

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: Domain-specific Language, Syntactic Sugar, Interpreter, 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 reursive 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 [Pombrio and Krishnamurthi 2014]. Todo: pattern-based?
- *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. 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.

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

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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 reduction 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 mixture approach of resugaring.* We introduce an mixture of two different resugaring approaches to combine the advances of following approaches. The lazy dusugaring is common feature of two approaches, which give each approach some good properties.
- *A lightweight but powerful dynamic approach.* The dynamic approach we proposed is based on core language's reduction semantics. It takes surface language and core language as a whole, then decided whether expanding 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 dynamic approach on many applications. The result shows that in addition to handle what existing work can handle, our dynamic approach can process recursive sugar easily, which makes it powerful. And the rewriting system based on reduction semantics makes it possible to write syntactic sugar easily.
- *An independent and efficient static approach.* The static approach we proposed also used core language's reduction semantics. But instead of executing at the level of core language, we turn the core language's semantics into automata. Then for each syntactic sugar, we would generate the surface language's semantics without depending on some rules in core language. (some meta-functions may be necessary.) Thus, it is efficient because many steps in core language can be omitted. todo: complete
- *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 firstly show an example of traditional resugaring approach. Then we will describe the framework of our whole approach, with two different approaches which work together and their separate examples.

2.1 Existing resugaring method

This subsection is original from [Pombrio and Krishnamurthi 2014] and [Pombrio and Krishnamurthi 2015]. But their original idea is from the first one, and the second one is a optimized version on hygienic macros and rewriting system.

DEFINITION 2.1 (RESUGARING). *Given core language (named **CoreLang**) and its evaluator, together with surface language based on syntactic sugars of CoreLang (named **Surflang**). For any syntactic sugar, getting the evaluation sequences of the expression in Surflang's syntax. It's not strict, so they use three properties for defining correctness.*

For correctness of the resugaring, the evaluation sequences should maintain the following three properties:

- (1) *Emulation* Every surface term desugars to (a term isomorphic to) the core term it purports to represent.
- (2) *Abstraction* If a term is shown in the reconstructed surface evaluation sequence, then each non-atomic part of it originated from the original program and has honest tags.
- (3) *Coverage* A sugar with good coverage shows many steps in the reconstructed surface evaluation sequence.

It is a good summary for resugaring's properties, so we also use similar properties in our approach (using our domain).

Given an example to show how existing approach works. For syntactic sugar **and** and **or**, the sugar rules are:

$$\begin{aligned} (\text{And } e_1 \ e_2) &\rightarrow_d (\text{if } e_1 \ e_2 \ \#f) \\ (\text{Or } e_1 \ e_2) &\rightarrow_d (\text{if } e_1 \ \#t \ e_2) \end{aligned}$$

which forms a simple `SurfLang`.

The evaluation rules of **if** is:

$$\begin{aligned} (\text{if } \#t \ e_1 \ e_2) &\rightarrow e_1 \\ (\text{if } \#f \ e_1 \ e_2) &\rightarrow e_2 \end{aligned}$$

Then for `SurfLang`'s expression $(\text{and } (\text{or } \#f \ \#t) (\text{and } \#t \ \#f))$ should get resugaring sequences as follow.

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

The reason we should get the sequences above is because $(\text{and } (\text{or } \#f \ \#t) (\text{and } \#t \ \#f))$ should desugar to $(\text{if } (\text{if } \#f \ \#t \ \#f) (\text{if } \#t \ \#f \ \#f) \ \#f)$. Then in the `CoreLang`, the evaluation sequences will be as follow.

$$\begin{aligned} &(\text{if } (\text{if } \#f \ \#t \ \#f) (\text{if } \#t \ \#f \ \#f) \ \#f) \\ \rightarrow &(\text{if } \#t (\text{if } \#t \ \#f \ \#f) \ \#f) \\ \rightarrow &(\text{if } \#t \ \#f \ \#f) \\ \rightarrow &\#f \end{aligned}$$

The second item in the sequences can be desugared from $(\text{and } \#t (\text{and } \#t \ \#f))$, so resugars to it. So as the third item. In summary, the traditional approach firstly desugars the whole expression, then tries to transform the core sequences into surface sequences by match and substitution.

2.2 Mixture Approach Framework

We limit the language to s-expressions. Given an expression $\text{Exp} = (\text{Headid Exp}^*)$, the process of mixture approach will as Fig 1.

