# Compositional Resugaring by Lazy Desugaring

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## Abstract

Syntactic sugar, first coined by Peter J. Landin in 1964, has proved to be very useful for defining domain-specific languages and extending languages. 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, which automatically converts the evaluation sequences of desugared expression in the core language into representative sugar's syntax in the surface language. However, the existing approach relies on reverse application of desugaring rules to desugared core expression whenever possible. When a desugaring rule is complex and a desugared expression is large, such reverse desugaring becomes very complex and costive.

In this paper, we propose a novel approach to compositional resugaring by lazy desugaring, where reverse application of desugaring rules is unnecessary. We recognize a sufficient and necessary condition for a syntactic sugar to be desugared, and propose a reduction strategy, based on the evaluator of the core languages and the desugaring rules, which can produce all necessary resugared expressions on the surface language. We have implemented a system based on this new approach. The result shows that our new approach is more efficient comparing to the existing approach, and the lazy desugaring also provides powerful expressiveness even for a simple rewriting so that it can also deal with the common hygienic sugars and flexible recursive sugars.

***Keywords:*** Resugaring, Syntactic Sugar, Interpreter, Domain-Specific Language, Reduction Semantics

## 1 Introduction

Syntactic sugar, first coined by Peter J. Landin in 1964 [12], 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 been proved to be very useful for defining domain-specific languages (DSLs) and extending languages [2, 5]. 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 [13, 14]. It can automatically convert the evaluation sequences of desugared expression in the core language into representative sugar's syntax in the surface language. Just like the existing approach, it is natural to try matching the programs after the desugared with syntactic sugars' rules to reversely desugar the sugars—that why it was named "resugaring". Just as the example in Fig. 1, here we use the sugar `Or` to see how existing resugaring approach works, with following desugaring rule. (Considering the `not` as a core language's constructor)

$$\texttt{(Or } e_1\ e_2\texttt{)} \rightarrow_d \texttt{(let ((t } e_1\texttt{)) (if t t } e_2\texttt{))}$$

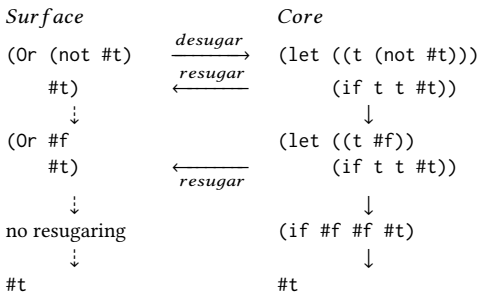


**Figure 1.** A Simple Example

But it is not as easy as the example above. Sometimes the program in the core language contains a desugared form of a sugar, but the form may belong to original (not desugared) program. (See the example in Fig. 2) In such cases, the reverse expansion of sugar should be noticed.

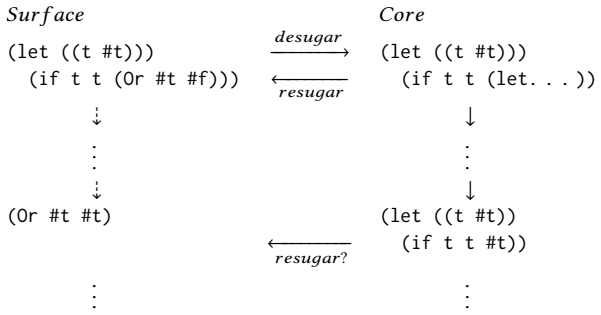


**Figure 2.** An Error example

Moreover, when meeting hygienic sugar, the simple match and substitution will not work as Fig. 3 shows. Here the `Double` sugar has the following desugaring rule.

$$\texttt{(Double } e_1\texttt{)} \rightarrow_d \texttt{(let (t } e_1\texttt{) (+ t t))}$$

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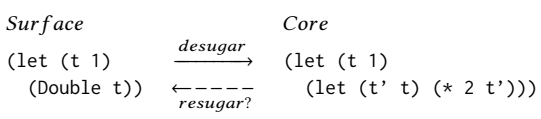


**Figure 3.** A Hygiene Example

If we use binder renaming for solving the simple case, some other information is needed (such as the permutation).

The existing resugaring approaches subtly solved the problems above by "tagging"[13] and "abstract syntax DAG"[14]. While those techniques successfully make the resugaring method usable, there is a key point which makes the existing approaches not very practical—the reverse expansion of sugars need to match the desugared programs to see if it is able to resugar. It is quite a huge job when the program contains many syntactic sugars or some syntactic sugars can be desugared to large sub-programs. Also, as the debugging for host language can be a good application of resugaring, the efficiency matters.

In this paper, we propose a novel approach to compositional resugaring, which does not use 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 becomes unnecessary. Rather than assuming a black-box stepper for the core language as the existing approach, our resugaring approach is based on the evaluation rules (consist of the context rules and reduction rules) of the core language. So our approach seems to be a meta-level language feature rather than a tool for existing languages. (Although it can also work with a black-box stepper, as we will discuss in Section 5.1) To this end, we consider the surface language and the core language as a whole language. We regard the desugaring rules as the reduction rules of surface language and calculate the context rules of surface language to see how lazy the desugaring of sugar expressions can be. Then the intermediate evaluation steps of the mixed language will contain the resugaring evaluation sequences of a program.

Our main technical contributions can be summarized as follows.

- We propose a novel approach to resugaring by lazy desugaring, where reverse application of desugaring rules becomes unnecessary. We recognize a algorithm to calculate the computation orders (limited by context rules) for syntactic sugars, and propose a reduction strategy, based on evaluator of the core languages and the desugaring rules together with the context rules of syntactic sugar, which is sufficient to produce all necessary resugared expressions on the surface language. We prove the correctness of our approach.
- We have implemented a system based on the new resugaring approach. It is much more efficient than the existing approach, because it completely avoids unnecessary complexity of the reverse desugaring. It also provides extra expressiveness for even the simple rewriting so that it can also deal with the common hygienic sugars and flexible recursive sugars. All the examples in this paper have passed the test of the system.
- We discuss how lazy desugaring makes sense, including how the approach can be extended to a model with black-box stepper, how it can easily deal with hygiene, and how we deal with the trade-off of correctness.

The rest of our paper is organized as follows. We start with an overview of our approach in Section 2. We then discuss the core of resugaring by lazy desugaring in Section 3. We describe our experiment and evaluation in Section 4. We discuss on some other issues in Section 5, on related work in Section 6, and conclude the paper in Section 7.

## 2 Overview

Todo: goals?

