# Towards Incremental Language Definition with Reusable Components

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# Definitional interpreters

$$\textit{interpreter} : \textit{program} \times \textit{config} \rightarrow \textit{config}$$

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A **language** $L$ is a structure $\langle P, \Gamma, \gamma^0, I \rangle$ with:

- $P$ a set of programs,
- $\Gamma$ a set of configurations (containing semantic entities, attributes, algebraic effects, etc..),
- $\gamma^0$ an initial configuration with $\gamma^0 \in \Gamma$ and
- $I$ a definitional interpreter assigning to each program $p \in P$ a function $I_p : \Gamma \to \Gamma$.

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Note that the interpreter can be applied repeatedly, i.e. that effects can be composed

# Deriving REPLs and Notebooks for DSLs

**From DSL Specification to Interactive Computer Programming Environment**


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Figure: SLE2019

**Bacatá: Notebooks for DSLs, Almost for Free**


Mauricio Verano Merino[a,d], Jurgen Vinju[a,b], and Tijs van der Storm[b,c]

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b Centrum Wiskunde & Informatica, The Netherlands

c University of Groningen, The Netherlands

d Océ Technologies B.V., The Netherlands


Figure: Art, Science, and Engineering of Programming

# Deriving REPL/Notebook – commonalities

- READ: Identify entry points, i.e. the alternatives in syntactic root
- EVAL: Connect entry points with evaluation function in DSL interpreter
- PRINT: Specify function to convert evaluation result to string
- LOOP:

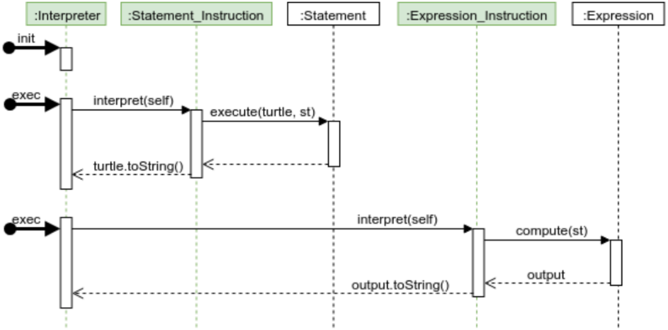


**Figure 8.** Overall Execution Flow for Logo

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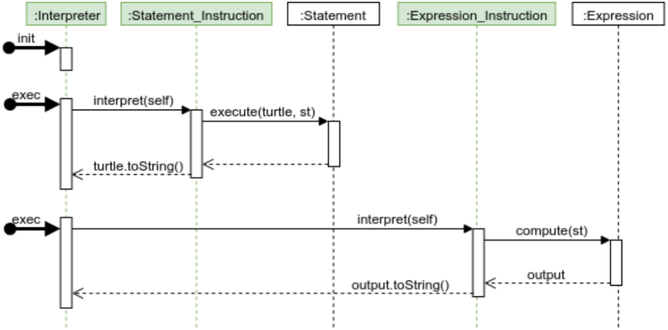


**Figure 8.** Overall Execution Flow for Logo

How does one execution affect the next?

# Idea..!

*Distinguish between REPL language and base language (e.g. JShell vs Java)*

## A Principled Approach to REPL Interpreters


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Figure: Onward!2020

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*A REPL is a monoid homomorphism between programs and their effects*

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- The effect of one phrase on the next is determined by its modifications to $\gamma \in \Gamma$
- REPL-first: what if we design all our languages as sequential languages?