Given an example based on the former section. Besides sugar **and**, **or**, we add a recursive sugar **mapf** based on another new sugar **f**. The recursive sugar can be handled by the dynamic approach, but not for the static one. (Reasons in later sections)

$$\begin{aligned} (\text{f } e_1 \ e_2) &\rightarrow (\text{let } x \ e_1 \ (\text{or } x \ (\text{and } e_2 \ x))) \\ (\text{mapf } e \ \text{lst}) &\rightarrow (\text{if } (\text{empty? } \text{lst}) \ \text{empty} \ (\text{cons } (\text{f } e \ (\text{first } \text{lst})) \ (\text{mapf } e \ (\text{rest } \text{lst})))) \end{aligned}$$

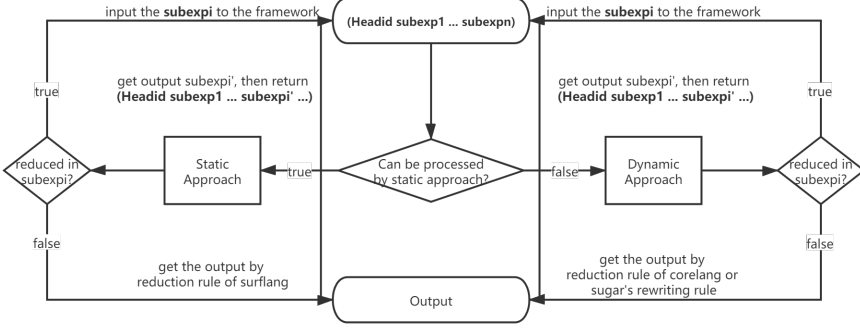


Fig. 1. One step in framework of mixture approach

In the mapf (map of f) sugar, we use both core language's term (such as **if**, **empty?**, **cons**, **let**, **first**, **rest**) and existing syntactic sugar (**and**, **or**). The semantics of core language is as common. But to show some exact steps, we set the term **cons** as a common expression (belonging to core language, but being displayed as surface language).

If we execute

```
(mapf #t (list #f #t))
```

the mixture approach will judge whether sugar mapf can be handle by the static approach. No, then we use the dynamic approach in one step and get the intermediate expression.

```
(mapf #t (list #f #t))
```

```
→ (cons (f #t (first (list #f #t))) (mapf #t (rest (list #f #t))))
```

Then according to semantics of **cons**, the first subexpression should be reduced. The subexpression can be handled by the static approach, so getting a subsequence.

```
(cons (f #t (first (list #f #t))) (mapf #t (rest (list #f #t))))
```

```
→ (cons (f #t #f) (mapf #t (rest (list #f #t))))
```

```
→ (cons #t (mapf #t (rest (list #f #t))))
```

Then the second subexpression should be reduced, which is a recursive process. Finally, the subexpression (mapf #t (list)) will be processed by dynamic approach.

```
(mapf #t (list))
```

```
--> (if (empty? (list)) empty ...)
```

```
→ empty
```

Note that there are some steps should not be displayed, we define the common expressions above in syntaxes to restrict which intermediate step should be displayed.

The key idea of our dynamic approach, is that, regarding surface language and core language as a whole under the strategy of lazy desugaring. We design a core algorithm to choose the right reduction rule for any expression during the execution. Take the example (and (or #f #t) (and #t #f)) again. We will get the sequence as Fig2.

At step 1, we found the outermost *and* sugar don't have to expand, because its first sub-expression will reduce earlier. At step 2, the same as step 1. At step 3, the outermost *and* sugar have to expand, because no sub-expression will reduce after the whole expression desugar. At step 4, the inner *and*

```

197 (and (or #f #t) (and #t #f)) -->_{step1} (and (if #f #t #t) (and #t #f)) -->_{step2}
198 (and #t (and #t #f)) -->_{step3} (if #t (and #t #f) #f) -->_{step4} (and #t #f) -->_{step5}
199 (if #t #f #f) -->_{step6} #f

```

Fig. 2. core-algo example

sugar don't have to expand either. At step 5, the sugar have to desugar to CoreLang. Finally at step 6, we get the final result. Note that there are some sequences which should not be shown, we use another function to filter them.