In this section, we give a brief overview of our approach, explaining its difference from the existing approach and highlighting its new features. To be concrete, we will consider the following simple core language, defining boolean expressions based on `if` construct:

$$\begin{array}{lcll} \texttt{CoreExp} & ::= & \texttt{(if } e\ e\ e\texttt{)} & \text{// if construct} \\ & | & \#t & \text{// true value} \\ & | & \#f & \text{// false value} \end{array}$$

The semantics of the language is very simple, consisting of the following context rule defining the computation order:

$$\begin{array}{rcl} C & ::= & \texttt{(if [•] } e\ e\texttt{)} \\ & & \mathit{hole} \end{array}$$

and two reduction rules (the letter c means core):

$$\texttt{(if \#}t\ e_1\ e_2\texttt{)} \rightarrow_c e_1 \qquad \texttt{(if \#}f\ e_1\ e_2\texttt{)} \rightarrow_c e_2$$

Assume that our surface language is defined by two syntactic sugars defined by:

$$\begin{array}{c} \texttt{(And } e_1\ e_2\texttt{)} \rightarrow_d \texttt{(if } e_1\ e_2\ \#f\texttt{)} \\ \texttt{(Or } e_1\ e_2\texttt{)} \rightarrow_d \texttt{(if } e_1\ \#t\ e_2\texttt{)} \end{array}$$

Now let us demonstrate how to execute `(And (Or #t #f) (And #f #t))`, and get the resugaring sequences as Fig. 4 by our approach.

```
  (And (Or #t #f) (And #f #t))
⟶ (And #t (And #f #t))
⟶ (And #f #t)
⟶ #f
```

**Figure 4.** A Typical Resugaring Example

We propose a new resugaring approach by eliminating "reverse desugaring" via "lazy desugaring", where a syntactic

sugar will be desugared only when it is necessary. While giving the evaluation rules of the core language, we can figure out the following context rules of the surface language.

$$\begin{array}{rcl} C & := & (\texttt{And}\ [\bullet]\ e) \\ & | & (\texttt{Or}\ [\bullet]\ e) \\ & | & \mathit{hole} \end{array}$$

Then we can just mix the surface language and the core language as Fig. 5.

$$\begin{array}{lcl} \texttt{MixedExp} & ::= & \texttt{CoreExp} \\ & | & \texttt{SurfExp} \\ & | & \texttt{CommonExp} \\ \texttt{CoreExp} & ::= & (\texttt{if}\ e\ e\ e) \\ \texttt{SurfExp} & ::= & (\texttt{And}\ e\ e) \\ & | & (\texttt{Or}\ e\ e) \\ \texttt{CommonExp} & ::= & \#t \\ & | & \#f \end{array}$$

**(a)** Syntax

$$\begin{array}{rcl} C & := & (\texttt{if}\ [\bullet]\ \texttt{e}\ \texttt{e}) \\ & | & (\texttt{And}\ [\bullet]\ \texttt{e}) \\ & | & (\texttt{Or}\ [\bullet]\ \texttt{e}) \\ & | & \mathit{hole} \end{array}$$

**(b)** Context

$$\begin{array}{rcl} (\texttt{And}\ e_1\ e_2) & \rightarrow_m & (\texttt{if}\ e_1\ e_2\ \#f) \\ (\texttt{Or}\ e_1\ e_2) & \rightarrow_m & (\texttt{if}\ e_1\ \#t\ e_2) \\ (\texttt{if}\ \#t\ e_1\ e_2) & \rightarrow_m & e_1 \\ (\texttt{if}\ \#f\ e_1\ e_2) & \rightarrow_m & e_2 \end{array}$$

**(c)** Reduction

**Figure 5.** Mixed Language Example

Finally the program `(And (Or #t #f) (And #f #t))` will got the evaluation sequence in Fig. 6 in the mixed language. We can just filter the intermediate sequences without `Coreexp` in any sub-expressions to get the resugaring sequence as Fig. 4.

```
    (And (Or #t #f) (And #f #t))
⟶ (And (if #t #t #f) (And #f #t))
⟶ (And #t (And #f #t))
⟶ (if #t (And #f #t) #f)
⟶ (And #f #t)
⟶ (if #f #t #f)
⟶ #f
```

**Figure 6.** Example of Mixed Language's Reduction

Note that the context rules should restrict the computation order of a sugar expression's sub-term, we should let the context rule be correct—reflecting what should be executed in the desugared expression. Also, as the goal of resugaring is to present evaluation of sugar expressions, we clearly defined which expression should be outputted. For the example in this section, of course the sugar `And` and `Or` should be outputted, and also the boolean expressions should be. So by clearly separate what `DisplayableExp` (defined in next section) is, we can alway get the resugaring evaluation sequences we need. (Slightly different from the existing approach's setting, as we will discuss in Section 3.3.)

$$\begin{array}{lcll} \texttt{CoreExp} & ::= & x & \text{variable} \\ & | & c & \text{constant} \\ & | & (\texttt{CoreHead}\ \texttt{CoreExp}_1\ \ldots\ \texttt{CoreExp}_n) & \text{constructor} \\ & & & \\ \texttt{SurfExp} & ::= & x & \text{variable} \\ & | & c & \text{constant} \\ & | & (\texttt{SurfHead}\ \texttt{SurfExp}_1\ \ldots\ \texttt{SurfExp}_n) & \text{sugar constructor} \end{array}$$

**Figure 7.** Core and Surface Expressions Todo:

## 3 Resugaring by Lazy Desugaring

In this section, we present our new approach to resugaring. Different from the existing approach that clearly separates the surface from the core languages, we intentionally combine them as one mixed language, allowing free use of 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 necessary to be resugared by the existing approach can be correctly produced.

### 3.1 Mixed Language for Resugaring

As a preparation for our resugaring algorithm, we define a mixed language that combines a core language with a surface language (defined by syntactic sugars over the core language). An expression in this language is reduced step by step by the evaluation rules for the core language and the desugaring rules for the syntactic sugars in the surface language. Our approach assumes the evaluation is **compositional** (as the definition in [14]), that is, for evaluation contexts $E_1$ and $E_2$, $E_1[E_2]$ is also a evaluation context.

**3.1.1 Core Language.** For our core language, its evaluator is driven by evaluation rules (context rules and reduction rules), with three natural assumptions. First, the evaluation is deterministic, in the sense that any expression in the core language will be reduced by a unique reduction sequence (restricted by context rules). Second, evaluation of a sub-expression has no side-effect on other parts of the expression. Third, the context rules have no conditions; a counterexample for this assumption is in Fig. 8.

