Generation of Interactive Programming Environments

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GIPE: Generation of Interactive Programming Environments

Started with two people in 1984; by now grown to at about ten people.

Two more years to go; After that continuation in new project

Presentation of some of the most interesting results of this work.
Programming environments with knowledge of programming language will help the programmer.

Environments for different languages will have many aspects in common.

Given a description of the programming language generate a programming environment.

Advantages: Reduced environment construction time; Intra- and Inter-environmental uniformity.

Investigation of aspects of environment generation; construction of prototype generator.
Generation of programming environments:

- Give an algebraic specification of all relevant aspects of language (syntax, static semantics, dynamic semantics, transformations, etc.)

- Generate tools (parser, type checker, interpreter, optimizer, etc.) from each specification.

- Integrate generated tools into environment by a description of layout and behavior of user interface

- Give support to specification phase by *meta-environment*. 
Contents:

1. Introduction

2. Algebraic Specification with free syntax

3. Tool generation

4. Tool integration

5. Support by the *meta-environment*

6. (Example: the $\lambda$-calculus)
Algebraic Specification of the Booleans:

sorts
  BOOL
functions
  true: -> BOOL
  false: -> BOOL
  and: BOOL # BOOL -> BOOL
  or: BOOL # BOOL -> BOOL
variables
  p, q: -> BOOL
equations
  [1] and(true, p) = p
  [2] and(false, p) = false
  [3] or(true, p) = true
  [4] or(false, p) = p
ASF: Algebraic Specification Formalism

SDF: Syntax Definition Formalism

Combined, ASF+SDF: specifications with free syntax.

imports Layout

exports
  sorts BOOL
  context-free syntax
    true -> BOOL
    false -> BOOL
    BOOL and BOOL -> BOOL {left}
    BOOL or BOOL -> BOOL {left}
  variables
    p[’]* -> BOOL
  priorities
    and > or
  equations
    [1] true and p = p
    [2] false and p = false
    [3] true or p = true
    [4] false or p = p
module TC

imports Booleans Types

exports
  sorts PROGRAM DECLS STAT EXP ...
  context-free syntax
      ....
      program DECLS begin STAT+ end  \rightarrow PROGRAM
      if EXP then STAT fi            \rightarrow STAT
          ....
      tc "(" STAT "," DECLS ")"      \rightarrow BOOL
      tc "(" EXP "," DECLS ")"      \rightarrow TYPE
  ....
variables
  Exp  \rightarrow EXP
  Stat \rightarrow STAT
  Decls \rightarrow DECLS
      ....
equations
      ....

[7]          tc( Exp, Decls ) = bool-type
                          ================================
                          tc( if Exp then Stat fi, Decls ) = tc(Stat,Decls)
      ....
Derive from each module:

- A *parser* for the signature part producing abstract syntax trees.

From a rule \( \mathsf{BOOL} \ "\text{and}" \mathsf{BOOL} \to \mathsf{BOOL} \) derive:

- BNF rule
  \[ \langle \mathsf{BOOL} \rangle ::= \langle \mathsf{BOOL} \rangle "\text{and}" \langle \mathsf{BOOL} \rangle \]

- Abstract function
  \[ \text{and} : \mathsf{BOOL} \times \mathsf{BOOL} \to \mathsf{BOOL} \]

- A *Term Rewriting System* able to perform reductions by interpreting each equation \( t_1 = t_2 \) as a rewrite rule \( t_1 \to t_2 \).

Use parser for syntax-directed editing, and TRS for execution of specified functions.
Given a grammar, a syntax-directed editor can be derived.

- Plain text-editing within a focus.

  A focus designates a subtree in the tree obtained by parsing the complete text in the editor

- Structural-editing allows to move the focus around, and to expand nonterminal symbols.
begin
  declare
  input: natural, output: natural,
  repnr: natural, rep: natural;

  input := 3; output := 1;
  while <EXP>
    do
      rep := output;
      <STATEMENT>;
      while repnr - 1
        do
          output := output + rep;
          repnr := repnr - 1
        od;
    od;
  input := input - 1
end
Algebraically specified functions can be linked to editors by *buttons*.

The action for a button typically involves rewriting a specified function with focusses of one (or more) editor(s) as arguments.

The action may replace the current focus, or may retrieve arguments from several editors.

A user interface description language defines precisely which buttons and actions are attached to each editor.
Several editors with all kinds of buttons attached to them constitute a generated environment.

A generated environment consists of editors parameterized with a generated parser, with buttons attached to them performing rewrites in the generated term rewriting system.
The *meta*-environment:

- Syntax-directed editing of specifications.

- Immediate static analysis

- Incremental updates of generated parsers, scanners, and term rewriting systems.

- Generated environment can be tested simultaneously.
Module Pico-typecheck

imports Booleans Pico-syntax Type-environments

exports
context-free syntax
  "tc" "[" PROGRAM "]" -> BOOL
  "tc" "[" DECLS "]" -> TENV
  "tc" "[" SERIES "]" in TENV -> BOOL
  "tc" "[" EXP "]" in TENV -> TYPE

equations

[Tc1a]  \text{tc}\left[\text{Series}\right]\text{ in }\text{tc}\left[\text{Decls}\right] = \text{true}

\text{begin Begin Decls Series end } = \text{true}

[Tc1b]  \text{tc}\left[\text{Series}\right]\text{ in }\text{tc}\left[\text{Decls}\right] \neq \text{true}

\text{begin Begin Decls Series end } = \text{false}

[Tc2]  \text{tc}\left[\text{declare Id-type-list ;} \right] = \text{[Pair-list]}

\text{begin declare Id-Type, Id-type-list; } =
\text{[(Id-Type), Pair-list]}

[Tc2\hat{\hfill}]<\text{TENV}> \cong <\text{TENV}>

[Tc3]  \text{tc}\left[\text{declare ;} \right] = \text{[]}
The GIPE project thus far:

- Results: Algebraic specification formalism with free syntax, incremental generation of parsers, scanners and term rewriting systems, incremental term rewriting, generic syntax-directed editors

- Testing specifications (and environments) for several toy languages, the $\lambda$-calculus, parts of the system, SQL, static semantics of Pascal and subset of ML, LOTOS

- Future work: Automatic error handling, generic debuggers, origin tracking, C-code generation, dynamic syntax, fine-grain incremental rewriting, bootstrapping, user interface description
An example: specification and generation of a λ-calculus environment.

