Towards Incremental Language Definition with Reusable Components

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Incremental programming

- Stepwise
- Submitting small snippets of code
- Immediate feedback

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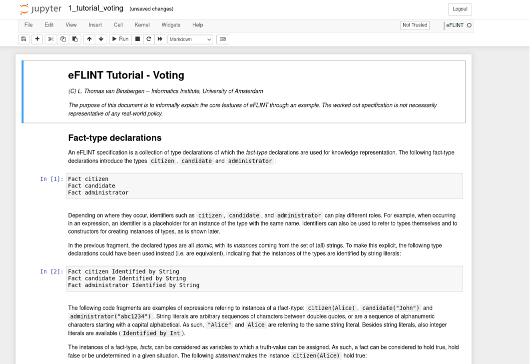
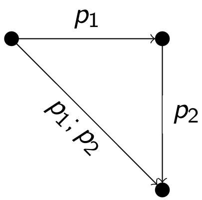


Sequential languages[1]



[1]A principled approach to REPL interpreters. Van Binsbergen, et al.

Incremental language development

Compose languages without losing flexibility while promoting reusability

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- Compose language construct semantics

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- Promote re-use and compatibility
  $\therefore$ Use funcons as a lingua franca

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Compose languages without losing flexibility while promoting reusability

- Compose language constructs
- Compose language construct semantics
  $\Longrightarrow$ the Expression Problem
  $\therefore$ Data types ‘a la carte (DTC)
- Promote re-use and compatibility
  $\therefore$ Use funcons as a lingua franca
- Modify the structure of the language
  $\therefore$ A new approach for language definitions

Data types 'a la carte[2]

```
data Num a = Num int
    deriving Functor
data Add a = Add a a
    deriving Functor
data Lang = Fix (Num :+: Add)
data Fix f = In (f (Fix f))
```

[2] Swierstra. JFP 2008

Data types ‘a la carte[2]

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data Lang = Fix (Num :+: Add)
data Fix f = In (f (Fix f))
```

```
foldLang :: Functor f -> (f a -> a)
      -> Fix f -> a
instance Eval Num where
    eval (Num n) = n
instance Eval Add where
    eval (Add e1 e2) = e1 + e2
```

[2] Swierstra. JFP 2008

Funcons[4]

- Component-based approach towards formal, dynamic semantics
- A library of reusable, fundamental constructs (funcons)
- Executable micro-interpreters[3]

[3] Executable Component-Based Semantics. Van Binsbergen, Sculthorpe, Mosses. JLAMP 2019
[4] PLanCompS project lead by Peter Mosses

Funcons[4]

- Component-based approach towards formal, dynamic semantics
- A library of reusable, fundamental constructs (funcons)
- Executable micro-interpreters[3]

$$\textbf{apply}(\textbf{bound}(''f''), \textbf{integer-add}(12))$$

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Contribution

A method that supports incremental language definition via composition by delaying language structure choices

Language structure

$$
\begin{aligned}
Var_{\mathscr{O}} &: String \to Expr \\
Abs_{\mathscr{O}} &: String \times Expr \to Expr \\
App_{\mathscr{O}} &: Expr \times Expr \to Expr
\end{aligned}
$$

Language structure

$$\begin{aligned} Var_{\mathscr{O}} &: String \to Expr \\ Abs_{\mathscr{O}} &: String \times Expr \to Expr \\ App_{\mathscr{O}} &: Expr \times Expr \to Expr \end{aligned}$$

Language structure is decided by the types of our constructors

Delayed language structure

Operator declarations

introduces operators, arities and name 'operand positions'

$$\begin{aligned} \mathit{Var}_{\mathscr{O}} &: \mathit{VarVar} \\ \mathit{Abs}_{\mathscr{O}} &: \mathit{AbsVar} \times \mathit{AbsBody} \\ \mathit{App}_{\mathscr{O}} &: \mathit{AppAbs} \times \mathit{AppArg} \end{aligned}$$

Delayed language structure

Operator declarations

introduces operators, arities and name ‘operand positions’

$$Var_{\mathscr{O}} : VarVar$$
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Sort constraints

assign (one or more) operators to (possibly new) sorts.

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Operator assignments

$$Var_{\mathscr{O}} \in \mathit{AbsBody}$$

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Sort constraints

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Operator assignments

$$Var_{\mathscr{O}} \in AbsBody$$
$$Var_{\mathscr{O}} \in Expr$$
$$App_{\mathscr{O}} \in Expr$$
$$Abs_{\mathscr{O}} \in Expr$$

Sub-sort constraints

$$Expr \subseteq AbsBody$$
$$Expr \subseteq AppAbs$$
$$Expr \subseteq AppArg$$

Operator semantics

$$
\begin{aligned}
\mathit{Var}_{\mathscr{F}}(\mathit{lit}) &= \textbf{bound string } \mathit{lit} \\
\mathit{Abs}_{\mathscr{F}}(x, b) &= \textbf{function closure scope}(\textbf{bind}(\textbf{string } x, \textbf{given}), b) \\
\mathit{App}_{\mathscr{F}}(\mathit{abs}, \mathit{arg}) &= \textbf{apply}(\mathit{abs}, \mathit{arg})
\end{aligned}
$$

Semantic functions translate operator occurrences to funcon terms (semantic domain).

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Existing operator semantics not always enough for every language

Operator specialization

Associating 'wrapper funcon terms' as part of sort constraints

$$Return_{\mathscr{O}} : ReturnVal \qquad \text{(Operator declaration)}$$

$$Return_{\mathscr{F}}(val) = \textbf{return}\ val \qquad \text{(Semantic function)}$$

$$Return_{\mathscr{O}} \in AbsBody \qquad \text{(Sort constraint with glue code)}$$

$$\hookrightarrow \textbf{handle-return}(AbsBody_{\mathscr{F}}) \qquad \text{(glue code)}$$

Language definition

Definition

A language L is a structure $\langle O, T, S, F, G, I\rangle$ with:

O a set of operators,

$T \subset O$ the set of operators assigned to the top-level,

S a family of sets representing operator assignments

F a family of functions representing the semantic functions

G a family of glue functions

I a function for initialisation over top-level operators

Implementation

