

Lifting Resugaring by Lazy Desugaring

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Syntactic sugars provide an effective way to define and implement domain-specific languages. However, the programs after desugaring to a host language would be unrecognizable for people who are unfamiliar with the host language, which is bad because domain-specific languages are not always used by programmers.

Resugaring is an method to solve the problem above. In this paper, we purposed an approach of resugaring mixed with two approaches, based on lazy desugaring—getting evaluation sequences without fully desugaring the whole syntactic sugar expression. The first approach is lightweight but powerful, which lazy desugaring the sugars in programs. The second approach is efficient, which gets inference rules of sugars, then runs the programs using new inferences rules.

Additional Key Words and Phrases: Resugaring, Syntactic Sugar, Interpreter, Domain-specific language, Reduction Semantics

1 INTRODUCTION

Syntactic sugar, first coined by Peter J. Landin in 1964 [Landin 1964], was introduced to describe the surface syntax of a simple ALGOL-like programming language which was defined semantically in terms of the applicative expressions of the core lambda calculus. It has proved to be very useful for defining domain specific languages (DSLs) and extending languages [Culpepper et al. 2019; Felleisen et al. 2018]. Unfortunately, when syntactic sugar is eliminated by transformation, it obscures the relationship between the user's source program and the transformed program.

Resugaring is a powerful technique to resolve this problem [Pombrio and Krishnamurthi 2014, 2015]. It can automatically convert the evaluation sequences of desugared expression in the core language into representative sugar's syntax in the surface language. As demonstrated in Section 2, the key idea in this resugaring is "tagging" and "reverse desugaring": it tags each desugared core term with the corresponding desugared rule, and follows the evaluation steps in the core language but keep applying the desugaring rules reversibly as much as possible to find surface-level representations of the tagged core terms.

While it is natural to do resugaring by reverse desugaring of tagged core terms, it introduces complexity and inefficiency.

- *Tricky to handle recursive sugar.* While tagging is used to remember the position of desugaring so that reverse desugaring can be done at correct position when desugared core expression is evaluated, it becomes very tricky and complex when recursive sugars are considered. Moreover, it can only handle the recursive sugar which can be written by pattern-based desugaring rules [Pombrio and Krishnamurthi 2014].
- *Complicated to handle hygienic sugar.* For reverse desugaring, we need to match part of the core expression on the RHS of the desugar rule and to get the surface term by substitution. But when a syntactic sugar introduce variable bindings, this match-and-substitute turns out to be very complex if we consider local bindings (hygienic sugars) [Pombrio and Krishnamurthi 2015].
- *Inefficient in reverse desugaring.* It need to keep checking whether reverse desugaring is applicable during evaluation of desugared expression, which is very costive. Moreover, the match-and-substitute for reverse desugaring is costive particularly when the core term is big.

2018. 2475-1421/2018/1-ART1 \$15.00

<https://doi.org/>

In this paper, we propose a novel approach to resugaring, which does not use tagging and reverse desugaring at all. The key idea is "lazy desugaring", in the sense that desugaring is delayed so that the reverse application of desugaring rules become unnecessary. We consider the surface language and the core language as one language, and reduce expressions dynamically either by the reduction rules in the core language or by the desugaring rules for defining syntactic sugars. To gain more efficiency, we can make a shortcut of a sequence of core expression reduction to a one-step reduction of the surface language, by automatically deriving evaluation rules on the surface language from those on the core language.

Our main technical contributions can be summarized as follow. [Todo: The following contributions will be revised later.](#)

- *A lightweight, efficient and powerful resugaring approach by lazy desugaring.* The resugaring approach we proposed is based on reductions of a mixed language. It takes surface language and core language as a whole, then decided whether desugaring the sugars or reducing the subexpressions according to properties that make the resugaring correct. Thus, it is lightweight because many match and substitution processes can be omitted. We test the approach on many applications. The result shows that in addition to handle what existing work can handle, our dynamic approach can process non-pattern-based recursive sugar and hygienic sugar easily, which makes it powerful. And the rewriting system based on reduction semantics makes it possible to write syntactic sugar easily.
- *Automatic derivation of syntactic sugar's evaluation rule.* We abstract our resugaring approach to a derivation of syntactic sugar's evaluation rule. The derivation turns core language's evaluation rules into *Inference automaton* ([Todo: see ...](#)). And for each syntactic sugar, we would generate the surface language's evaluation rules without depending on some rules in core language. (some meta-functions may be necessary.) The the resugaring sequences can be easily got from the evaluation rules. Since the derivation can work together with the basic resugaring, our resugaring approach becomes more efficient because many steps in core language can be omitted.
- *Correctness.*

We have implemented lazy desugaring and automatic derivation of reduction rules for syntactic sugars. All the example in this paper have passed the test of the system.

The rest of our paper is organized as follow. We start with an overview of our approach in Section 2. We then discuss the core of resugaring by lazy desugaring in Section 3, and automatic derivation of reduction rules for syntactic sugars in Section ???. We discuss relative work in Section 5, and conclude the paper in Section 6.

2 OVERVIEW

In this section, we show a simple example processed by existing approach and our approach. Firstly, we define a simple core language with following syntax and semantic.

$$\begin{array}{lcl}
 e & ::= & (\text{if } e \ e \ e) \\
 & | & \#t \\
 & | & \#f \\
 \\
 & & \frac{e \rightarrow e'}{(\text{if } e \ e1 \ e2) \rightarrow (\text{if } e' \ e1 \ e2)} \quad (\text{CONTEXT RULE OF IF}) \\
 \\
 & & (\text{if } \#t \ e1 \ e2) \rightarrow e1 \quad (\text{REDUCTION RULE OF IFTRUE})
 \end{array}$$

(if #f e1 e2) \rightarrow e2 (REDUCTION RULE OF IFFALSE)

We define two syntactic sugars—*and* sugar and *or* sugar based on the core language.

(and e1 e2) \rightarrow_d (if e1 e2 #f)

(or e1 e2) \rightarrow_d (if e1 #t e2)

and execute (and (or #t #f) (and #f #t)) as an example.

2.1 Existing resugaring approach

As we mentioned above, the existing approach use "tagging" and "reverse desugaring" to get resugaring sequences. Tags is to show where are terms from, and reverse dusugaring is what resugaring needs. We simplify the existing resugaring process as follows.

(and (or #t #f) (and #f #t))

\rightarrow (if-andtag (if-ortag #t #t #f) (if-andtag #f #t #f) #f) //desugar
start evaluating

\rightarrow (if-andtag #t (if-andtag #f #t #f) #f) //check resugarable
get (and #t (and #f #t)) by reverse desugaring

\rightarrow (if-andtag #f #t #f) //check resugarable
get (and #f #t) by reverse desugaring

\rightarrow #f end of resugaring

We can find that the expression fully desugared before resugaring. The subexpression (and #f #t), though desugars to (if-andtag #f #t #f), doesn't be reduced in first two steps after desugaring. But the reverse desugaring tries on it in these two steps, which is redundant. Moreover, there will be some intermediate steps which can not be resugared by reverse desugaring during the evaluation in a more complex core language. Many useless resugarings on subexpressions will take place.