An expression form of the core language is defined in Fig. 7. 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

$$
\begin{array}{lcl}
\texttt{C} & ::= & (\texttt{notif}\ [\bullet]\ e_2\ e_3) \\
& | & (\texttt{notif}\ v_1\ [\bullet]\ e_3), (side-condition\ (equal?\ v_1\ \#t)) \\
& | & (\texttt{notif}\ v_1\ e_2\ [\bullet]), (side-condition\ (equal?\ v_1\ \#f))
\end{array}
$$

**Figure 8.** An Example of Context Rules with Conditions

core language defined in Fig. 9 to demonstrate our approach. Here the [e/x] is a capture-avoiding substitution.

#### 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, variable. The surface language has expressions as given in Fig. 7.

Here we just assume a simple rewriting for a syntactic sugar expression. We will show how this approach can be combined with other complex rewriting. A syntactic sugar is defined by a desugaring rule in the following form.

$$(\texttt{SurfHead}\ e_1\ e_2\ \ldots\ e_n) \rightarrow_d \texttt{exp}$$

where its left-hand-side (LHS) is a pattern and its left-hand-side (RHS) is an expression of the surface language or the core language.The LHS can be nested or not, that means, we can write sugar like (SurfHead $(e_1\ (e_2\ e_3))\ \ldots\ e_n$). And any pattern variable (e.g., $e_1$) in LHS only appears once in RHS. For instance, we may define syntactic sugar And by

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

And if we need to use a pattern variable multiple times in RHS, a `let` binding may be used (a normal way in syntactic sugar). We take the following sugar as an example

$$(\texttt{Twice}\ e_1) \rightarrow_d (\texttt{+}\ e_1\ e_1).$$

If we execute `(Twice (+ 1 1))`, it will firstly be desugared to `(+ (+ 1 1) (+ 1 1))`, then reduced to `(+ 2 (+ 1 1))` by one step. The subexpression `(+ 1 1)` has been reduced but should not be resugared to the surface, because the other `(+ 1 1)` has not been reduced yet. So we just use a `let` binding to resolve this problem. The RHS should be `(let x` $e_1$ `(+ x x))` in this case.

Note that in the desugaring rule, we do not restrict the RHS to be a CoreExp. We can use SurfExp (more precisely, we allow the mixture use of syntactic sugars and core expressions) to define recursive syntactic sugars, as seen in the following example.

$$(\texttt{Odd}\ e) \rightarrow_d (\texttt{let}\ ((x\ e))\ (\texttt{if}\ (>\ x\ 0)\ (\texttt{Even}\ (-\ x\ 1))\ \#f))$$
$$(\texttt{Even}\ e) \rightarrow_d (\texttt{let}\ ((x\ e))\ (\texttt{if}\ (>\ x\ 0)\ (\texttt{Odd}\ (-\ x\ 1))\ \#t))$$

As described above, we only assume the desugaring is a textural rewriting, thus there will be many kinds of ill-formed syntactic sugar which cannot desugared well (just as the Odd, Even sugars above, although can be processed by our lazy desugaring), or the semantics of the sugar cannot be defined clearly. Todo: maybe an example needed

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

#### 3.1.3 Mixed Language.

Our mixed language for resugaring combines the surface language and the core language, described in Fig. 10. The differences between expressions in our core language and those in our surface language are identified by their Head. But there may be some expressions in the core language which are also used in the surface language for convenience, or we need some core language's expressions to help us getting better resugaring sequences. So we take CommonHead as a subset of the CoreHead, which can be displayed in resugaring sequences. Then if any sub-terms in a expression contains no CoreHead except for CommonHead, we should let them display during the evaluation process (named DisplayableExp). Otherwise, the expression should not be displayable. We just use a MixedExp term to present the expressions which is not necessarily displayed for concision.

We distinguish the displayable expressions for the *abstraction* property (discussed in Section 5).

As an example, for the core language in Fig. 9, we may assume `arithop`, `lambda` (call-by-value lambda calculus), `cons` as CommonHead, `if`, `let`, `lambdaN` (call-by-name lambda calculus), `listop` as CoreHead but out of CommonHead. This will allow `arithop`, `lambda` and `cons` to appear in the resugaring sequences, and thus display more useful intermediate steps during resugaring.

Note that some expressions with CoreHead contain subexpressions with SurfHead, they are of CoreExp but not in the core language. In the mixed language, we process these expressions by the context rules of the core language, so that the reduction rules of core language and the desugaring rules of surface language can be mixed as a whole (the $\rightarrow_c$ in former section). For example, suppose we have the context rule of `if` expression[1]

$$\frac{e_1 \rightarrow e_1'}{(\texttt{if}\ e_1\ e_2\ e_3) \rightarrow (\texttt{if}\ e_1'\ e_2\ e_3)}$$

then if $e_1$ is a reducible expression in the core language, it will be reduced by the reduction rule in the core language: if $e_1$ is a SurfExp, it will be reduced by the evaluation rule of $e_1$'s Head; if $e_1$ is also a CoreExp which has one or more non-core subexpressions, a recursive reduction by $\rightarrow_c$ is needed.

### 3.2 Resugaring Algorithm

Our resugaring algorithm works on the mixed language, based on the evaluation rules of the core language and the

[1] It is another presentation of `(if [•] e e)`, we use this form here for convenience.

```
CoreExp  ::=  (CoreExp CoreExp ...) // apply
           |  (if CoreExp CoreExp CoreExp) // condition
           |  (let ((x CoreExp) ...) CoreExp) // binding
           |  (listop CoreExp) // first, rest, empty?
           |  (cons CoreExp CoreExp) // data structure of list
           |  (arithop CoreExp CoreExp) // +, -, *, /, >, <, =
           |  x // variable
           |  value
value    ::=  (λ (x ...) CoreExp) // call-by-value
           |  c // boolean, number and list
```

**(a)** Syntax

```
C  ::=  (value ... [•] CoreExp ...)
     |  (if [•] CoreExp CoreExp)
     |  (let ((x value) ... (x [•]) (x CoreExp) ...) CoreExp)
     |  (listop [•])
     |  (cons [•] CoreExp)
     |  (cons CoreExp [•])
     |  (arithop [•] CoreExp)
     |  (arithop CoreExp [•])
```