# Onward!2020 (MiniJava case study)

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Config eval((Phrase)`<Expression e> ;`, Config c)
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$\hookrightarrow$ Such as suggested for 'funcons'

# PLanCompS project (2011-2015...) – `http://plancomps.org`

- Component-based approach towards formal, dynamic semantics

Main contributions:

  - A library of highly reusable, *fun*damental *con*structs (*funcons*)
  - The meta-language CBS for defining funcons and object languages[1]
  - A method for translating funcon definitions to executable micro-interpreters[1]

- Funcons are defined in I-MSOS with a fixed set of entity *classes*

[1] *Executable Component-Based Semantics*. Van Binsbergen, Sculthorpe, Mosses. JLAMP 2019

# What is the state of the funcon library?

**Verified and available: `https://plancomps.github.io/CBS-beta/Funcons-beta/`**

- Procedural: procedures, references, scoping, iteration
- Functional: functions, bindings, datatypes, pattern matching
- Object-oriented: objects, classes, inheritance
- Abnormal control: exceptions, break/continue, delimited continuations

**Unverified as of yet (i.e. not used in large case studies)**

- Concurrency: multi-threading
- Logical programming: backtracking, unification
- Meta-programming: AST conversions, staged evaluation[2]

[2] *Funcons for Homogeneous Generative Meta-Programming*. Van Binsbergen. GPCE 2018

```
Rule
  initialise[[ 'function' Id '(' Ids? ')' Block ]] =
    assign(
      bound(id[[ Id ]]),
      function closure(
        scope(
          match(given,tuple(patts[[ Ids? ]])),
          handle-return(exec[[ Block ]]))))
```

```
Rule
  rval[[ Exp '(' Exps? ')' ]] = apply(rval[[ Exp ]], tuple(rvals[[ Exps? ]]) )
```

# Incremental language definition with reusable components

**Modular reusable operators definitions, determining:**

- The arity and signature (sorts) of an operator, i.e. abstract syntax
- A semantic function expressing a translation to funcons
- Optionally: a context-free grammar production rule

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A language is defined by (in the context of some operator declarations):

- Assigning operators to the 'top-level', e.g. the entry-points (coarse-grained composition)
- Assigning operators to operand positions (fine-grained composition)

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## Incremental? Language experimentation in a REPL/Notebook

Develop the specification as a sequence of operator declarations and sort constraints

# Example

## Conventional approach (e.g. ADTs or Variants)

$$
\begin{aligned}
\mathit{Var}_{\mathscr{O}} &: \mathit{String} \rightarrow \mathit{Expr} \\
\mathit{Abs}_{\mathscr{O}} &: \mathit{String} \times \mathit{Expr} \rightarrow \mathit{Expr} \\
\mathit{App}_{\mathscr{O}} &: \mathit{Expr} \times \mathit{Expr} \rightarrow \mathit{Expr}
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$$Var_{\mathscr{O}} : String \to Expr$$

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## Alternative approach

$$Var_{\mathscr{O}} : String$$

$$Abs_{\mathscr{O}} : String \times AbsBody$$

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$$\begin{aligned} Var_{@} &\in Expr \\ App_{@} &\in Expr \\ Abs_{@} &\in Expr \\ Expr &\subseteq AbsBody \\ Expr &\subseteq AppAbs \\ Expr &\subseteq AppArg \end{aligned}$$

# Incremental language development (abstract syntax)

$$
\begin{aligned}
Var_{\mathscr{O}} &: String \\
Abs_{\mathscr{O}} &: String \times AbsBody \\
App_{\mathscr{O}} &: AppAbs \times AppArg
\end{aligned}
$$

Operator declarations introduce operators, arities and name ‘operand positions’

$$
\begin{aligned}
Var_{\mathscr{F}}(lit) &= \textbf{bound string } lit \\
Abs_{\mathscr{F}}(x, b) &= \textbf{function closure scope}(\textbf{bind}(\textbf{string } x, \textbf{given}), b) \\
App_{\mathscr{F}}(abs, arg) &= \textbf{apply}(abs, arg)
\end{aligned}
$$

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

# Incremental language development (language construction)

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

$$
\begin{aligned}
\mathit{Var}_{\mathscr{O}} &\in \mathit{Expr} \\
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\mathit{Abs}_{\mathscr{O}} &\in \mathit{Expr} \\
\mathit{Expr} &\subseteq \mathit{AbsBody} \\
\mathit{Expr} &\subseteq \mathit{AppAbs} \\
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$$