The key idea of our static approach, is that, converting reduction semantics of core language into automata (called *IFA*), building IFA for syntactic sugar, converting the IFA of sugars into reduction semantics. It is an abstract of dynamic approach in a sence, we will discuss it in Sec6. Take another **or** sugar for example.

$$(\text{or } e_1 e_2) \rightarrow_d (\text{let } x e_1 (\text{if } x x e_2))$$

where the rules of *if* and *let* is the same following

$$\begin{aligned} (\text{if } \#t e_1 e_2) &\rightarrow_d e_1 \\ (\text{if } \#f e_1 e_2) &\rightarrow_d e_2 \end{aligned}$$

From the IFA of *or* expression, we can get the following reduction semantics.

$$\frac{e_1 \rightarrow e'_1}{\begin{aligned} (\text{Or } e_1 e_2) &\rightarrow (\text{Or } e'_1 e_2) \\ (\text{Or } \#t e_2) &\rightarrow \#t \\ (\text{Or } \#f e_2) &\rightarrow e_2 \end{aligned}}$$

Then the resugaring sequences can be get by the reduction semantics.

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 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 [Todo: need to be corrected](#). 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.

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

Fig. 3. Core and Surface Expressions

Syntax	Reduction rules
(if e e e)	(if #t e2 e3) \rightarrow e2 (if #f e2 e3) \rightarrow e3
((lam (x ...) e) e ...)	((lam (x0 x1 ...) e) v0 v1 ...) \rightarrow (let ((x0 v0)) ((lam (x1 ...) e) v1 ...))
((lamN (x ...) e) e ...)	((lamN (x0 x1 ...) e) e0 e1 ...) \rightarrow (let ((x0 e0)) ((lamN (x1 ...) e) e1 ...))
(let ((x e) ...) e)	(let ((x0 e0) (x1 e1) ...) e) \rightarrow (let ((x1 e1) ...) (subst x0 e0 e)) (let () e) \rightarrow e (where subst is a meta function)
(first e)	(first (list v1 v2 ...)) \rightarrow v1
(rest e)	(rest (list v1 v2 ...)) \rightarrow (list v2 ...)
(empty e)	(empty (list)) \rightarrow #t (empty (list v1 ...)) \rightarrow #f
(cons e e)	(cons v1 (list v2 ...)) \rightarrow (list v1 v2 ...)
(op e e)	(op v1 v2) \rightarrow arithmetic result
op=+-*/><==	

Fig. 4. An Core Language Example

An expression of the core language is defined in Figure 3. 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 the core language defined in Figure 4 to demonstrate our approach.

3.1.2 Surface Language. Our surface language is defined by a set of syntactic sugars, together with some language constructs in the core language. So an expression of the surface language is some core constructor expressions with sugar expressions, as defined in Figure 3.

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

$$(\text{SurfHead } x_1 x_2 \dots x_n) \rightarrow_d \text{Exp}$$

where its LHS is a simple pattern (unnested) and its RHS is a surface expression. For instance, we may define syntactic sugar And by

$$(\text{And } x y) \rightarrow_d (\text{if } x y \#f).$$

Note that if the pattern is nested, we can introduce a new syntactic sugar to flatten it. One may wonder why 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

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

Fig. 5. Our Mixed Language

example.

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

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

3.1.3 Mixed Language. Our mixed language for resugaring combines the surface language and the core language. The difference between our core language (CoreLang) and our surface language (SurfLang) is identified by their Head. But there are some terms in the core language should be displayed during evaluation, or we need some 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 sub-expressions are displayable. The CommonExp terms are terms with displayable CoreLang's Head (named CommonHead, together with displayable sub-expressions). There exists some other expression during our resugaring process, which have displayable Head, but one or more subexpressions cannot. They are UndisplayableExp.

Take some terms in the core language in Figure 4 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. For

expression (CoreHead $e_1 \dots e_n$), replacing all subexpression not in core language with different reducible core language's term. Then getting a result after inputting the new expression exp' to the original blackbox stepper. If reduction appears at subexpressions after e_i replaced by, then the stepper with the extension should return (CoreHead $e_1 \dots e'_i \dots e_n$), where e'_i is e_i after desugaring. (an example in Fig 6) Otherwise, stepper should return exp' , with all the replaced subexpressions replacing back. (an example in Fig 7) 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.

```

(if (and e1 e2) true false)
  ↓replace
(if tmp1 true false)
  ↓blackbox
(if tmp1' true false)
  ↓desugar
(if (if e1 e2 false))

```

Fig. 6. e1

```

(if (if true true false) (and ...) (or ...))
  ↓replace
(if (if true true false) tmp2 tmp3)
  ↓blackbox
(if true tmp2 tmp3)
  ↓reback
(if true (and ...) (or ...))