2.2 Resugaring by lazy desugaring

To solve the problem in existing resugaring approach, we try "lazy desugaring", which means that a syntactic sugar should only desugar when it has to desugar. We use a one-step try method to judge it.

(resugar (and (or #t #f) (and #f #t)))

\rightarrow (tmp (if (or #t #f) (and #f #t) #f)) // should reduce on (or #t #f)

\rightarrow (and (resugar (or #t #f)) (and #f #t)) // no reduction

\rightarrow (and (tmp (if #t #t #f)) (and #f #t)) // (or #t #f) has to desugar and reduce

\rightarrow (desugar (and #t (and #f #t)))

\rightarrow (tmp (if #t (and #f #t))) // the outermost and sugar has to desugar and reduce

\rightarrow (desugar (and #f #t))

\rightarrow (tmp (if #f #t #f)) // have to desugar and reduce

\rightarrow #f // end

For each step in the processes above we use one reduction or none. So 7 reduction steps is needed for the whole resugaring, while the existing approach needs 9 (3 in desugaring, 3 in evaluator, 3 reversed reduction in resugaring). Note that reversed reduction is more complex because of the match and substitution, the existing approach will be more redundant on larger expressions than ours. Also, there is no need for tagging, which makes our approach lightweight.

Moreover, derivation of semantics for syntactic sugar will make our approach more efficient for part of sugars. Both *and* sugar and *or* sugar can be handled by the derivation. We can get the following semantics (consisted of reduction rules and context rules).

$$\begin{array}{c}
 \frac{e_1 \rightarrow e'_1}{\text{(and } e_1 \ e_2) \rightarrow \text{(and } e'_1 \ e_2)}} \\
 \text{(and } \#t \ e_2) \rightarrow e_2 \\
 \text{(and } \#f \ e_2) \rightarrow \#f \\
 \frac{e_1 \rightarrow e'_1}{\text{(or } e_1 \ e_2) \rightarrow \text{(or } e'_1 \ e_2)}} \\
 \text{(or } \#t \ e_2) \rightarrow \#t \\
 \text{(or } \#f \ e_2) \rightarrow e_2
 \end{array}$$

Then the resugaring sequences can be got not depending on core language.

$$\begin{aligned}
 & \text{(and (or } \#t \ \#f) \text{ (and } \#f \ \#t))} \\
 & \longrightarrow \text{(and } \#t \text{ (and } \#f \ \#t))} \\
 & \longrightarrow \text{(and } \#f \ \#t) \\
 & \longrightarrow \#f
 \end{aligned}$$

Only 4 steps is needed by using the rules. Although the derivation of rules cannot work for all syntactic sugars which can be handled by our resugaring approach, it can work together with the resugaring. For example, we have another sugar named *hard* (regardless of its desugar rule) whose reduction rules cannot be derivate. Then if we execute (and (hard (and #t #t) ...) ...), the *and*'s semantics will let the *hard* sugar execute recursively. Then the sugar *hard* will be processed by our basic resugaring approach because no semantic rules for it. Note that the resugaring process may also recursively execute on inner subexpression (e.g. (and #t #t)), the subexpression may use the semantic rules again.

In summary, our resugaring approach with lazy desugaring is lightweight and efficient. Following chapters will show that, though lightweight, the approach is more powerful than existing approach in some ways. **Todo: following chapter will also show lightweight and efficient. but how to express?**

3 RESUGARING BY LAZY DESUGARING

In this section, we present our new approach to resugaring. Different from the traditional approach that clearly separates the surface and the core languages, we combine them together as one mixed language, allowing users to freely use the language constructs in both languages. We will show that any expression in the mixed language can be evaluated in such a smart way that a sequence of all expressions that are necessarily to be resugared by the traditional approach can be correctly produced.

3.1 Mixed Language for Resugaring

We will define a mixed language for a given core language and a surface language defined over the core language. An expression in this language will be reduced step by step by the reduction

CoreExp	::=	x	variable
		c	constant
		$(\text{CoreHead}' \text{CoreExp}_1 \dots \text{CoreExp}_n)$	constructor
		$(\text{CommonHead} \text{SurfExp}_1 \dots \text{SurfExp}_n)$	selected core constructor
SurfExp	::=	x	variable
		c	constant
		$(\text{SurfHead} \text{SurfExp}_1 \dots \text{SurfExp}_n)$	sugar expression

Fig. 1. Core and Surface Expressions

rules for the core language and the desugaring rules for defining the syntactic sugars in the surface language.

3.1.1 Core Language. For our host language, we consider its evaluator as a blackbox but with two natural assumptions. First, there is a deterministic stepper in the evaluator which, given an expression in the host language, can deterministically reduce the expression to a new expression. Second, the evaluation of any sub-expression has no side-effect on other parts of the whole expression.

An expression of the core language is defined in Figure 1. It is a variable, a constant, or a (language) constructor expression. Here, CoreHead stands for a language constructor such as if and let. To be concrete, we will use a simplified core language defined in Figure 2 to demonstrate our approach. [Todo: semantic needed?](#)

CoreExp	::=	$(\text{CoreExp} \text{CoreExp})$ // apply
		$(\text{lambda } (x) \text{CoreExp})$ // call-by-value
		$(\text{lambdaN } (x) \text{CoreExp})$ // call-by-need
		$(\text{if } \text{CoreExp} \text{CoreExp} \text{CoreExp})$
		$(\text{let } (x \text{CoreExp}) \text{CoreExp})$
		$(\text{first } \text{CoreExp})$
		$(\text{empty } \text{CoreExp})$
		$(\text{rest } \text{CoreExp})$
		$(\text{cons } \text{CoreExp} \text{CoreExp})$
		$(\text{arithop } \text{CoreExp} \text{CoreExp})$ // +, -, *, /, >, <, =
		x
		c // boolean, number and list

Fig. 2. An Core Language Example

3.1.2 Surface Language. Our surface language is defined by a set of syntactic sugars, together with some basic elements in the core language, such as constant and variable. So an expression of the surface language is some core constructor expressions with sugar expressions, as defined in Figure 1.