Sort constraints determine the precise relations between operators and operands

# Glue code (problem)

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What if the body of an abstract can terminate abruply? e.g. due to a return command.

$$
\mathit{Abs}_{\mathscr{F}}(x, b) = \textbf{function closure scope}(\textbf{bind}(\textbf{string } x, \textbf{given}), \textbf{handle-return } b)
$$

# Glue code (possible solution)

Associating 'wrapper funcon terms' as part of sort constraints

$$
\begin{aligned}
Return_{\mathscr{O}} &: ReturnVal && \text{(Operator declaration)}\\
Return_{\mathscr{F}}(val) &= \textbf{return}\ val && \text{(Semantic function)}\\
Return_{\mathscr{O}} &\in Command && \text{(Sort constraint)}\\
Command &\subseteq AbsBody && \text{(Sort constraint with glue code)}\\
&\hookrightarrow \textbf{handle-return}(Command_{\mathscr{F}}) && \text{(glue code)}
\end{aligned}
$$

# Full paper

## Realisation

- Haskell EDSL implementation reflecting our approach
- Building on from (Swierstra 2008) and (Bahr & Hvitved 2011)
- Enforce sort constraints and language definedness through Haskell's type system
- Optionally: GLL combinators for concrete syntax (Van Binsbergen et al. 2018)

## Evaluation

- Case studies to demonstrate: use of glue code, language variations, etc.
- Positioning within meta-language analysis frameworks of (Erdweg et al. 2012), (Méndez-Acuña et al. 2016), and/or (Leduc et al. 2019)
- Comparison with related work

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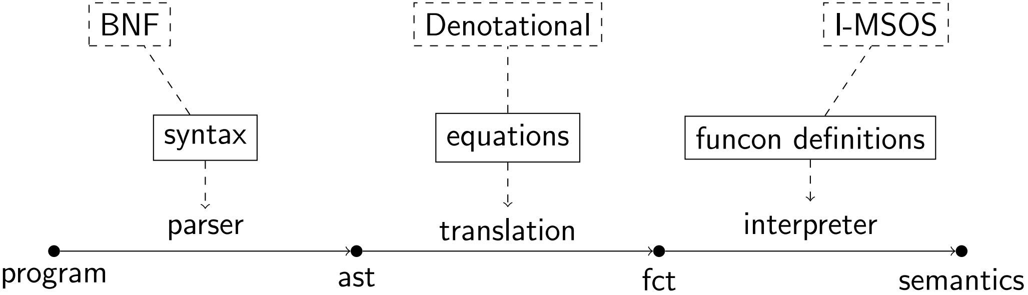
- **CBS & funcons** (topic of next slides):
  I-MSOS + monolithic monad implementing the entity classes
- **Implicit equations in Attribute Grammars (e.g. UUAG)**: Every entity is an attribute.
  Missing attribute equations are generated according to built-in schemes

# Language Engineering with Funcons




*Can this pipeline support modular, incremental language development?*

... a requirement for Agile Language Engineering

- Funcons also have informal semantics (no need to always worry about the details!)
- I-MSOS funcon definitions serve as a reference

# Incremental language development (concrete syntax)

$$\mathit{Var}_{\mathscr{S}}(\mathit{lit}) ::= \mathit{lit} \qquad \text{(Syntax declaration)}$$

$$\mathit{App}_{\mathscr{S}}(\mathit{abs}, \mathit{arg}) ::= \mathit{abs}\ \mathit{arg} \qquad \text{(Syntax declaration)}$$

$$\mathit{Abs}_{\mathscr{S}}(\mathit{param}, \mathit{body}) ::= \texttt{'('}\ \texttt{'\textbackslash'}\ \mathit{param}\ \texttt{"->"}\ \mathit{body}\ \texttt{')'} \qquad \text{(Syntax declaration)}$$

In a syntax declaration, the operands are names for nonterminals, whose productions rules are determined by sort constraints and (other) syntax declarations.

# REPL feature model