```

Fig. 7. e2

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_c denote the one-step 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.

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

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

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

The CoreRed rule describes how our mixed language handle expressions with CoreHead—just leave it to the core language’s evaluator. 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 .

```

desugar(e) = if isNormal(e) then return
            else
              let  $e \rightarrow_m e'$  in
              if  $e' \in \text{DisplayableExp}$ 
                output( $e'$ ), desugar( $e'$ )
              else desugar( $e'$ )

```

We use the DisplayableExp to restrict immediate sequences to be output or not. It is more explicit compared to existing approaches.

3.3 Correctness

First of all, because the difference between our lightweight resugaring algorithm and the existing one is that we only desugar the syntactic sugar when needed, and in the existing approach, all syntactic sugar desugars firstly and then executes on CoreLang.

Then, to prove convenience, define some terms.

$\text{Exp} = (\text{Headid Subexp}_1 \text{ Subexp} \dots)$ is any reducible expression in our language.

If we use the reduction rule that desugar Exp ’s outermost syntactic sugar, then the reduction process is called **Outer Reduction**.

If the reduction rule we use reduce Subexp_i , where Subexp_i is $(\text{Headid}_i \text{ Subexp}_{i1} \text{ Subexp}_{i\dots})$

- If the reduction process is Outer Reduction of $\text{Subexp}_i = (\text{Headid}_i \text{ Subexp}_{i1} \text{ Subexp}_{i\dots})$, then it is called **Surface Reduction**.
- If the reduction process reduces Subexp_{ij} , then it is called **Inner Reduction**.

Example:

$(\text{if } \#t \text{ Exp}_1 \text{ Exp}_2) \rightarrow \text{Exp}_1$	Outer Reduction
$(\text{if } (\text{And } \#t \#f) \text{ Exp}_1 \text{ Exp}_2) \rightarrow (\text{if } (\text{if } \#t \#f \#f) \text{ Exp}_1 \text{ Exp}_2)$	Surface Reduction
$(\text{if } (\text{And } (\text{And } \#t \#t) \#t) \text{ Exp}_1 \text{ Exp}_2) \rightarrow (\text{if } (\text{And } \#t \#t) \text{ Exp}_1 \text{ Exp}_2)$	Inner Reduction

DEFINITION 3.1 (UPPER AND LOWER EXPRESSION). For $\text{Exp} = (\text{Headid Subexp}_1 \text{ Subexp} \dots)$, Exp is called **upper expression**, Subexp_i is called **lower expression**.

Case 2, 4, 6 in the core algorithm are of outer reduction. And case 3 or 5 are of surface reduction if the reduced subexpression is processed by outer reduction, or they are of inner reduction. What we need to prove is that all the 6 cases of core algorithm core-algo satisfy the properties. Case 1 and case 2 won’t effect any properties, because it does what CoreLang should do.

DEFINITION 3.2 (EMULATION). For $\text{Exp} = (\text{SurfHead } e_1 \dots e_i \dots e_n)$, if $\text{Exp} \rightarrow_m \text{Exp}'$ and $\text{Desugar}(\text{Exp}) \neq \text{Desugar}(\text{Exp}')$, then $\text{Desugar}(\text{Exp}) \rightarrow_c \text{Desugar}(\text{Exp}')$

LEMMA 3.1. For $\text{Exp} = (\text{SurfHead } e_1 \dots e_i \dots e_n)$, if inputting $\text{Desugar}(\text{Exp})$ 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. For $(\text{SurfHead } x_1 \dots x_i \dots x_n) \rightarrow_d e$

if e is of normal form, the $\text{Desugar}(\text{Exp})$ will not be reduced by core evaluator.

if e is headed with CoreHead , then according to the CoreRed rule, the \rightarrow_c will execute on e , 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 EMULATION.