A syntactic sugar is defined by a desugaring rule in the following form:

$$(\text{SurfHead } e_1 e_2 \dots e_n) \rightarrow_d \text{Exp}$$

where its LHS is a simple pattern (unnested) and its RHS is an expression of surface language or core language, and any subterms (e.g. e_1) in LHS only appear once in RHS. For instance, we may

define syntactic sugar And by

$$(\text{And } e_1 e_2) \rightarrow_d (\text{if } e_1 e_2 \#f).$$

Note that if the pattern is nested, we can introduce a new syntactic sugar to flatten it. And if we need a subterm multi times in RHS, a let binding is needed (a normal way in syntactic sugar). One may wonder why **Todo: don't understand.** not restricting the RHS to be a core expression CoreExp, which sounds more natural. We use surfExp to be able to allow definition of recursive syntactic sugars, as seen in the following example.

$$\begin{aligned} (\text{Odd } e) &\rightarrow_d (\text{if } (> e 0) (\text{Even } (- e 1)) \#f) \\ (\text{Even } e) &\rightarrow_d (\text{if } (> e 0) (\text{Odd } (- e 1)) \#t) \end{aligned}$$

We assume that all desugaring rules are not overlapped in the sense that for a syntactic sugar expression, only one desugaring rule is applicable.

Exp	::=	DisplayableExp UndisplayableExp
DisplayableExp	::=	SurfExp CommonExp
UndisplayableExp	::=	CoreExp' OtherSurfExp OtherCommonExp
CoreExp	::=	CoreExp' CommonExp
CoreExp'	::=	(CoreHead' Exp*)
SurfExp	::=	(SurfHead DisplayableExp*)
CommonExp	::=	(CommonHead DisplayableExp*) c // constant value x // variable
OtherSurfExp	::=	(SurfHead Exp * UndisplayableExp Exp*)
OtherCommonExp	::=	(CommonHead Exp * UndisplayableExp Exp*)

Fig. 3. Our Mixed Language

3.1.3 Mixed Language. Our mixed language for resugaring combines the surface language and the core language. The differences between terms in our core language (CoreLang) and those in our surface language (SurfLang) are identified by their Head. But there may be some terms in the core language should be displayed during evaluation, or we need some core terms to help us getting better resugaring sequences. So we defined CommonExp, which origin from CoreLang, but can be displayed in resugaring sequences. The Core'Exp terms are terms with undisplayable

CoreHead (named CoreHead'). The SurfExp terms are terms with SurfHead and all subexpressions are displayable. The CommonExp terms are terms with displayable CoreLang's Head (named CommonHead), together with displayable subexpressions. There exists some other expressions during our resugaring process, which have displayable Head, but one or more subexpressions should not display. They are UndisplayableExp. We distinct the two kinds of expression for *abstraction* property (discussed in Section 3.3.2).

Take some terms in the core language in Figure 2 as examples. We may assume if, let, λ_N (call-by-name lambda calculus), empty, first, rest as CoreHead', op, λ , cons as CommonHead. Then we would show some useful intermediate steps.

Note that some expressions with CoreHead contains subexpressions with SurfHead, they are of CoreExp but not in core language, we need a tricky extension for the core language's evaluator. We use \rightarrow_c to donate a reduction step of core language's expression, and \rightarrow_e to donate a step in the extension evaluator for the mixed language. We may use \rightarrow_m to donate one-step reduction in our mixed language, defined in the next section.

$$\frac{\forall i. e_i \in \text{CoreExp} \quad (\text{CoreHead } e_1 \dots e_n) \rightarrow_c e'}{(\text{CoreHead } e_1 \dots e_n) \rightarrow_e e'} \quad (\text{CORERED})$$

$$\frac{\forall i. \text{subst}_i = (e_i \in \text{SurfExp} ? \text{tmpexp} : e_i), \text{ where tmpexp is any reducible CoreExp} \quad (\text{CoreHead } \text{subst}_1 \dots \text{subst}_i \dots \text{subst}_n) \rightarrow_c (\text{CoreHead } \text{subst}_1 \dots \text{subst}'_i \dots \text{subst}_n)}{(\text{CoreHead } e_1 \dots e_i \dots e_n) \rightarrow_e (\text{CoreHead } e_1 \dots e'_i \dots e_n) \quad \text{where } e_i \rightarrow_m e'_i \text{ if } e_i \in \text{SurfExp, else } e_i \rightarrow_c e'_i} \quad (\text{COREEXT1})$$

$$\frac{\forall i. \text{subst}_i = (e_i \in \text{SurfExp} ? \text{tmpexp} : e_i), \text{ where tmpexp is any reducible CoreExp} \quad (\text{CoreHead } \text{subst}_1 \dots \text{subst}_n) \rightarrow_c e' // \text{ not reduced in subexpressions}}{(\text{CoreHead } e_1 \dots e_n) \rightarrow_e e' [e_1/\text{subst}_1 \dots e_n/\text{subst}_n]} \quad (\text{COREEXT2})$$

For expression $(\text{CoreHead } e_1 \dots e_n)$, replacing all subexpression not in core language with any reducible core language's term tmpexp. Then getting a result after inputting the new expression e' to the original blackbox stepper. If reduction appears at a subexpression at e_i or what the e_i replaced by, then the stepper with the extension should return $(\text{CoreHead } e_1 \dots e'_i \dots e_n)$, where e'_i is e_i after the mixed language's one-step reduction (*redm*) or after core language's reduction (\rightarrow_c) (the rule CoreExt1, an example in Figure 4). Otherwise, stepper should return e' , with all the replaced subexpressions replacing back. (the rule CoreExt2, an example in Figure 5) The extension will not violate properties of original core language's evaluator. It is obvious that the evaluator with the extension will reduce at the subexpression as it needs in core language, if the reduction appears in a subexpression. One may notice that the stepper with extension behaves the same as mixing the evaluation rules of core language and surface language. The extension is just to make it works when the evaluator of core language is a blackbox stepper. That's why the extension is tricky.

3.2 Resugaring Algorithm

Our resugaring algorithm works on our mixed language, based on the reduction rules of the core language and the desugaring rules for defining the surface language. Let \rightarrow_e denote the one-step

```

344      (if (and e1 e2) true false)
345          ↓replace
346      (if tmpe1 true false)
347          ↓blackbox
348      (if tmpe1' true false)
349          ↓desugar
350      (if (if e1 e2 false) true false)

```

Fig. 4. CoreExt1's example

```

353      (if (if true ture false) (and ...) (or ...))
354          ↓replace
355      (if (if true ture false) tmpe2 tmpe3)
356          ↓blackbox
357      (if true tmpe2 tmpe3)
358          ↓replaceback
359      (if true (and ...) (or ...))