λ-calculus; important for functional programming, denotational semantics, etc.

λ-expressions, α, β, η conversion, left-most reductions, λ-definitions like zero ≡ λfx.x, or succ ≡ λnfx.nf(fx)

Environment should be suited to play around with new λ-definitions
module Lambda-syntax

imports Identifiers renamed by sorts ID => VAR

exports
  sorts L-EXP
    context-free syntax
      VAR           -> L-EXP
      "lambda" VAR+ "." L-EXP   -> L-EXP
      L-EXP L-EXP     -> L-EXP  {left}
      "(" L-EXP ")"   -> L-EXP  {bracket}
    variables
      E[0-9]*        -> L-EXP
      V[0-9]*        -> VAR
      V[0-9]*"+"     -> VAR+

  priorities
    { "lambda" VAR+ "." L-EXP   -> L-EXP } <
      { L-EXP L-EXP   -> L-EXP }

  equations
module Substitute

imports Booleans Lambda-syntax
  Sets parameter P bound by sorts ELM => VAR to Lambda-syntax renamed by sorts SET => VAR-SET

exports
  context-free syntax
    L-EXP "[" L-EXP "]" -> L-EXP
    free-vars "(" L-EXP ")" -> VAR-SET
    get-fresh ")" VAR "," VAR-SET ")" -> VAR

equations
  [s1] \[ V \ [E/V] = E \]
  [s2] \[ V' \ [E/V] = V' \text{ when } V \neq V' \]
  [s3] \[ (E1 \ E2) \ [E/V] = (E1[E/V]) \ (E2[E/V]) \]
  [s4] \[ (\text{lambda } V . E1) \ [E/V] = \text{lambda } V . E1 \]
  [s5] \[ (\text{lambda } V' . E1) \ [E/V] = \text{lambda } V' . (E1[E/V]) \]
    \[ \text{ when } V \neq V', \ \text{member-of?}(V', \ \text{free-vars}(E)) = \text{false} \]
  [s6] \[ (\text{lambda } V' . E1) \ [E/V] = \text{lambda } V' . (E1[V'/V'][E/V]) \]
    \[ \text{ when } V \neq V', \ \text{member-of?}(V', \ \text{free-vars}(E)) = \text{true}, \]
    \[ \text{get-fresh}(V', (E E1)) = V' \]

  [f1] \[ \text{free-vars}(V) = [V] \]
  [f2] \[ \text{free-vars}(E1 \ E2) = \text{free-vars}(E1) \cup \text{free-vars}(E2) \]
  [f3] \[ \text{free-vars}(\text{lambda } V . E) = \text{free-vars}(E) - V \]

  [g1] \[ \text{get-fresh}(V, E) = \text{get-fresh}(\text{prime}(V), E) \]
    \[ \text{when } \ \text{member-of?}(V, \ \text{free-vars}(E)) = \text{true} \]
  [g2] \[ \text{otherwise: } \text{get-fresh}(V, E) = V \]

+ 19
module Convert

imports Substitute

exports
    context-free syntax
    alpha "(" L-EXP ")" -> L-EXP
    beta "(" L-EXP ")" -> L-EXP
    eta "(" L-EXP ")" -> L-EXP

equations
    [b1] beta( (lambda V . E1) E2 ) = E1 [ E2/V ]

    [a1] alpha( lambda V1 . E, V2 ) = lambda V2 . (E[V2/V1])
        when member-of?(V2, free-vars(E)) = false

    [e1] eta( lambda V . E V ) = E
        when member-of?(V, free-vars(E)) = false
module Let

imports Lambda-syntax Substitute

exports
  sorts DEF LET
  context-free syntax
    "expand" "(" L-EXP "," LET ")"   -> L-EXP
    "(" VAR ":" L-EXP ")"           -> DEF
    "(" "let" DEF+ ")"             -> LET
    "(" "let" DEF+ ")"             -> LET

  variables
    D[0-9]*"+"                    -> DEF+
    D[0-9]*                      -> DEF

equations
  [e0]  expand(E, ) = E
  [e1]  expand(E, (let (V:E'))) = E[E'/V]
  [e2]  expand(E, (let D+ D)) =
        expand(expand(E, (let D)), (let D+))
<table>
<thead>
<tr>
<th>Button</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>alpha(\ Current-focus )</td>
</tr>
<tr>
<td>Beta</td>
<td>beta(\ Current-focus )</td>
</tr>
<tr>
<td>Eta</td>
<td>eta(\ Current-focus )</td>
</tr>
<tr>
<td>LMStep</td>
<td>lm-step(\ Current-focus )</td>
</tr>
<tr>
<td>LMRReduce</td>
<td>lm-red( \ Current-focus )</td>
</tr>
<tr>
<td>Expand</td>
<td>expand( \ Current-focus , \Defs-focus )</td>
</tr>
</tbody>
</table>
Concluding Remarks

- Formalism for algebraic specification with user-defined syntax

- Environment Generator

- Meta-environment helping when developing specifications

- Source of inspiration for new ideas