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 $\text{Desugar}(e_i) = \text{Desugar}(e_i'')$, then $\text{Desugar}(\text{Exp}) = \text{Desugar}(\text{Exp}')$. If not, what we need to prove is that, $\text{Desugar}(\text{Exp}) \rightarrow_c \text{Desugar}(\text{Exp}')$. Note that the only difference between Exp and Exp' is the i -th subexpression, and we have proved the lemma 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 $\text{Desugar}(\text{Exp}) = \text{Desugar}(\text{Exp}')$. \square

PROOF OF ABSTRACTION.

It's true, because we only display the sequence which satisfies abstraction property. \square

LEMMA 3.2. *If no syntactic sugar desugared before necessary (if the sugar not desugared, the expression of mixed language cannot be reduced after other sugars desugared, then coverage property is satisfied).*

PROOF OF LEMMA3.2. Assume that no syntactic sugar not necessarily expanded desugars too early, existing an expression in CoreLang

$\text{Exp} = (\text{Head } e_1 \dots e_i \dots e_n)$ which can be resugared to

$\text{ResugarExp}' = (\text{Surfid } \text{Subexp}'_1 \text{Subexp}'_2 \dots)$, and $\text{ResugarExp}'$ is not displayed during lightweight-resugaring process. Then

- Or existing

$\text{ResugarExp} = (\text{Surfid } \text{Subexp}'_1 \dots \text{Subexp}'_i \text{Subexp}'_{i+1} \dots)$ in resugaring sequences, such that the expression after ResugarExp desugaring reduces to Exp , and the reduction reduces ResugarExp 's sub-expression Subexp'_i . If so, outermost syntactic sugar of ResugarExp is not expanded. So if $\text{ResugarExp}'$ is not displayed, then the sugar not necessarily expanded desugars too early, which is contrary to assumption.

- Or existing

$\text{ResugarExp} = (\text{Surfid}' \dots \text{ResugarExp}' \dots)$ in resugaring sequences, such that the expression after ResugarExp desugaring reduces to Exp , and Exp is desugared from $\text{ResugarExp}'$'s sub-expression. If $\text{ResugarExp}'$ is not displayed, then the outermost syntactic sugar is expanded early, which is contrary to assumption.

- Or though the Exp exists, it doesn't from ResugarExp .

\square

PROOF OF COVERAGE.

For case 4 and 6, the syntactic sugar has to desugar.

For case 3 and 5, the reduction occurs in sub-expression of Exp . So if applying core algorithm core-algo on the subexpression doesn't desugar syntactic sugars not necessarily expanded, then this two cases don't. If the reduction is surface reduction, then the reduction of the subexpression is

processed by case 2, 4 or 6, which don't desugar sugars not necessarily expanded; if the reduction is inner reduction, then it's another recursive proof as emulation. So in these two cases, the core-algo only desugar the sugar which has to be desugared. \square

3.4 Implementation

Our lightweight resugaring approach is implemented using PLT Redex[Felleisen et al. 2009], which is a semantic engineering tool based on reduction semantics[Felleisen and Hieb 1992]. The whole framework is as Fig8.

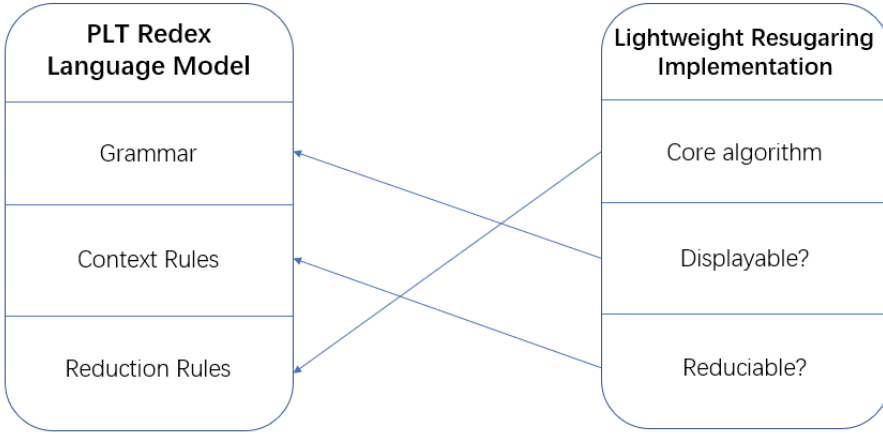


Fig. 8. framework of implementation

The grammar of the whole language contains Coreexp', Surfexp and Commonexp as the language setting in sec3. OtherSurfexp is of Surfexp and OtherCommonexp is of Commonexp. The identifier of any kind of expression is Headid of expression. If we need to add a syntactic sugar to the whole language, only three steps is needed.