```

Fig. 5. CoreExt2's example

reduction of the core language (based on the blackbox stepper with extension), and \rightarrow_d the one-step desugaring of outermost sugar. We define \rightarrow_m , the one-step reduction of our mixed language, as follows.

$$\frac{(\text{CoreHead } e_1 \dots e_n) \rightarrow_e e'}{(\text{CoreHead } e_1 \dots e_n) \rightarrow_m e'} \quad (\text{EXTRED})$$

$$\frac{\begin{array}{c} (\text{SurfHead } x_1 \dots x_i \dots x_n) \rightarrow_d e, e_i \rightarrow_m e_i'' \\ \exists i. e[e_1/x_1, \dots, e_i/x_i, \dots, e_n/x_n] \rightarrow_m e[e_1/x_1, \dots, e_i'/x_i, \dots, e_n/x_n] \end{array}}{(\text{SurfHead } e_1 \dots e_i \dots e_n) \rightarrow_m (\text{SurfHead } e_1 \dots e_i'' \dots e_n)} \quad (\text{SURFRED1})$$

$$\frac{\begin{array}{c} (\text{SurfHead } x_1 \dots x_i \dots x_n) \rightarrow_d e \\ \neg \exists i. e[e_1/x_1, \dots, e_i/x_i, \dots, e_n/x_n] \rightarrow_m e[e_1/x_1, \dots, e_i'/x_i, \dots, e_n/x_n] \end{array}}{(\text{SurfHead } e_1 \dots e_i \dots e_n) \rightarrow_m e[e_1/x_1, \dots, e_i/x_i, \dots, e_n/x_n]} \quad (\text{SURFRED2})$$

The CoreRed rule describes how our mixed language handles expressions with CoreHead—just leave it to the core language's evaluator with the extension. Then for the expression with SurfHead, we will firstly desugar the outermost sugar (identified by the SurfHead), then recursively executing \rightarrow_m . In the recursive call, if one of original subexpression e_i is reduced (SurfRed1), then the original sugar is not necessarily desugared, we should only reduce the subexpression e_i ; if not (SurfRed2), then the sugar have to desugar.

Then our desugaring algorithm is defined based on \rightarrow_m .

```

386      resugar(e) = if isNormal(e) then return
387                  else
388                      let e →m e' in
389                      if e' ∈ DisplayableExp
390                          output(e'), resugar(e')
391                      else resugar(e')

```


During the resugaring, we just call the mixed language's reduction (\rightarrow_m) on the input expression until the expression becomes a normal form. We use the `DisplayableExp` to restrict immediate sequences to be output or not. It is more explicit compared to existing approaches. And because \rightarrow_m will be executed recursively on the subexpressions, it can be optimized. (see in 3.4, because the current description is more easier to understand.)

3.3 Correctness

Existing resugaring works [Pombrio and Krishnamurthi 2014, 2015] define three properties for correctness of resugaring. We think they are also reasonable to describe correctness of our approach. We describe the following properties in our mixed language's domain, then prove or discuss on them.

Emulation. For each reduction of an expression in our mixed language, it should reflect on one step reduction of the expression totally desugared in the core language, or one step desugaring on a syntactic sugar.

Abstraction. Only displayable expressions defined in our mixed language appear in our resugaring sequences.

Coverage. No syntactic sugar is desugared before its sugar structure should be destroyed in core language.

3.3.1 Emulation. It is a basic property for correctness. Since desugaring won't change an expression after totally desugared, what we need to prove is that a non-desugaring reduction in the mixed language shows the exactly reduction which should appear after the expression totally desugared. We express it by following lemma. (`fulldesugar(exp)` returns the expression after `exp` totally desugared)

LEMMA 3.1. For $\text{exp} = (\text{SurfHead } e_1 \dots e_i \dots e_n) \in \text{SurfExp}$, if $\text{exp} \rightarrow_m \text{exp}'$ and $\text{fulldesugar}(\text{exp}) \neq \text{fulldesugar}(\text{exp}')$, then $\text{fulldesugar}(\text{exp}) \rightarrow_c \text{fulldesugar}(\text{exp}')$

DEFINITION 3.1 (EMULATION). If the mixed language satisfies Lemma 3.1, then the resugaring satisfies emulation property.

LEMMA 3.2. For $\text{exp} = (\text{SurfHead } e_1 \dots e_i \dots e_n)$, if inputting `fulldesugar(exp)` to core language's evaluator reduces the term original from e_i in one step, then the \rightarrow_m will reduce `exp` at e_i .

PROOF OF LEMMA 3.2. For $(\text{SurfHead } x_1 \dots x_i \dots x_n) \rightarrow_d e$

if e is of normal form, the `fulldesugar(exp)` will not be reduced by core evaluator.

if e is headed with `CoreHead`, then according to the `CoreRed` rule, the \rightarrow_e will execute on e according to `ExtRed`, which will reduce the subexpression e_i according to the blackbox evaluator with extension. Then the `SurfRed2` rule will reduce e_i . Because of the extension of evaluator reduces the subexpression in correct location, so it is for \rightarrow_m .

if e is headed with `SurfHead`, then the `redm` will execute recursively on e . If the new one satisfies the lemma, then it is for the former. Because any sugar expression will finally be able to desugar to expression with `CoreHead`, it can be proved recursively. \square

PROOF OF LEMMA 3.1.

For `SurfRed1` rule, $(\text{SurfHead } e_1 \dots e_i \dots e_n) \rightarrow_m (\text{SurfHead } e_1 \dots e_i'' \dots e_n)$, where $e_i \rightarrow_m e_i''$. If $\text{fulldesugar}(e_i) = \text{fulldesugar}(e_i'')$, then $\text{fulldesugar}(\text{Exp}) = \text{fulldesugar}(\text{Exp}')$. If not, what we need to prove is that, $\text{fulldesugar}(\text{Exp}) \rightarrow_c \text{fulldesugar}(\text{Exp}')$. Note that the only difference between `Exp` and `Exp'` is the i -th subexpression, and we have proved the lemma

3.2 that the subexpression is the one to be reduced after the expression desugared totally, it will be also a recursive proof on the subexpression e_i .

For SurfRed2 rule, Exp' is Exp after the outermost sugar resugared. So $\text{fulldesugar}(\text{Exp}) = \text{fulldesugar}(\text{Exp}')$.

□

So our resugaring approach satisfies evaluation property.

3.3.2 Abstraction. Abstraction is not a restrict properties, because each expression has its meaning. Users may choose what they want to output during the process. Existing resugaring approaches use marks to determine whether to display a term generated by desugaring, or only changes on original terms will show.

We define the abstraction by catalog the expression in the mixed language, from the reason why we need resugaring—sugar expressions become unrecognizable after desugaring. So why cannot a recursive sugar's resugaring sequences show the sugars generated by itself? We think the users should be allowed to decide which terms are recognizable. Then during the resugaring process, if no unrecognizable term for the user appears in the whole expression, the expression should be shown as a step in resugaring sequences. Lazy resugaring, as the key idea of our approach, makes any intermediate steps retain as many sugar structures as possible, so the abstraction is easy.

3.3.3 Coverage. The coverage property is important, because resugaring sequences are useless if lose intermediate steps. By lazy desugaring, it becomes obvious, because there is no chance to lose. In Lemma 3.3, we want to show that our reduction rules in the mixed language is *lazy* enough. Because it is obvious, we only give a proof sketch here.