**(b)** Context Rules

$$
\begin{array}{lcl}
((\lambda\ (x_1\ x_2\ \ldots)\ \texttt{CoreExp})\ \texttt{value}_1\ \texttt{value}_2\ \ldots) & \to_c & ((\lambda\ (x_2\ \ldots)\ \texttt{CoreExp}[\texttt{value}_1/x_1])\ \texttt{value}_2\ \ldots) \\
(\texttt{if}\ \#t\ \texttt{CoreExp}_1\ \texttt{CoreExp}_2) & \to_c & \texttt{CoreExp}_1 \\
(\texttt{if}\ \#f\ \texttt{CoreExp}_1\ \texttt{CoreExp}_2) & \to_c & \texttt{CoreExp}_2 \\
(\texttt{let}\ ((x_1\ \texttt{value}_1)\ (x_2\ \texttt{value}_2)\ \ldots)\ \texttt{CoreExp}) & \to_c & (\texttt{let}\ ((x_2\ \texttt{value}_2)\ \ldots)\ \texttt{CoreExp}[\texttt{value}_1/x_1]) \\
\ldots &&
\end{array}
$$

**(c)** Part of Reduction Rules

**Figure 9.** A Core Language Example

```
Exp             ::=  DisplayableExp
                  |  MixedExp

DisplayableExp  ::=  (SurfHead DisplayableExp*)
                  |  (CommonHead DisplayableExp*)
                  |  c
                  |  x

MixedExp        ::=  (SurfHead MixedExp*)
                  |  (CoreHead MixedExp*)
                  |  c
                  |  x
```

**Figure 10.** Our Mixed Language

desugaring rules for defining the surface language. The process for getting the resugaring sequence contains two separate parts.

- Calculating the context rules of syntactic sugar.
- Filtering `DisplayableExp` during the execution of the mixed language.

We describe the algorithm of calculating the context rules for a syntactic sugar as follows.

For sugar

$$(\texttt{SurfHead}\ e_1\ e_2\ \ldots\ e_n) \to_d (\texttt{Head}\ \ldots\ e'_1\ e'_2\ \ldots\ e'_m)$$

we can just run `calcontext(LHS, RHS)`, and add the context rules to the mixed language.

If `Head` is a `CoreHead`, for each context rule of the `Head` in order, we should just recursively make context rules for each hole. See example in Fig. 11

$$(\texttt{Sg1}\ e_1\ e_2\ e_3\ e_4) \to_d (\texttt{if}\ (=\ (+\ e_4\ e_2)\ (*\ e_1\ e_3))\ \#t\ \#f)$$

$$
\begin{array}{lr}
\mathit{OrderList} = \{(=\ (+\ e_4\ e_2)\ (*\ e_1\ e_3))\} & \text{(depth1)} \\
\mathit{OrderList} = \{(+\ e_4\ e_2),\ (*\ e_1\ e_3)\} & \text{(depth2)} \\
\mathit{OrderList} = \{e_4,\ e_2\} & \text{(depth3.1, getting rules} \\
 & \{(\texttt{Sg1}\ e_1\ e_2\ e_3\ [\bullet]),\ (\texttt{Sg1}\ e_1\ [\bullet]\ e_3\ v_4)\}) \\
\mathit{OrderList} = \{e_1,\ e_3\} & \text{(depth3.2, getting rules} \\
 & \{(\texttt{Sg1}\ [\bullet]\ v_2\ e_3\ v_4),\ (\texttt{Sg1}\ v_1\ v_2\ [\bullet]\ v_4)\})
\end{array}
$$

**Figure 11.** Example of calcontext

Or if the `Head` is a `SurfHead` with its context rules calculated, then we regard it as `CoreHead`. If it is without context rules we should calculate its context rules first. However, if the recursive process has tried calculating it, it will be an ill-formed recursive sugar, as the following example.

$$(\texttt{Odd}\ e) \to_d (\texttt{Even}\ (-\ e\ 1))$$

**Algorithm 1** calcontext

**Input:**
`currentLHS = (SurfHead` $t_1$ $t_2$ ... $t_n$`)` //where $t_i$ is $e$ or $v$(value).
`currentContext = (Head ...` $e'_1$ $e'_2$ ... $e'_m$`)` //where $e'_i$ can be at any depth of sub-expressions.
`currentIncal = {...}` //list of contexts in calculation.
**Output:**
`ListofRule`

```
Let ListofRule = {}, tmpLHS = currentLHS, InCal = append(currentIncal, SurfHead)
if ∄ contexts rules of Head then
  if ∃ Head in InCal then
    return error
  else
    ListofRule = append(ListofRule,
        calcontext(Head.LHS,Head.RHS,InCal))
  end if
end if
Let OrderList = {e'_i, e'_j, ...} //computation order got by context rules
for flag in OrderList do
  if ∃i, s.t.e_i = flag then
    ListofRule= append(ListofRule,
        tmpLHS[[•]/e_i])
  else
    Let recRule, recLHS = calcontext(
        tmpLHS, flag, Incal)
    tmpLHS = recLHS
    ListofRule = append(ListofRule, recRule)
  end if
end for
return ListofRule, tmpLHS
```

$$(\text{Even } e) \rightarrow_d (\text{Odd } (- e\ 1))$$

After calculating all context rules, we can add them to the mixed language's context rule; we can also add the desugaring rules to the mixed language's reduction rule as what we showed in Section 2.

Now, our resugaring algorithm can be easily defined based on evaluation rules of the mixed language. Let $\rightarrow_m$ be one step reduction in the mixed language.

```
resugar(e) = if isNormal(e) then return
             else
                 let e →_m e' in
                 if e' ∈ DisplayableExp
                     output(e'), resugar(e')
                 else resugar(e')
```

During the resugaring, we just apply the reduction ( $\rightarrow_m$ ) on the input expression step by step until no reduction can be applied (`isNormal`), while outputting those intermediate expressions that belong to `DisplayableExp`.

### 3.3 Correctness

We give following properties to describe the correctness of our resugaring approach.

**Defination 3.1** (fulldesugar). *The function that recursively desugars any expressions of the mixed language is defined as Fig. 12.*

```
fulldesugar(v) = v
fulldesugar(x) = x
fulldesugar((CoreHead e_1 e_2 ...)) =
  (CoreHead fulldesugar(e_1) fulldesugar(e_2) ...)
fulldesugar((SurfHead e_1 e_2 ...)) =
  (CoreHead fulldesugar(e'_1) fulldesugar(e'_2) ...)
where desugar((SurfHead e_1 e_2 ...)) = (CoreHead e'_1 e'_2 ...)
```

**Figure 12.** Defination of `fulldesugar`

A program `P` can be fulldesugared if `fulldesugar(P)` is terminable.