```
data Abs u t where
    Abs :: IsTrue (AbsBody t) => String -> u t -> Abs u AbsType
data AbsType
type family AbsBody t
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$(genSortConstraint [(''AbsType, ''AbsBody)])
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$\Longrightarrow \mathit{Abs}_{\mathscr{O}} \in \mathit{AbsBody}$

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type family AbsBody t
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$\Longrightarrow Abs_{\mathcal{O}} \in AbsBody$

```
type family Expr t
$(genSortConstraint [(''AbsType, ''Expr)])
$(genSubSort [(''Expr, ''AbsBody)])
```

$\Longrightarrow Abs_{\mathcal{O}} \in Expr$

$Expr \subseteq AbsBody$

Semantics

```
instance ToFuncons Abs where
    toFuncons (Abs s (K body)) = K $
        function [closure [scope [bind [string s, given], body]]]
```

Glue code

```
$(genGlue (''AbsBody, ''P(Command), ''absGlueReturn))
absGlueReturn command_f = handle_return [command_f]
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$\Longrightarrow$

```
instance GetGlue AbsGlue Command Funcons where
    getGlue AbsVarGlue  _ = id
    getGlue AbsBodyGlue l = absGlueReturn

class GetGlue operand (f :: (* -> *) -> * -> *) target where
    getGlue :: operand -> f (Term a) b -> target -> target
    getGlue _ _ = id
```

Why we delay

```
data Language = Language
{ operators :: [Operator]
, op_assign :: [OperatorAssignment]
, sub_sorts :: [SubSort]
, glue_code :: [(Sort, MetaType, GlueFunction)]
, init_code :: [(MetaType, GlueFunction)]
} deriving (Show)
```

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```
type family Expr
lambdaLanguage = Language
{operators =
  [(''Var, ''VarType), (''Abs, ''AbsType),
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,op_assign =
  [(op, ''Expr) | op <-
    [''VarType, ''AbsType, ''AppType]]
,sub_sorts =
  [(''Expr, t) | t <-
    [''AbsBody, ''AppLeft, ''AppRight, ''TopLevel]],
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...
})
```

```
<*> :: Language -> Language -> Language
```

Example

```
import Lambda(Expr)
arithLanguage = Language
{ operators = [(''Add, ''AddType), (''IntV, ''IntVType)]
, op_assign = [(op, ''Expr) | op <- [''AddType, ''IntVType]]
, sub_sorts = [(''Expr, t) | t <- [''AddLeft, ''AddRight]]
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Can now extend the lambda language with the arithmetic language (extension)

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lambdaLanguage <*> arithLanguage
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Without a dependency (unification)

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lambdaLanguage <*> arithLanguage <*> arithLambdaGlue
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With restriction

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functional = lambdaLanguage <*> arithLanguage <*> modExceptionsLanguage
    where
        modExceptionsLanguage = exceptionsLanguage {
            op_assign = removeCatch $ op_assign modExceptionsLanguage
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Correspond to the operations used by Erdweg

Conclusion

Approach

- \+ Highly flexible
- \+ Permits rapid prototyping
- \- Difficult to track composition effects

Implementation

- \+ Properties are statically checked by Haskell
- \+ Languages are just Haskell data types
- \+ Semantic functions are just Haskell functions
- \- Interactivity hampered by Template Haskell
- \- Language definitions can be verbose

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Future work

- Development of an external DSL to fully utilise interactivity
- User defined concrete syntax
- Explore other algebras

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