LEMMA 3.3. *A syntactic sugar only desugars when necessary, that means after a reduction on the fully-desugared expression, the sugar's structure is destroyed.*

DEFINITION 3.2 (COVERAGE). *If the reduction of mixed language satisfies Lemma 3.3, then the resugaring satisfies coverage property.*

PROOF SKETCH OF LEMMA 3.3. From Lemma 3.2, we know the \rightarrow_m recursively reduces a expression at correct subexpression. Or the \rightarrow_m will destroy the outermost sugar (of the current expression) in rule SurfRed2. Note that it is the only rule to desugar sugars directly (other rules only desugar sugars when recursively call SurfRed2), we can prove the lemma recursively if SurfRed1 is *lazy* enough.

In SurfRed2 rule, we firstly expand the outermost sugar and get a temp expression with structure of the outermost sugar. Then when we recursively call \rightarrow_m , the reduction result shows the structure has been destroyed, so the outermost sugar has to be desugared. Since the recursive reduction of a terminable (Some bad sugars may never stop which are pointless.) sugar expression will finally terminate, the lemma can be proved recursively. □

3.4 Implementation

Our resugaring approach is implemented using PLT Redex[Felleisen et al. 2009], which is an semantic engineering tool based on reduction semantics[Felleisen and Hieb 1992]. The framework of the implementation is as Figure 6.

Instead of implementing a blackbox stepper of core language, we just used the core language's reduction semantics, because its behavior is same as the stepper with extension for mixed language. We have proved or discussed the correctness with the assumption that the core language's evaluator is a blackbox stepper. In the language model, desugaring rules are written as reduction

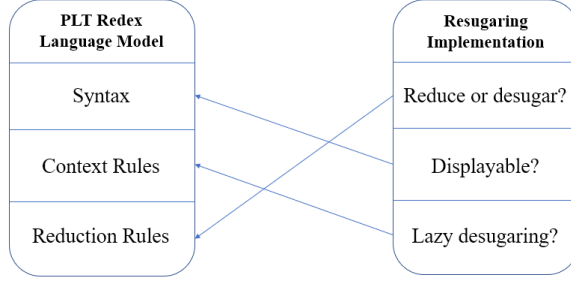


Fig. 6. framework of implementation

rules of SurfExp. And context rules of SurfExp have no restrict (every subexpressions is reducible as a hole). Then for each resugaring step, we should choose the exact reduction which satisfies the reduction of mixed language's rule (see in section 3.2).

Note that in SurfRed1 rule and CoreExt1 rule, there is a recursive call on \rightarrow_m . We can optimize the resugaring algorithm by recursively resugaring. For example, (Sugar1 (Sugar2 e21 e22 ...) e11 e12 ...) as the input, and find the first subexpression should be reduced. We can firstly get the resugaring sequences of (Sugar2 e21 e22)

(Sugar2 e21 e22 ...)

\rightarrow exp1

\rightarrow^* exp... // may be 0 or more steps

\rightarrow expn

Then a resugaring subsequence is got as

(Sugar1 (Sugar2 e21 e22 ...) e11 e12 ...)

\rightarrow (Sugar1 exp1 e11 e12 ...)

\rightarrow^* (Sugar1 exp... e11 e12 ...) // may be 0 or more steps

\rightarrow (Sugar1 expn e11 e12 ...)

Thus, we will not need to try to expand the outermost sugar for each inner step (recursively resugaring for inner expression).

3.5 Application

We test some applications on the tool. Note that we set call-by-value lambda calculus as terms in CommonExp, because we need to output some intermediate sequences including lambda expressions in some examples. It's easy if we want to skip them.

3.5.1 simple sugar. We construct some simple syntactic sugars and try it on our tool. Some sugar is inspired by the first work of resugaring[Pombrio and Krishnamurthi 2014]. The result shows that our approach can handle all sugar features of their first work.

We take a SKI combinator syntactic sugar as an example. We will show why our approach is lightweight.

$S \rightarrow_d (\text{lambdaN } (x1 \ x2 \ x3) (x1 \ x2 \ (x1 \ x3)))$

$K \rightarrow_d (\text{lambdaN } (x1 \ x2) x1)$

$I \rightarrow_d (\text{lambdaN } (x) x)$

Although SKI combinator calculus is a reduced version of lambda calculus, we can construct combinators' sugar based on call-by-need lambda calculus in our CoreLang. For sugar expression $(S (K (S I)) K xx yy)$, we get the following resugaring sequences.

```

(S (K (S I)) K xx yy)
→ (((K (S I)) xx (K xx)) yy)
→ (((S I) (K xx)) yy)
→ (I yy ((K xx) yy))
→ (yy ((K xx) yy))
→ (yy xx)

```

For the existing approach, the sugar expression should firstly desugar to

```

((lambdaN
  (x1 x2 x3)
  (x1 x3 (x2 x3)))
 (lambdaN (x1 x2) x1)
 (lambdaN
  (x1 x2 x3)
  (x1 x3 (x2 x3)))
 (lambdaN (x) x))
(lambdaN (x1 x2) x1)
xx yy)

```

Then in our CoreLang, the execution of expanded expression will contain 33 steps. For each step, there will be many attempts to match and substitute the syntactic sugars to resugar the expression. It will omit more steps for a larger expression. So the unidirectional resugaring algorithm makes our approach lightweight, because no attempts for resugaring the expression are needed.

3.5.2 hygienic sugar. The second work[Pombrio and Krishnamurthi 2015] of existing resugaring approach mainly processes hygienic sugar compared to first work. It use a DAG to represent the expression. However, hygiene is not hard to handle by our lazy desugaring strategy. Our algorithm can easily process hygienic sugar without special data structure.