**Theorem 3.1.** *For a program of the mixed language* `P` *which can be fulldesugared, if a sugar expression* `S` *in the program* `P` *is desugared in one step of the mixed language's evaluation, and program* `P'` *is the* `P` *after* `fulldesugar` *to the core language, then one step of the core language's evaluation on* `P'` *will destroy the sugar* `S`*'s desugared form.*

**Theorem 3.2.** *For a program of the mixed language* `P` *which can be fulldesugared, if a core language's expression* `E` *in a program* `P` *of the mixed language is reduced by reduction rules, and program* `P'` *is the* `P` *after* `fulldesugar` *to the core language, then one step of the core language's evaluation on* `P'` *will reduce on the* `P'` *will also reduce on the correspond expression of* `E`.

The properties limit the laziness of our mixed language—the resugaring sequences should behave as the sequences after desugared to the core language.

**Defination 3.2** (Desugaring of context rule). *For syntactic sugar S*

$$(\text{SurfHead } e_1\ e_2\ \ldots\ e_n) \rightarrow_d (\text{Head } \ldots\ e'_1\ e'_2\ \ldots\ e'_m)$$

*and context rule* $C = S.LHS[[\bullet]/e_i]$*, where* $[\bullet]$ *is at* $e_i$*'s location. Then* $desugar(C) = S.RHS[[\bullet]/e_i]$

**Lemma 3.1.** *The context rules of syntactic sugar are correct if computable.*

*Or to say, for sugar* `S`*, the context rules* $C_1$, $C_2$ ...*, if the context rules limit reduction order of* $S.LHS$ *in* $\{e_i, \ldots, e_j\}$*, then the reduction order of* $S.RHS$ *is also of this sequence.*

*Proof.* In algo 1, we recursively search the sugar's RHS to find $e_i$ ... in RHS's computation order, so the sugar's context rules are correct. □

*Proof of Theorem 3.1.* Consider a context `C`, where the sugar `S` in the hole. So the P is the program `C[S/hole]`.

If no sugar expression in `C`, then it is to prove the program `C[fulldesugar(S)/hole]` will reduce on `fulldesugar(S)`. It is obvious because that is where the hole at.

If there is any sugar in `C`, then it is to prove the program `fulldesugar(C[S/hole])` will reduce on `fulldesugar(S)`. According to the lemma, it is true because the hole will be at the same place after any sugar recursively desugared. □

*Proof of Theorem 3.2.* According to the lemma, any sugar has the correct context rules. So the hole is also correct for the mixed language. □

### 3.4 Combining with Other Rewriting

We describe a resugaring approach based on a simple rewriting. What if we need a more complex rewriting system to describe more complex semantics for syntactic sugar? For example, we may need a type system for checking; we may specify the binding of syntactic sugar for a more general hygiene (We solved the hygiene in our core language without specific the binding, as described in Section 5.3); we may use some other functions to help the desugaring. All of these extensions are possible as long as following some conditions. We summarize the conditions as follows.

1. *Compositional*: Generally speaking, the desugaring order and should not effect the semantics of a sugar expression. Otherwise, the lazy desugaring will not be correct.
2. *Unique evaluation order*: For any rules of syntactic sugar, the context rules should limit a expression to have only one computational order. Otherwise the algorithm calcontext will not be deterministic.
3. *Clear Semantic*: If a syntactic sugar's desugaring rule is ambiguous or wrong, the calcontext algorithm may go wrong.

We find a possible problem that if we want a desugar rule like follows,

$$\texttt{(Sugar } e_1\ e_2\ \ldots\ e_n\texttt{)} \rightarrow_d \texttt{(if (Helper } e_1\ e_2\texttt{) ...)}$$

where `Helper` is a external function, that means we don't have the evaluation rules of `Helper`. In this case, we can force the expansion of sugar expressions headed by `Sugar`. We describe how to force the expansion in Section 4.1.1.

## 4 Experiment

In this section, we present several examples to show different aspects of our approach.

### 4.1 Case Study on Expressiveness

We have implemented our resugaring approach using PLT Redex [4], which is a semantic engineering tool based on reduction semantics [6]. We show several case studies to demonstrate the power of our approach. Some examples we will discuss in this section are in Fig. 13. Note that we set call-by-value lambda calculus as terms in `CommonExp`, because we want to output some intermediate expressions including lambda expressions in some examples. It's easy if we want to skip them.

#### 4.1.1 Simple Sugars.

We construct some simple syntactic sugars and try it on our tool. Some sugars are inspired by the first work of resugaring [13]. Take an SKI combinator syntactic sugar as an example. We can regard `S` as an expression headed with S, without subexpression. And for showing a concise result, we add the call-by-need lambda calculus in the core language for this example.

$$\texttt{S} \rightarrow_d \texttt{(}\lambda_N\ \texttt{(x1 x2 x3) (x1 x2 (x1 x3)))}$$
$$\texttt{K} \rightarrow_d \texttt{(}\lambda_N\ \texttt{(x1 x2) x1)}$$
$$\texttt{I} \rightarrow_d \texttt{(}\lambda_N\ \texttt{(x) x)}$$

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 core language. For the sugar expression `(S (K (S I)) K xx yy)`, we get the resugaring sequences as Fig. 13a. Here the sugars contains no sub-expression, then the sugar should just desugar to the core expression. It is interesting that the sugar without sub-expressions (written by lambda calculus) and the sugar with sub-expressions will behave different. For example, in this case we can write the sugar as `(S e e e ...)` and so on, then the sugar may not have to be desugared. Moreover, we can use this difference to force a syntactic sugar desugared by call-by-need lambda calculus. See if we want a sugar `ForceAnd` which does not want to use the context rules of `if` to getting the resugaring sequence, we can just write the following sugar.

$$\texttt{ForceAnd} \rightarrow_d \texttt{(}\lambda_N\ \texttt{(}e_1\ e_2\texttt{) (if } e_1\ e_2\ \texttt{\#f))}$$

#### 4.1.2 Hygienic Sugars.

The second work [14] of existing resugaring approach mainly processes hygienic sugar compared to first work. It uses a DAG to represent the expression. However, hygiene is not hard to be handled by our lazy desugaring strategy. Our algorithm can easily process hygienic sugar without a special data structure. A typical hygienic problem is as the following example.

$$\texttt{(Hygienicadd } e_1\ e_2\texttt{)} \rightarrow_d \texttt{(let ((x } e_1\texttt{)) (+ x } e_2\texttt{))}$$

