

# FI

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## Abstract

**Keywords** intersection types, inheritance

## 1. Introduction

Intersection types provides a power mechanism for functional programming, in particular for extensibility and allowing new forms of composition.

We present a polymorphic language with intersection types and records, and show how this language can be used to solve various common tasks in functional programming in a nicer way.

Prototype-based programming is one of the two major styles of object-oriented programming, the other being class-based programming which is featured in languages such as Java and C#. It has gained increasing popularity recently with the prominence of JavaScript in web applications. Prototype-based programming supports highly dynamic behaviors at run time that are not possible with traditional class-based programming. However, despite its flexibility, prototype-based programming is often criticized over concerns of correctness and safety. Furthermore, almost all prototype-based systems rely on the fact that the language is dynamically typed and interpreted.

This paper introduces System  $F_{IR}$

## 2. Overview

There should be a section informally describing the language (System FI) through various examples. Intersection types provide a general mechanism for ad-hoc polymorphism.

While elaboration intersection types has been

In summary, the contributions of this paper are:

- elaboration typing rules which given a source expression with intersection types, typecheck and translate it into an ordinary F term. Prove a type preservation result: if a term  $e$  has type  $\tau$  in the source language, then the translated term  $|e|$  is well-typed and has type  $|\tau|$  in the target language.
- present an algorithm for detecting incoherence which can be very important in practice.

- explores the connection between intersection types and object algebra by showing various examples of encoding object algebra with intersection types.

Mention properties informally via examples:

Typeclasses

Intersection types in Scala

show :: (Int  $\rightarrow$  String) & (Float  $\rightarrow$  String)

show

### 2.1 Algebras

### 2.2 Lenses

### 2.3 Embedded DSLs

## 3. System F

The target language is System F extended with a base type Int. The syntax and typing is completely standard. The types are function, universal quantification.

## 4. System FI

The source language, System FI, is identical to the source language described in the previous section, except for the two additions: intersection types and records. The formalization includes only single records and single record types as the multi-records can be desugared into the merge of multiple single records.

Dunfield has described a language that includes a “top” type but it does not appear in our language.

Remark. The operational semantics of FI is not presented in this paper. However,

## 5. Type-Directed Translation to System F

In this section, we present a relatively lightweight type-directed elaboration from FI to F. The elaboration consists of four sets of rules, which are explained below:

### • Coercion

The coercion judgment  $\Gamma \vdash \tau_1 <: \tau_2 \hookrightarrow C$  extends the subtyping judgment with a coercion on the right hand side of  $\hookrightarrow$ . A coercion, which is just an expression in the target language, is guaranteed to have type  $\tau_1 \rightarrow \tau_2$ , as proved by Lemma 1. It is read “In the environment  $\Gamma$ ,  $\tau_1$  is a subtype of  $\tau_2$ ; and if any expression  $e$  has a type  $t_1$  that is a subtype of the type of  $t_2$ , the elaborated  $e$ , when applied to the corresponding coercion  $C$ , has exactly type  $|t_2|$ ”. For example,  $\Gamma \vdash \text{Int} \& \text{Bool} <: \text{Bool} \hookrightarrow fst$ , where  $fst$  is the projection of a tuple on the first element. The coercion judgment is only used in the TrApp case.

### • Elaboration

The elaboration judgment  $\Gamma \vdash e : \tau \hookrightarrow E$  extends the typing judgment with an elaborated expression on the right hand side

of  $\hookrightarrow$ . It is also standard, except for the case of  $\text{TrApp}$ , in which a coercion from the inferred type of the argument to the expected type of the parameter is inserted before the argument; and the case of  $\text{TrRcdEim}$  and  $\text{TrRcdUpd}$ , where the “get” and “put” rules will be used. The two set of rules are explained below.

- “get” rules

The “get” judgment can be thought as producing a field accessor.

- “put” rules

The “put” judgment can be thought as producing a field updater.

Type-Directed Translation to System F. Main results: type-preservation + coherence.

## 6. Implementation

We extend the implementation of the type system extended with type synonyms.

type T A1 A2 = ... in

## 7. Case Study?

## 8. Properties

## 9. Case Studies

## 10. Related work

- Elaborating simply-typed lambda calculus

Dunfield has introduced a type system with intersection polymorphism but no parametric polymorphism.

Nystrom et. al. OOPSLA 06

Applications:

- Object/Fold Algebras. How to support extensibility in an easier way.