A typical hygienic problem is as the following example.

$$(\text{Hygienicadd } e1 \ e2) \rightarrow_d (\text{let } (x \ e1) \ (+ \ x \ e2))$$

For existing resugaring approach, if we want to get sequences of $(\text{let } ((x \ 2)) \ (\text{Hygienicadd } 1 \ x))$, it will firstly desugar to $(\text{let } ((x \ 2)) \ (\text{let } ((x \ 1)) \ (+ \ x \ x)))$, which is awful because the two x in $(+ \ x \ x)$ should be bind to different value. So existing hygienic resugaring approach use abstract syntax DAG to distinct different x in the desugared expression. But for our approach based on lazy desugaring, the hygienicadd sugar does not have to desugar until necessary, so, getting following sequences based on a hygienic rewriting system.

```

(let ((x 2)) (Hygienicadd 1 x))
→ (Hygienicadd 1 2)
→ (+ 1 2)
→ 3

```

The lazy desugaring is also convenient for hygienic resugaring for non-hygienic rewriting. For example, $(\text{let } ((x \ 1)) \ (+ \ x \ (\text{let } ((x \ 2)) \ (+ \ x \ 1))))$ may be reduced to $(+ \ 1 \ (\text{let } ((1$

2)) (+ 1 1))) by a simple core language whose let expression does not handle cases like that. But by writing a simple sugar Let,

$$(\text{Let } e1 \ e2 \ e3) \rightarrow_d (\text{let } ((e1 \ e2)) \ e3)$$

and some simple modifies in the reduction of mixed language, we will get the following sequences in our system.

$$\begin{aligned} & (\text{Let } x \ 1 \ (+ \ x \ (\text{Let } x \ 2 \ (+ \ x \ 1)))) \\ \longrightarrow & (\text{Let } x \ 1 \ (+ \ x \ (+ \ 2 \ 1))) \\ \longrightarrow & (\text{Let } x \ 1 \ (+ \ x \ 3)) \\ \longrightarrow & (+ \ 1 \ 3) \\ \longrightarrow & 4 \end{aligned}$$

In practical application, we think hygiene can be easily processed by rewriting system, so we just use a rewriting system which can rename variable automatically. But our result shows lazy desugaring is really a good way to handle hygienic sugar in any systems.

3.5.3 recursive sugar. Recursive sugar is a kind of syntactic sugars where call itself or each other during the expanding. For example,

$$\begin{aligned} (\text{Odd } e) & \rightarrow_d (\text{if } (> \ e \ 0) \ (\text{Even } (- \ e \ 1)) \ \#f) \\ (\text{Even } e) & \rightarrow_d (\text{if } (> \ e \ 0) \ (\text{Odd } (- \ e \ 1)) \ \#t) \end{aligned}$$

are common recursive sugars. The existing resugaring approach can't process syntactic sugar written as this (non pattern-based) easily, because boundary conditions are in the sugar itself.

Take (*Odd 2*) as an example. The previous work will firstly desugar the expression using the rewriting system. Then the rewriting system will never terminate as following shows.

$$\begin{aligned} & (\text{Odd } 2) \\ \rightsquigarrow & (\text{if } (> \ 2 \ 0) \ (\text{Even } (- \ 2 \ 1)) \ \#f)) \\ \rightsquigarrow & (\text{if } (> \ (- \ 2 \ 1) \ 0) \ (\text{Odd } (- \ (- \ 2 \ 1) \ 1)) \ \#t)) \\ \rightsquigarrow & (\text{if } (> \ (- \ (- \ 2 \ 1) \ 1) \ 0) \ (\text{Even } (- \ (- \ (- \ 2 \ 1) \ 1) \ 1)) \ \#f)) \\ \rightsquigarrow & \dots \end{aligned}$$

Then the advantage of our approach is embodied. Our lightweight approach doesn't require a whole expanding of sugar expression, which gives the framework chances to judge boundary conditions in sugars themselves, and showing more intermediate sequences. We get the resugaring sequences of the former example using our tool.

$$\begin{aligned} & (\text{Odd } 2) \\ \longrightarrow & (\text{Even } (- \ 2 \ 1)) \\ \longrightarrow & (\text{Even } 1) \\ \longrightarrow & (\text{Odd } (- \ 1 \ 1)) \\ \longrightarrow & (\text{Odd } 0) \\ \longrightarrow & \#f \end{aligned}$$

We also construct some higher-order syntactic sugars and test them. The higher-order feature is important for constructing practical syntactic sugars. And many higher-order sugars should be

constructed by recursive definition. The first sugar is `filter`, implemented by pattern matching term rewriting.

```
(filter e (list v1 v2 ...))
→d (if (e v1) (cons v1 (filter e (list v2 ...))) (filter e (list v2 ...)))
(filter e (list)) →d (list)
```

and getting the following result. (by making `(lambda ...)` `CommonExp`)

```
(filter (lambda (x) (and (> x 1) (< x 4))) (list 1 2 3 4))
→ (filter (lambda (x) (and (> x 1) (< x 4))) (list 2 3 4))
→ (cons 2 (filter (lambda (x) (and (> x 1) (< x 4))) (list 3 4)))
→ (cons 2 (cons 3 (filter (lambda (x) (and (> x 1) (< x 4))) (list 4))))
→ (cons 2 (cons 3 (filter (lambda (x) (and (> x 1) (< x 4))) (list))))
→ (cons 2 (cons 3 (list)))
→ (cons 2 (list 3))
→ (list 2 3)
```

Here, although the sugar can be processed by existing resugaring approach, it will be redundant. The reason is that, a filter for a list of length n will match to find possible resugaring $n * (n - 1)/2$ times. Thus, lazy desugaring is really important to reduce the resugaring complexity of recursive sugar.

Moreover, just like the *Odd and Even* sugar above, there are some simple rewriting systems which do not allow pattern-based rewriting. Or there are some sugars which need to be expressed by the terms in core language as rewriting conditions. Take the example of another higher-order sugar `map` as an example.

```
(map e1 e2) →d
(let ((x e2)) (if (empty x) (list) (cons (e1 (first x)) (map e1 (rest x)))))
```

Get following resugaring sequences.

```
(map (lambda (x) (+ x 1)) (cons 1 (list 2)))
→ (map (lambda (x) (+ x 1)) (list 1 2))
→ (cons 2 (map (lambda (x) (+ 1 x)) (list 2)))
→ (cons 2 (cons 3 (map (lambda (x) (+ 1 x)) (list))))
→ (cons 2 (cons 3 (list)))
→ (cons 2 (list 3))
→ (list 2 3)
```

Note that the `let` term is to limit the subexpression only appears once in RHS. In this example, we can find that the list `(cons 1 (list 2))`, though equal to `(list 1 2)`, is represented by core language's term. So it will be difficult to handle such inline boundary conditions by rewriting system. But our approach is easy to handle cases like this.

3.6 Compare to previous work

As mentioned many times before, the biggest difference between previous resugaring approach and our approach, is that our approach doesn't need to desugar the sugar expression totally. Thus, our approach has the following advantages compared to previous work.

- *Lightweight and efficient.* Our approach does not need tags to mark desugaring information as existing approaches, and only unidirectional desugaring is needed, so it is a lightweight approach. As the example at sec3.5.1, the match and substitution process searches all intermediate sequences many times. It will cause huge cost for a large program. So our approach—only expanding a syntactic sugar when necessarily, is a efficient approach.
- *Friendly to hygienic sugar* Previous hygienic resugaring approach use a new data structure to process resugaring of hygienic sugar. Our approach simply desugar the sugars
- *More syntactic sugar features* The ability of processing non-pattern-based (Todo: inline?) recursive sugar is a superiority compared to previous work. The key point is that recursive syntactic sugar must handle boundary conditions. Our approach handle them easily by not necessarily desugaring all syntactic sugars. Higher-order functions, as an important feature of functional programming, was supported by many daily programming languages. Lazy desugaring makes writing higher-order sugars easier.
- *Todo: easier sugar?*

4 STATIC APPROACH

In this section, we introduce a static approach, which is more efficient than the one discussed above.