For existing resugaring approach, if we want to get sequences of `(let (x 2) (Hygienicadd 1 x))`, it will firstly desugar to `(let (x 2) (let x 1 (+ x x)))`, which is awful because the two $x$ in `(+ x x)` should be bound to different values. So the existing hygienic resugaring approach uses

```
(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)
```

**(a)** Example of SKI

```
(let x 2 (Hygienicadd 1 x))
⟶ (Hygienicadd 1 2)
⟶ (+ 1 2)
⟶ 3
```

**(b)** Example of `Hygienicadd`

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

**(c)** Example of `Odd` and `Even`

```
(Map (λ (x) (+ x 1)) (cons 1 (list 2)))
⟶ (Map (λ (x) (+ x 1)) (list 1 2))
⟶ (cons 2 (Map (λ (x) (+ 1 x)) (list 2)))
⟶ (cons 2 (cons 3 (Map (λ (x) (+ 1 x)) (list))))
⟶ (cons 2 (cons 3 (list)))
⟶ (cons 2 (list 3))
⟶ (list 2 3)
```

**(d)** Example of `Map`

```
(Filter (λ (x) (and (> x 1) (< x 4))) (list 1 2 3 4))
⟶ (Filter (λ (x) (and (> x 1) (< x 4))) (list 2 3 4))
⟶ (cons 2 (Filter (λ (x) (and (> x 1) (< x 4))) (list 3 4)))
⟶ (cons 2 (cons 3 (Filter (λ (x) (and (> x 1) (< x 4))) (list 4))))
⟶ (cons 2 (cons 3 (Filter (λ (x) (and (> x 1) (< x 4))) (list))))
⟶ (cons 2 (cons 3 (list)))
⟶ (cons 2 (list 3))
⟶ (list 2 3)
```

**(e)** Example of `Filter`

**Figure 13.** Resugaring Examples

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, thus, getting resugaring sequences as Fig. 13b based on a non-hygienic rewriting system.

In practical application, we think hygiene can be easily processed by more complex rewriting systems (such as [10]), so we also try combining the lazy desugaring with other rewriting system in later chapter. Overall, our results show lazy desugaring is a good way to handle hygienic sugars in any systems.

#### 4.1.3 Recursive Sugars.

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

$$(\texttt{Odd}\ e) \ \rightarrow_d\ (\texttt{let}\ ((x\ e))\ (\texttt{if}\ (>\ x\ 0)\ (\texttt{Even}\ (-\ x\ 1))\ \#f))$$
$$(\texttt{Even}\ e) \ \rightarrow_d\ (\texttt{let}\ ((x\ e))\ (\texttt{if}\ (>\ x\ 0)\ (\texttt{Odd}\ (-\ x\ 1))\ \#t))$$

are recursive sugars. The existing resugaring approach can't process syntactic sugar written like 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.

```
(Odd 2)
⇢ (let ((x 2)) (if (> x 0) (Even (- x 1)) #f))
⇢ (let ((x 2)) (if (> x 0)
    (let ((x1 (- x 1))) (if (> x1 0) (Odd (- x1 1)) #t))
    #f))
⇢ ...
```

Then the advantage of our approach is embodied. Our lightweight approach does not 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 as Fig. 13c of the former example using our tool.

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.

$$\begin{aligned}&(\texttt{Filter}\ e\ (\texttt{list}\ v_1\ v_2\ \ldots)) \rightarrow_d \\ &\quad (\texttt{let}\ ((\texttt{f}\ e))\ (\texttt{if}\ \ (\texttt{f}\ v_1) \\ &\qquad\qquad\qquad\qquad (\texttt{cons}\ v_1\ (\texttt{Filter}\ \texttt{f}\ (\texttt{list}\ v_2\ \ldots))) \\ &\qquad\qquad\qquad\qquad (\texttt{Filter}\ \texttt{f}\ (\texttt{list}\ v_2\ \ldots)))) \\ &(\texttt{Filter}\ e\ (\texttt{list})) \rightarrow_d (\texttt{list})\end{aligned}$$

and getting resugaring sequences as Fig. 13e. 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 that need to be expressed by the expressions in core language as branching conditions. Take the example of another higher-order sugar Map as an example, and get resugaring sequences as Fig. 13d.

```
(Map e1 e2) →d Todo :format?
  (let ((f e1))
    (let ((x e2))
       (if  (empty? x)
            (list)
            (cons (f (first x)) (Map f (rest x))))))
```

Note that the let expression 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 expression. So it will be difficult to naturally handle such inline boundary conditions for existing rewriting systems. (The case can be specific by some setting, such as Todo: local-expansion in Racket's macro.) But our approach is easy to handle cases like this.

**4.1.4 Limitation on Presentation.** One may note that the context rules of our sugar setting limit the presentation of syntactic sugar. For example, it is difficult to present a sugar with ellipsis, because the form of its context rule may vary. It is still possible if we add some restriction (so that the algorithm 1 will work), or we can just make it using the list operation just as what the sugar Map, Filter work. Overall, the presentation of our sugar system is not so flexible, but it won't affect the expressiveness. Todo: Automaton

### 4.2 Efficiency

To show the efficiency of our approach, we try some programs from simple to hard. We use the reduction steps comparing to the existing approach as the metrics. The following Fig. 14 shows the difference of the two approach. Notice that both approaches have pre-processions—for the existing one, it is to desugar the programs to the core language together with some tags; for ours, it is to calculate the context rules of syntactic sugars. We do not consider the steps during these pre-processes. Besides, we derive the reduction steps of existing approach into three different kinds—the reductions in core language, the reverse expansion with failed resugaring, the reverse expansion with successful resugaring.

The general regularity is—the more complex the sugar is, the more steps will our approach save. Note that if the RHS of a syntactic sugar is huge, one step reduction of the reverse desugaring will also be more complex, because the huge sugars will contains many failed attempts to resugar. So avoiding reverse expansion of syntactic sugar can improve

| *Sugar* | *steps of ours* | *Steps of existing* | *Description* |
|---|---|---|---|
| And, Or | 4 | 2+0+2=4 | |
| And, Newor | 10 | 7+6+3=16 | Or with binding |
| Filter | 29 | 22+78+10=110 | |
| Sg, and, or | 11 | 5+0+10=15 | Sg is nested |
| HygienicAdd | 6 | 5+1+1=7 | |
| S, K, I | 16 | 11+13+10=34 | |

**Figure 14.** Comparison on Reduction Steps

the efficiency for practical use, because there is not always small programs like the demos.