See Datatypes a la Carte

- Mixins

- Lenses? Can intersection types help with lenses? Perhaps making the types more natural and easy to understand/use?

- Embedded DSLs? Extensibility in DSLs? Composing multiple DSL interpretations?

<http://www.cs.ox.ac.uk/jeremy.gibbons/publications/embedding.pdf>

$$|\tau| = T$$

$$\begin{aligned} |\alpha| &= \alpha \\ |\tau_1 \rightarrow \tau_2| &= |\tau_1| \rightarrow |\tau_2| \\ |\forall \alpha. \tau| &= \forall \alpha. |\tau| \\ |t_1 \&t_2| &= \langle |\tau_1|, |\tau_2| \rangle \\ |\{l : \tau\}| &= |\tau| \end{aligned}$$

**Lemma 1.** *If*

$$\Gamma \vdash \tau_1 <: \tau_2 \hookrightarrow C$$

*then*

$$|\Gamma| \vdash C : |\tau_1| \rightarrow |\tau_2|$$

*Proof.* By structural induction on the types and the corresponding inference rule.

(SubVar)  
(SubFun)  
(SubForall)

(SubAnd1)  
(SubAnd2)  
(SubAnd3)  
(SubRcd)

□

**Lemma 2.** *If*

$$\Gamma \vdash_{\text{get}} \tau; l = C; \tau_1$$

*then*

$$|\Gamma| \vdash C : |\tau| \rightarrow |\tau_1|$$

*Proof.* By structural induction on the type and the corresponding inference rule.

$$(\text{Get-Base}) \Gamma \vdash_{\text{get}} \{l : \tau\}; l = \lambda(x : |\{l : \tau\}|).x; \tau$$

By the induction hypothesis

$$|\Gamma| \vdash \lambda(x : |\{l : \tau\}|).x : |\{l : \tau\}| \rightarrow |\tau|$$

(Get-Left)  
(Get-Right)

□

**Lemma 3.** *If*

$$\Gamma \vdash_{\text{put}} \tau; l; E = C; \tau_1$$

*then*

$$|\Gamma| \vdash C : |\tau| \rightarrow |\tau|$$

*Proof.* By structural induction on the type and the corresponding inference rule.

(Put-Base)  
(Put-Left)  
(Put-Right)

□

**Lemma 4.** *If*

$$\Gamma \vdash \tau$$

*then*

$$|\Gamma| \vdash |\tau|$$

*Proof.* Since

$$\Gamma \vdash \tau$$

It follows from (FI-WF) that

$$\text{ftv}(\tau) \subseteq \text{ftv}(\Gamma)$$

And hence

$$\text{ftv}(|\tau|) \subseteq \text{ftv}(|\Gamma|)$$

By (F-WF) we have

$$\Gamma \vdash \tau$$

□

**Theorem 1** (Type preserving translation). *If*

$$\Gamma \vdash e : \tau \hookrightarrow E$$

*then*

$$|\Gamma| \vdash E : |\tau|$$

*Proof.* By structural induction on the expression and the corresponding inference rule.

$$(\text{TrVar}) \Gamma \vdash x : \tau \hookrightarrow x$$

It follows from (TrVar) that

$$(x : \tau) \in \Gamma$$

Based on the definition of  $|\cdot|$ ,

$$(x : |\tau|) \in |\Gamma|$$

Thus we have by (F-Var) that

$$|\Gamma| \vdash x : |\tau|$$

$$(\text{TrAbs}) \Gamma \vdash \lambda(x : \tau_1).e : \tau_1 \rightarrow \tau_2 \hookrightarrow \lambda x : |\tau_1|.E$$