- (1) Add grammar of the syntactic sugar.
- (2) Add context rules of the sugar, such that any sub-expressions can be reduced.
- (3) Add desugar rules of the sugar to reduction rules of the whole language.

Then inputting an expression of the syntactic sugar to lightweight-resugaring will get the resugaring sequences.

3.5 Application

We test some applications on the tool implemented using PLT Redex. Note that we set CBV's 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 sugar 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.

$S \mapsto (\text{lamN } (x1 \ x2 \ x3) (x1 \ x2 \ (x1 \ x3)))$

540 $K \rightarrow (\text{lamN } (x_1 \ x_2) \ x_1)$

541 $I \rightarrow (\text{lamN } (x) \ x)$

542
543 Although SKI combinator calculus is a reduced version of lambda calculus, we can construct
544 combinators' sugar based on call-by-need lambda calculus in our CoreLang. For expression
545 $(S (K (S I)) K \ xx \ yy)$, we get the following resugaring sequences as following.

546 $(S (K (S I)) K \ xx \ yy)$

547 $\rightarrow (((K (S I)) \ xx \ (K \ xx)) \ yy)$

548 $\rightarrow (((S I) (K \ xx)) \ yy)$

549 $\rightarrow (I \ yy \ ((K \ xx) \ yy))$

550 $\rightarrow (yy \ ((K \ xx) \ yy))$

551 $\rightarrow (yy \ xx)$

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

553
554
555 $((\text{lamN}$
556 $(x_1 \ x_2 \ x_3)$
557 $(x_1 \ x_3 \ (x_2 \ x_3)))$
558 $((\text{lamN } (x_1 \ x_2) \ x_1)$
559 $((\text{lamN}$
560 $(x_1 \ x_2 \ x_3)$
561 $(x_1 \ x_3 \ (x_2 \ x_3)))$
562 $(\text{lamN } (x) \ x)))$
563 $(\text{lamN } (x_1 \ x_2) \ x_1)$
564 $\ xx \ yy)$

565
566 Then in our CoreLang, the execution of expanded expression will contain 33 steps. For each step,
567 there will be many attempts to match and substitute the syntactic sugars. It will omit more steps
568 for a larger expression.

569 So the unidirectional resugaring algorithm makes our approach lightweight, because no at-
570 tempts for resugaring the expression take place.

571
572 **3.5.2 *hygienic macro*.** The second work[Pombrio and Krishnamurthi 2015] mainly processes hy-
573 gienic macro compared to first work. It use a DAG to represent the expression. However, hygiene
574 is not hard to handle by our lazy desugaring strategy. Our algorithm can easily process hygienic
575 macro without special data structure.

576 A typical hygienic example is as the example originated from Hygienic resugaring[Pombrio and
577 Krishnamurthi 2015]. We simplify the example to the following one.

578 $(\text{Hygienicadd } e_1 \ e_2) \rightarrow (\text{let } ((x \ e_1)) \ (+ \ x \ e_2))$

579
580 For existing resugaring approach, if we want to get sequences of $(\text{let } ((x \ 2)) \ (\text{Hygienicadd}$
581 $1 \ x))$, it will firstly desugar to $(\text{let } ((x \ 2)) \ (\text{let } ((x \ 1)) \ (+ \ x \ x)))$, but it is awful because
582 the two x in $(+ \ x \ x)$ should be bind to different value. But for our lazy desugaring, the `hygienicadd`
583 sugar does not have to desugar until necessary, so, getting following sequences.

584 $(\text{let } ((x \ 2)) \ (\text{Hygienicadd } 1 \ x))$

585 $\rightarrow (\text{Hygienicadd } 1 \ 2)$

586 $\rightarrow (+ \ 1 \ 2)$

→ 3

The lazy desugaring is also convenient for hygienic resugaring for non-hygienic core language. 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`,

$$(\text{Let } e_1\ e_2\ e_3) \rightarrow_d (\text{let } ((e_1\ e_2))\ e_3)$$

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

```
(Let x 1 (+ x (Let x 2 (+ x 1))))
→ (Let x 1 (+ x (+ 2 1)))
→ (Let x 1 (+ x 3))
→ (+ 1 3)
→ 4
```