## 5 Other Discussion

### 5.1 Model Assumption

As we mentioned in the introduction (Section 1), our approach has a more specific assumption compared to the existing approach. Here is a small gap between the motivation of existing approach and ours—existing approach focused mainly on a tool for existing language, while our approach considered more on a basic feature for language implementation. The examples in Section 4.1.3 have shown how the lazy desugaring solve some problems in practice.

In addition, as what we need for the lazy desugaring is just the computation order of the syntactic sugar, we can make a extension for the resugaring algorithm to see how it is able to work with only a black-box core language stepper. The most important difference between black-box stepper and the evaluation rules is the computation order—while the same language will behave uniquely, the evaluation rules can show the computation order statically (without running the program). So when meeting the black-box stepper for the core language, we can just use some simple program to "get" the computation order of the core language as the example in Fig. 15 shows: we simply let the sub-expressions of a Head be some reducible expressions and test the computation order.

```
(if tmpe1 tmpe2 tmpe3)
        ⇓stepper
(if tmpe1' tmpe2 tmpe3)
        ⇓getnext
(if tmpv1 tmpe2 tmpe3)
        ⇓stepper
        tmpei
```

**Figure 15.** getting the order

But that's not enough—the core language and the surface language cannot be mixed easily. We should do the same try during the evaluation to make the core language's stepper useful when meeting some surface language's term.

**Defination 5.1** (dynamic mixed language's one step reduction $\rightarrow_m$ ). *Defined in Fig. 16.*

$$\frac{\forall\ i.\ e_i \in \texttt{CoreExp} \qquad (\texttt{CoreHead}\ e_1\ \ldots\ e_n)\ \rightarrow_c\ e'}{(\texttt{CoreHead}\ e_1\ \ldots\ e_n)\ \rightarrow_m\ e'} \quad (\textsc{CoreRed})$$

$$\frac{\forall\ i.\ tmp_i = (e_i \in \texttt{SurfExp}\ ?\ \texttt{tmpe}\ :\ e_i) \qquad (\texttt{CoreHead}\ tmp_1\ \ldots\ tmp_i\ \ldots\ tmp_n)\ \rightarrow_c\ (\texttt{CoreHead}\ tmp_1\ \ldots\ tmp_i'\ \ldots\ tmp_n)}{(\texttt{CoreHead}\ e_1\ \ldots\ e_i\ \ldots\ e_n)\ \rightarrow_m\ (\texttt{CoreHead}\ e_1\ \ldots\ e_i'\ \ldots\ e_n)\ \ where\ e_i\ \rightarrow_m\ e_i'} \quad (\textsc{CoreExt1})$$

$$\frac{\forall\ i.\ tmp_i = (e_i \in \texttt{SurfExp}\ ?\ \texttt{tmpe}\ :\ e_i) \qquad (\texttt{CoreHead}\ tmp_1\ \ldots\ tmp_n)\ \rightarrow_c\ e'\ \text{// not reduced in subexpressions}}{(\texttt{CoreHead}\ e_1\ \ldots\ e_n)\ \rightarrow_m\ e'[e_1/tmp_1\ \ldots\ e_n/tmp_n]} \quad (\textsc{CoreExt2})$$

where tmpe is any reduciable CoreExp term

**Figure 16.** Dynamic reduction

Putting them in simple words. For expression (CoreHead $e_1\ \ldots\ e_n$) whose subexpressions contain SurfExp, replacing all SurfExp subexpressions not in core language with any reducible core language's term tmpe. Then getting a result after inputting the new expression $e'$ to the original black-box 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 (CoreHead $e_1\ \ldots\ e_i'\ \ldots\ e_n$), where $e_i'$ is $e_i$ after the mixed language's one-step reduction ( $\rightarrow_m$ ) or after core language's reduction with extension ( $\rightarrow_e$ ) (rule CoreExt1, an example in Fig. 17). Otherwise, the stepper should return $e'$, with all the replaced subexpressions replacing back (rule CoreExt2, an example in Fig. 18). The extension will not violate the 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. The stepper with extension behaves the same as mixing the evaluation rules of core language and desugaring rules of surface language.

```
(if (and e1 e2) true false)
        ⇓replace
(if tmpe1 true false)
        ⇓blackbox
(if tmpe1' true false)
        ⇓desugar
(if (if e1 e2 false) true false)
```

**Figure 17.** CoreExt1's Example

But something goes wrong when substitution takes place during CoreExt2. For a expression like (let x 2 (Sugar x y)) as an example, it should reduce to (Sugar 2 y) by the CoreRed2 rule, but got (Sugar x y) by the CoreExt2 rule. So when using the extension of black-box stepper's

```
(if (if true ture false) (and ...) (or ...))
        ⇓replace
(if (if true ture false) tmpe2 tmpe3)
        ⇓blackbox
(if true tmpe2 tmpe3)
        ⇓replaceback
(if true (and ...) (or ...))
```

**Figure 18.** CoreExt2's Example

rule (ExtRed2), we need some other information about in which subexpression a substitution will occur. Then for these subexpressions, we need to do the same substitution before replacing back. The substitution can be got by a similar idea as the dynamic reduction in our simple core language's setting. For example, we know the third subexpression of a expression headed with let is to be substituted. we should first try (let x 2 x), (let x 2 y) in one-step reduction to get the substitution [2/x], then, getting (Sugar 2 y).

Then for any sugar expression, we can process them dynamically by "one-step try"—trying which hole is to be reduced after the outermost sugar desugared, as example in Fig. 19. (The bold Head means trying on this term.)

### 5.2 Correctness and Trade-off

The existing resugaring approach proposed following three properties to define the correctness.

> Emulation: Each term in the generated surface evaluation sequence desugars into the core term which it is meant to represent.
> Abstraction: Code introduced by desugaring is never revealed in the surface evaluation sequence, and code originating from the original input program is never hidden by resugaring.
> Coverage: Resugaring is attempted on every core

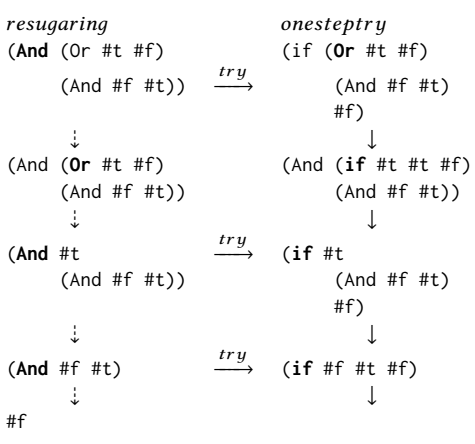


**Figure 19.** simple example

step, and as few core steps are skipped as possible.