It follows from (TrAbs) that

$$\Gamma, x : \tau_1 \vdash e : \tau_2 \hookrightarrow E$$

And by the induction hypothesis that

$$|\Gamma|, x : |\tau_1| \vdash E : |\tau_2|$$

By (TrAbs) we also have

$$\Gamma \vdash \tau_1$$

It follows from Lemma 4 that

$$|\Gamma| \vdash |\tau_1|$$

Hence by (F-Abs) and the definition of  $|\cdot|$  we have

$$|\Gamma| \vdash \lambda x : |\tau_1|.E : |\tau_1 \rightarrow \tau_2|$$

$$(\text{TrApp}) \Gamma \vdash e_1 e_2 : \tau_2 \hookrightarrow E_1(CE_2)$$

From (TrApp) we have

$$\Gamma \vdash \tau_3 <: \tau_1 \hookrightarrow C$$

Applying Lemma 1 to the above we have

$$|\Gamma| \vdash C : |\tau_3| \rightarrow |\tau_1|$$

Also from (TrApp) and the induction hypothesis

$$|\Gamma| \vdash E_1 : |\tau_1| \rightarrow |\tau_2|$$

Also from (TrApp) and the induction hypothesis

$$|\Gamma| \vdash E_2 : |\tau_3|$$

Assembling those parts using (F-App) we come to

$$|\Gamma| \vdash E_1(CE_2) : |\tau_2|$$

□

$$(\text{TrTAbs}) \Gamma \vdash \Lambda \alpha.e : \forall \alpha.\tau \hookrightarrow \forall \alpha.E$$

From (TrTAbs) we have

$$\Gamma \vdash e : \tau \hookrightarrow E$$

By the induction hypothesis we have

$$|\Gamma| \vdash E : |\tau|$$

Thus by (F-TAbs) and the definition of  $|\cdot|$

$$\Gamma \vdash \Lambda \alpha.E : |\forall \alpha.\tau|$$

$$(\text{TrTApp}) \Gamma \vdash e \tau : [\alpha := \tau] \tau_1 \hookrightarrow E |\tau|$$

From (TrTApp) we have

$$\Gamma \vdash e : \forall \alpha.\tau_1 \hookrightarrow E$$

And by the induction hypothesis that

$$|\Gamma| \vdash E : \forall \alpha.|\tau_1|$$

Also from (TrTApp) and Lemma 4 we have

$$|\Gamma| \vdash |\tau|$$

Then by (F-TApp) that

$$|\Gamma| \vdash E |\tau| : [\alpha := |\tau|] |\tau_1|$$

Therefore

$$|\Gamma| \vdash E |\tau| : |[\alpha := \tau] \tau_1|$$

$$(\text{TrMerge}) \Gamma \vdash e_1, e_2 : \tau_1 \& \tau_2 \hookrightarrow \langle E_1, E_2 \rangle$$

From (TrMerge) and the induction hypothesis we have

$$|\Gamma| \vdash E_1 : |\tau_1|$$

and

$$|\Gamma| \vdash E_2 : |\tau_2|$$

Hence by (F-Pair)

$$|\Gamma| \vdash \langle E_1, E_2 \rangle : \langle |\tau_1|, |\tau_2| \rangle$$

Hence by the definition of  $|\cdot|$

$$|\Gamma| \vdash \langle E_1, E_2 \rangle : |\tau_1 \& \tau_2|$$

$$(\text{TrRcdIntro}) \Gamma \vdash \{l = e\} : \{l : \tau\} \hookrightarrow E$$

From (TrRcdIntro) we have

$$\Gamma \vdash e : \tau \hookrightarrow E$$

And by the induction hypothesis that

$$|\Gamma| \vdash E : |\tau|$$

Thus by the definition of  $|\cdot|$

$$|\Gamma| \vdash E : |\{l : \tau\}|$$

$$(\text{TrRcdElim}) \Gamma \vdash e.l : \tau_1 \hookrightarrow CE$$

From (TrRcdElim)

$$\Gamma \vdash e : \tau \hookrightarrow E$$

And by the induction hypothesis that

$$|\Gamma| \vdash E : |\tau|$$

Also from (TrRcdElim)

$$\Gamma \vdash_{\text{get}} e; l = C; \tau_1$$

Applying Lemma 2 to the above we have

$$|\Gamma| \vdash C : |\tau| \rightarrow |\tau_1|$$

Hence by (F-App) we have

$$|\Gamma| \vdash CE : |\tau_1|$$

$$(\text{TrRcdUpd}) \Gamma \vdash e \text{ with } \{l = e_1\} : \tau \hookrightarrow CE$$

From (TrRcdUpd)

$$\Gamma \vdash e : \tau \hookrightarrow E$$

And by the induction hypothesis that

$$|\Gamma| \vdash E : |\tau|$$

Also from (TrRcdUpd)

$$\Gamma \vdash_{put} t; l; E = C; \tau_1$$

Applying Lemma 3 to the above we have

$$|\Gamma| \vdash C : |\tau| \rightarrow |\tau|$$

Hence by (F-App) we have

$$|\Gamma| \vdash CE : |\tau|$$

## A. Proofs

This is the text of the appendix, if you need one.

## Acknowledgments

Acknowledgments, if needed.

## References

[1] P. Q. Smith, and X. Y. Jones. ...reference text...