4.1 Inference Automaton

Based on the idea of DFA (Deterministic Finite Automaton), we designed inference automaton (IFA). An IFA describes the inference rules of a certain syntactic structure. To help readers better understand it, first we give a few examples, then we give the formal definition of IFA and proofs of theorems.

4.1.1 IFA of if. The inference rules of `if` are shown as AAAR1. We can observe that an `if` term is first evaluated for `e1`, and is chosen to be evaluated for `e2` and `e3` depending on the value of it, then the result of the evaluation of `e2` or `e3` is the result of the evaluation of the term. Thus, we use AAAP1 to represent the inference rules of `if`.

The arrow from `e1` to `e2` indicate that this branch will be selected when the result of the `e1` evaluation is `#t`. The arrows between `e1` and `e3` are the same. The double circles of `e2` and `e3` denotes that their evaluation result is the result of the syntactic structure. When a term with an `if` syntactic structure needs to be evaluated (for example `if (if #t #t #f) #f #t`), first evaluating the `e1` (`if #t #t #f`) part. Note that in this process, evaluating a subexpression requires running another automaton based on its syntax, while the outer automaton hold the state at `e1`. According to the result of `e1` (`#f`), the IFA selects the branch (`e3`). Then the result of `e3` (`#t`) will be the evaluation result of the term.

4.1.2 IFA of nand. Sometimes the rules may be more complex, such as being reduced into another syntactic structure, or the term contains other syntactic structures. For example, we can express `nand`'s inference rule in the form of AAAR2. Based on the method discussed above, we can draw `nand`'s IFA as AAAP2.

When the automaton runs to the last node, its evaluation rule is essentially an evaluation of the `if` syntax structure. Thus we can replace the last node with an `IFA_if` and use the `IFA_if` termination

nodes as the termination nodes of the IFA_Nand. The results are shown in AAAP3. Further decomposing the intermediate nodes, connecting the terminating node of IFA_if to the node pointed to by the original output edge, we get AAAP4.

As can be seen, the nodes of IFA in AAAP4 have only the forms e_i , v_i and values, and no other composite syntactic structure. We call such an IFbA a *standard IFA*.

4.1.3 IFA of or. We represent the inference rule of or in a more complex way, as shown in AAAR3. In this case, we use the let binding, which expresses a class of rules containing substitution. At this point, we need to record the term represented by each variable at each node, denoted by Γ . The representation of IFA_or is shown in AAAP5.

More generally, the handling of substitution tables will be more complex. We will discuss this in more detail in AAAP1.

4.1.4 Definition of IFA.

DEFINITION 4.1 (INFERENCE AUTOMATON). *An inference automaton (IFA) of syntactic structure (Headid $e_1 \dots e_n$) is a 5-tuple, $(Q, \Sigma, q_0, F, \delta)$, consisting of*

- *A finite set of nodes Q , each node contains a term and a symbol table*
- *A finite set of pattern Σ*
- *A start node $q_0 \in Q$*
- *A set of terminal nodes $F \subseteq Q$*
- *A transition function $\delta : (Q - F) \times \Sigma' \rightarrow Q$ where $\Sigma' \subseteq \Sigma$*

and for each node q , there is no sequence of pattern $P = (p_1, p_2, \dots, p_n) \subseteq \Sigma^$, which makes that after q transfers sequentially according to P , it returns q .*

The last constraint requires that there be no circles in our IFA.

In IFA, state transition does not depend on input. The only input IFA accepts is the term to be evaluated with this syntactic structure. The state transition is through pattern matching on the evaluation result of the term in the previous node. Note that IFA is associated with syntactic structure. At Each IFA only represents the current evaluation of a syntactic structure. The state indicates that some sub-expressions of the syntactic structure have been evaluated, and the rest have not.

DEFINITION 4.2 (STANDARD IFA). *If the term of node in Q can only be e_i (where $i \in 1, \dots, n$) or a value, we name the IFA standard IFA.*

If an IFA is standard, it means there are no more composite syntactic structures in it. In the above example, for the syntactic structure of if, we substituted the IFA of the if into nand and converted it into a standard IFA. Below we will prove that it is always feasible to convert IFA to standard IFA, and give the algorithm.

LEMMA 4.1. *Considering an IFA of a syntactic structure, if the standard IFAs of all syntactic structures of terms contained in the IFA are known, then the IFA can be transformed into a standard IFA.*

PROOF OF LEMMA. □

4.2 Convert inference rules to IFA

Considering the inference rules in CoreLang, which we have more strict limits on.

Assumption 1. A syntactic structure Headid only contains the following inference rules.

$$\frac{(\text{Headid } v_1 \dots v_p \ e_1 \dots e_i \dots e_q) \rightarrow (\text{Headid } v_1 \dots v_p \ e_1 \dots e'_i \dots e_q)}{e_i \rightarrow e'_i} \quad (\text{E-HEAD})$$

$$(\text{Headid } v_1 \dots v_p \ e_1 \dots e_q) \rightarrow e$$

$$(\text{Headid } v_1 \dots v_p \ e_1 \dots e_q) \rightarrow \text{let } x = \text{Exp}_1 \text{ in } \text{Exp}_2$$

This assumption specifies the form of the inference rules to ensure that IFAs can be generated. The first one is context rule, and the others are reduction rules.

Assumption 2. The syntactic structure in CoreLang is finite. Think of all syntactic structures as points in a directed graph. If one of *Headid*'s inference rules can generate a term containing *Headid*', then construct an edge that points from *Headid* to *Headid*'. The directed graph generated from this method has no circles.

IFAs are not able to construct syntactic structures that contain recursive rules now. This assumption qualifies that we can find an order for all syntactic structures, and when we construct IFA of *Headid*, IFA of *Headid*' is known.

Assumption 3. The rules satisfy the determinacy of one-step evaluation.

By assumption 3, we can get the following lemma, which points out the feasibility of using a node in IFA to represent the evaluation process of sub-expressions.

LEMMA 4.2. *If a term $(\text{Headid } e_1 \dots e_n)$ does a one-step evaluation by rule (E-Head) of *Headid*, which is a one-step evaluation of e_i , then it will continue to use this rule until e_i becomes a value.*

PROOF OF LEMMA. According to Assumption 3, this lemma is trivial. \square

LEMMA 4.3. *If all syntactic structures in CoreLang satisfy Assumption 1 and Assumption 2, We can construct standard IFAs for all syntactic structures in CoreLang.*

PROOF OF LEMMA. By Assumption 2, we get an order of syntactic structures. We generate the IFA for each structure in turn.