In practical application, we think hygiene can be easily processed by rewriting system. But our result shows lazy desugaring is really a good way to handle hygienic macro 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,

```
(Odd e) → (if (> e 0) (Even (- e 1)) #f)
(Even e) → (if (> e 0) (Odd (- e 1)) #t)
```

are typical recursive sugars. The existing resugaring approach can't process this kind of syntactic sugar 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.

```
(Odd 2)
→ (if (> 2 0) (Even (- 2 1)) #f)
→ (if (> (- 2 1) 0) (Odd (- (- 2 1) 1)) #t)
→ (if (> (- (- 2 1) 1) 0) (Even (- (- (- 2 1) 1) 1)) #f)
→ ...
```

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.

```
(Odd 2)
→ (Even (- 2 1))
→ (Even 1)
→ (Odd (- 1 1))
→ (Odd 0)
→ #f
```

We also construct some higher-order syntactic sugars and test them. The higher-order feature is important for constructing practical syntactic sugar. 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 ...))
--> (if (e v1) (cons v1 (filter e (list v2 ...))) (filter e (list v2 ...)))
(filter e (list)) --> (list)
```

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

```
(filter (lam (x) (and (> x 1) (< x 4))) (list 1 2 3 4))
→ (filter (lam (x) (and (> x 1) (< x 4))) (list 2 3 4))
→ (cons 2 (filter (lam (x) (and (> x 1) (< x 4))) (list 3 4)))
→ (cons 2 (cons 3 (filter (lam (x) (and (> x 1) (< x 4))) (list 4))))
→ (cons 2 (cons 3 (filter (lam (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 conditions. Take the example of another higher-order sugar `map` as an example.

```
(map e1 e2)
--> (let ((x e2)) (if (empty? x) (list) (cons (e1 (first x)) (map e1 (rest x)))))
```

Get following resugaring sequences.

```
(map (lam (x) (+ x 1)) (cons 1 (list 2)))
→ (map (lam (x) (+ x 1)) (list 1 2))
→ (cons 2 (map (lam (x) (+ x 1)) (list 2)))
→ (cons 2 (cons 3 (map (lam (x) (+ x 1)) (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 the 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* 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 lightweight approach.
- *Friendly to hygienic macro* Previous hygienic resugaring approach use a new data structure—abstract syntax DAG, to process resugaring of hygienic macros. Our approach simply finds hygienic error after expansion, and gets the correct reduction instead.
- *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.

4 ZC

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.

The type resugaring work [[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 impossible because [Todo: the reason](#)

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. The dynamic approach is like the forward component, so the method to handle side effects in functional programs may be useful for a better resugaring with side effects.

Macros as Multi-Stage Computations[Ganz et al. 2001] is an old research similar to lazy expansion for macros. Some other researches[Rompf and Odersky 2010] about multi-stage programming[Taha 2003] indicate that it is a useful idea for implementing domain-specific languages. Macro systems in some language (such as Racket[Flatt 2012]) have support lazy expansion. Our dynamic approach is a combination of existing resugaring and lazy expansion, which achieves a more powerful approach. [Deursen et al. 1992; Fisher and Shivers 2006]

Addition to PLT Redex[Felleisen et al. 2009] 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 static approach.

6 CONCLUSION

In this paper, we propose a new approach (see Fig 1) or resugaring mixed with a dynamic approach and static approach, which has some advances compared to existing approaches. The two approaches are seemingly similar in lazy desugaring. Essentially, we would see the static approach is the abstract(todo:another express?) of dynamic approach. In the dynamic approach, the most important part is *reduction in mixed language* (see in sec ??), which decides whether reducing the subexpression or desugaring the outermost sugar. Reducing subexpressions are just the same as context rules in static approach; desugaring the outermost sugar is similar to reduction rules in static approach. However, the reduction rules are more convenient and efficient than dynamic resugaring, because the static approach evolves a process like abstract interpretation[Cousot and Cousot 1977], then reduces many steps executed in core language. Moreover, the semantics got by static approach 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.

As we mentioned before, the original intent of our research is finding a better method (or building a tool) for implementing DSL. We could see static approach 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 in the static approach can be solved. So the first future work may be achieving a more powerful static approach as our dynamic approach. Then we will carefully design a core language for as the host language of our dream system and find a better type resugaring approach for the system. Finally, a general optimization method for DSL in our system is needed.

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A APPENDIX

Text of appendix ...