Here we will show what are the similarities and differences between theirs and our properties.

*Emulation*: The properties in Section 3 is just the same as the emulation property. We should admit that this property is the most basic one.

*Abstraction and Coverage*: Actually, our reduction in the mixed language has some similarities to theirs. But since our framework has no execution for the fulldesugared program and no reverse desugaring, it will be some different in details.

Overall, our approach restricts the output by the `Head` of a program and its inner(or to say, sub) expressions. It is quite natural, since the motivation of the resugaring is to show useful intermediate sequences, we think it will be better than restricting the output by judging whether the program contains some components desugared from the original program's components. Let's see the following example in Fig. 20

```
(Nor x y) →d (And (not x) (not y))
(And x y) →d (if x y #f)
```

**Figure 20.** Nor sugar

Then for the program in a logic domain, what should be a resugaring sequence of the program `(not (And (Nor #f #t) #t))` ?

In our opinion, if the outer `not`, `And` can be displayed, so they should be after desugared. The existing approach will produce the sequences as follows.

```
(not (And (Nor #f #t) #t))
⟶ (not (And #f #t))
⟶ (not #f)
⟶ #t
```

while ours will produce the following sequences.

```
(not (And (Nor #f #t) #t))
⟶ (not (And (And (not #f) (not #t)) #t))
⟶ (not (And (And #t (not #t)) #t))
⟶ (not (And (not #t) #t))
⟶ (not (And #f #t))
⟶ (not #f)
⟶ #t
```

In summary, our approach choose a slightly different way for the *abstraction* for better *coverage* in the real application, which the authors of existing approach also mentioned (but by different processing). Todo: specify the displayable

### 5.3 Hygiene

As an important property for sugar or macro system, the existing approach use a data structure (ASD) to handle hygiene in resugaring, while in our approach the hygiene can be handled easily. Previous research[1] has discussed why some simple processing such as renaming is insufficient in some cases. But in our system, the hygiene problem is solved easily.

In our approach, the sugar can contain some bindings, written by the core language's `let`. The hygiene problem only happens when binders of a expanded sugar conflict with other binders. We file them into two categories—

- A sugar in binding's context.
- A sugar's subexpression containing bindings.

The Fig. 21 and 22 shows how the simple cases of these two.

```
(let (x #t) (Or #f x)) where
(Or e1 e2) →d (let (x e1) (if x x e2))
```

**Figure 21.** Case1's Example

```
(Subst (+ f (let (f 1) f)) f 5) where
(Subst e1 e2 e3) →d (let (e2 e3) e1)
```

**Figure 22.** Case1's Example

For the case1, the very basic and common hygiene problem, is not a problem, because our "lazy desugaring" setting won't let the sugar `Or` expanded before the `x` is substituted. Because the bound variables in sugar expressions are only introduced by let-binding, all of them can "delay" the expansion of the syntactic sugar.

For the case2, where the subexpression `f` is a free variable introduced by the sugar `Subst`, the program will firstly desugar the `Subst` (because the only hole at $e_3$ has been a

value), then hygiene problem is just about the core language—which can be easily solved by capture-avoiding substitution.

Because of the definition of desugaring in our approach, we can not achieve hygiene by proving the $\alpha - equivalence$. Here what we want to show is that, even without complex things like macro systems, specifying the scopes and so on, the lazy desugaring itself will solve the common hygienic problem with carefully-designed core language. And of course the lazy desugaring will also work together with a hygienic rewriting system (e.g., by specific the binding scope [10]). Also the scope inference of syntactic sugar[15] provide a good perspective for solving the hygienic problem.

## 6 Related Work

As discussed many times before, our work is much related to the pioneering work of *resugaring* in [13, 14]. The idea of "tagging" and "reverse desugaring" is a clear explanation of "resugaring", but it becomes very complex when the RHS of the desugaring rule becomes complex. Our approach does not need to reverse desugaring, and is more lightweight, powerful, and efficient. For hygienic resugaring, compared with the approach of using DAG to solve the variable binding problem in [14], our approach of "lazy desugaring" can achieve kind of natural hygiene without special treatment. It oughts to combine with existing hygienic resugaring approaches.

*Macros as multi-stage computations* [9] is a work related to our lazy expansion for sugars. Some other researches [17] about multi-stage programming [19] indicate that it is useful for implementing domain-specific languages. However, multi-stage programming is a metaprogramming method, which mainly works for run-time code generation and optimization. In contrast, our lazy resugaring approach treats sugars as part of a mixed language, rather than separate them by staging. Moreover, the lazy desugaring gives us a chance to derive evaluation rules of sugars, which is a new good point compared to multi-stage programming.

Our work is related to the *Galois slicing for imperative functional programs* [16], 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 $y$. This can also be considered as a bidirectional transformation [3, 8] and the round-tripping between desugaring and resugaring in existing approach. In contrast to these work, our resugaring approach is basically unidirectional, with a local bidirectional step for a one-step try in our lazy desugaring. It should be noted that Galois slicing may be useful to handle side effects in resugaring in the future (for example, slicing the part where side effects appear).

There is a long history to hygienic macro expansion[11], and a formal specific hygiene definition was given [10] by specific the binding scopes of macros. [1] is also another formal definition of hygienic macro.

Our implementation is built upon the PLT Redex [4], a semantics engineering tool, but it is possible to implement our approach on other semantics engineering tools such as those in [18, 20] which aim to test or verify the semantics of languages. The methods of these researches can be easily combined with our approach to implementing more general rule derivation. *Ziggurat* [7] is a semantic-extension framework, also allowing defining new macros with semantics based on existing terms in a language. It is should be useful for static analysis of macros.

## 7 Conclusion

Todo: rewrite

resugaring for other language

In this paper, we purpose a novel resugaring approach by lazy desugaring. In our resugaring approach, the most important part is calculating context rules for the syntactic sugars (see in Section 3), which decides whether it should reduce the subexpression or desugar the outermost sugar. The lazy desugaring gives our approach chances to achieve better efficiency and expressiveness.

As for the future work, we found side effects are troublesome to handle in resugaring, because once a side effect is taken in RHS of a desugaring rule, the sugar cannot be easily resugared according to *emulation* property. We need to find a gentler way to handle sugars with side effects. In addition, we found it is possible to derivate the stand-alone evaluation rules for the surface language by means same as calculating the context rules. Maybe there is a more gentle way for developing domain-specific languages.

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