We generate a node for each rule and insert them into Q . If the rule is a reduction rule, add them into F as terminal nodes. Next we will connect these nodes.

For a term like $(\text{Headid } e_1 \dots e_n)$, considering that $e_1 \dots e_n$ are not value, According to Assumption 3, we have the unique rule r of *Headid* for one-step evaluation. Let node q corresponding to r be q_0 .

If r is a context rule for e_i , let the term of q_0 be build a new node q and add it into Q . The term of q is e_i . And the symbol table is set to empty. Assume that the evaluation of e_i results in v_i , we get term $(\text{Headid } e_1 \dots e_{i-1} \ v_i \ e_{i+1} \dots e_n)$. For each possible value of v_i , choose the rules that should be used.

If r is a reduction rule, build a new node q and add it into Q and F . The term of q is e_i , and the symbol table is set to

\square

4.3 Convert IFA to Inference Rules

LEMMA 4.4. *For each IFA, it can be converted to inference rules.*

PROOF OF LEMMA. Give an algorithm: convert IFA to inference rules. \square

4.4 Syntactic Sugar

With the IFA, we can easily get the inference rules for syntactic sugars.

DEFINITION 4.3. *Considering the following syntactic sugar*

$$(\text{SurfHead } x_1 \dots x_n) \rightarrow_d e,$$

*the IFA of *SurfHead* is defined as the IFA of syntactic structure *SurfHead*' whose inference rule is*

$$(\text{SurfHead}' \ x_1 \dots x_n) \rightarrow e.$$

5 RELATED WORK

Resugaring sequences [Pombrio and Krishnamurthi 2014, 2015] As we have discussed many times, the concept of resugaring is original from their work, by the main idea of "tagging" and "reverse desugaring". Our approach is more lightweight, powerful and efficient, as discussed before. In summary, we also find some common issues about resugaring.

- Side effects in resugaring. In the first paper of resugaring, they try a letrec sugar based on set! term in core language and get no intermediate steps. After trying some syntactic sugars which contain side effect, we would say a syntactic sugar including side-effect is bad for resugaring, because after a side effect takes effect, the desugared expression should never resugar to the sugar expression. Thus, we don't think resugaring is useful for syntactic sugars including side effects, though it can be done by marking any expressions which have a side effect.
- Hygienic resugaring. As we showed in both approaches, hygiene is easily and naturally resolved by lazy desugaring, because it may behave as what the sugar ought to express. The second paper of resugaring presents a DAG to solve the problem, which is a smart but not concise way.
- Assumption on core language. The traditional resugaring and the dynamic approach both use a blackbox evaluator of core language, while the dynamic approach use the semantics of core language. We found that if given the semantics of core language, the resugaring will be more convenient. The blackbox evaluator in our dynamic approach will not need the extension, while the rules getting by our static approach is more express.

Type resugaring [Pombrio and Krishnamurthi 2018] indicates that it is possible to automatically construct surface language's semantics by unification. But after trying to do this as type resugaring does, we found it hard because the method may assume only one rule for multi-branches of one syntactic sugar, which is not suitable for evaluation rules. We also find getting evaluation rules in big-step semantics is easier, but not works well for syntactic sugar.

Macros as Multi-Stage Computations [Ganz et al. 2001] is a work similar to lazy expansion for macros. Some other researches [Rompf and Odersky 2010] about multi-stage programming [Taha 2003] indicate that it is an useful idea for implementing domain-specific languages. Overall, multi-stage programming is a metaprogramming method based on run-time code generation. In contrast, our resugaring approach gives abstraction by carefully design the reduction of mixed language. Moreover, the lazy desugaring gives us chance to derive evaluation rules of sugars, which is a new good point compared to multi-stage programming.

Galois slicing for Imperative Functional Programs [Ricciotti et al. 2017] is a work for dynamic analyzing functional programs during execution. The forward component of the Galois connection maps a partial input x to the greatest partial output y that can be computed from x ; the backward component of the Galois connection maps a partial output y to the least partial input x from which we can compute y . Our approach used a similar idea on slicing expressions and processing on subexpressions. It's just like bidirectional transformation [Czarnecki et al. 2009] and the round-tripping between desugaring and resugaring in existing approach. In contrast, our resugaring approach is unidirectional, by an attempt on expanding sugar, just like the forward component of Galois connection. It should be noted that Galois slicing may be useful to handle side effects in resugaring (for example, slicing the part where side effects appear).

Origin tracking [Deursen et al. 1992] is about tracking the origins of terms in rewriting system, which does not involve the use of syntactic sugar. The key idea *lazy desugaring* makes our approach easy to solve the problems introduced by syntactic sugar. And the tracking in their notation can be easily done for sugar whose rules can be derived automatically.

Since the existing resugaring approach firstly desugars all sugar in programs, it is more similar to debugging process, where as our approach is likely engineering the semantics of language. *Zigurat* [Fisher and Shivers 2006] is a semantic-extension framework. It allows defining new macros with semantics based on existing terms in a language. It is quite useful for static analysis on macros. Instead of semantics based on core language, the reduction rules of sugar derived by our approach is independent of core language, which may be more concise for static analysis. Addition to PLT Redex[Felleisen et al. 2009] which we used to engineer the semantics, there are some other semantics engineering tools [Rosu and Serbanuta 2010; Vergu et al. 2015] which aim to test or verify the semantics of languages. The methods of these researches can be easily combined with our approach to implement more general rule derivation.

6 CONCLUSION

In this paper, we purpose a lightweight, efficient and powerful resugaring approach by lazy desugaring. Essentially, we would see the derivation of rules is the abstract of the basic resugaring approach. In the basic approach, the most important part is *reduction in mixed language* (see in sec 3.2), which decides whether reducing the subexpression or desugaring the outermost sugar. Reducing subexpressions are just the same as derivated context rules; desugaring the outermost sugar is similar to derivated reduction rules. However, the derivated evaluation rules is more convinient and efficient than the basic resugaring, because the derivation evolves a process like abstract interpretation[Cousot and Cousot 1977], then reduces many steps executed in core language. Moreover, the semantics got by derivation make it possible to do some optimization at the surface language level, which is important for implementing a DSL. In contrast, the dynamic approach is more powerful by supporting recursive sugars' resugaring. Besides, the rewriting based on reduction semantics makes the sugar represented in many ways.

The original intent of our research is finding a better method (or building a tool) for implementing DSL. We could see derivated evaluation rules is better for achieving the goal, because getting the semantics of DSL (based on syntactic sugar) will be very useful for applying any other techniques on the DSL. But it will be better if the defects of expressiveness of sugar which the derivation can handle are improved. So we may be achieving a more powerful derivation which can recursive recursive sugar as a future work.

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A APPENDIX

Text of appendix ...