpha. A) \uplus \Delta} \quad (ex\text{-}fallu)$$

$$\overline{(A \uplus \Delta) \uplus \Delta' = A \uplus (\Delta \cup \Delta')} \quad (eq\text{-}uu)$$

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$$\frac{}{(A \rightarrow B)^\Delta = A^\Delta \rightarrow B^\Delta} \text{ (eq-arrc)}$$

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$$\text{map } (\lambda n. \text{add2 } (\text{pred } n)) [3; 0; 4] > [4; S (S (\text{raise } \varepsilon)); 5] : \text{list}(\mathbb{N}^{\{\varepsilon\}})$$

Examples

$$\begin{aligned} \text{pred} &\equiv \text{Rec } (\text{raise } \varepsilon) (\lambda x. \lambda y. x) &: \mathbb{N} \rightarrow \mathbb{N} \uplus \{\varepsilon\} \\ \text{pred}' &\equiv \lambda n. \text{try } (\text{pred } n) \text{ with } \varepsilon \mapsto 0 &: \mathbb{N} \rightarrow \mathbb{N} \\ \text{add2} &\equiv \lambda n. S (S \ n) \end{aligned}$$

We can define second order list and then:

$$\text{map } (\lambda n. \text{add2 } (\text{pred } n)) [3; 0; 4] > [4; S (S (\text{raise } \varepsilon)); 5] : \text{list}(\mathbb{N}^{\{\varepsilon\}})$$

$$\text{head } [4; S (S (\text{raise } \varepsilon)); 5] > 4$$

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A realisability model

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It is designed using orthogonality techniques.

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The interpretations of $A \uplus \Delta$ and A^Δ follow the idea that

- $A \uplus \Delta$ may raise exceptions at top-level.
- A^Δ may raise exceptions in some evaluation context.

Arrow types interpretation is not standard

With corruption, the arrow types is not the usual realisability one anymore.

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If we denote by $\xrightarrow{r}$ the realisability arrow, our arrow is understand as:

$$A \rightarrow B = \bigcap_{\Delta \subseteq \mathcal{E}} (A^{\Delta} \xrightarrow{r} B^{\Delta})$$

Model properties

Theorem (Model soundness)

The model is sound.

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Corollary (Type safety)

If M is a term such that $\vdash M : \mathbb{N}$, then $M \succ^* S^n 0$.

Corollary (Weak normalization)

Terms of F_x are weakly normalizing.

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Conclusion

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- It should be adaptable to dependent types.
- That's all, thanks for your attention.