Lifting Resugaring by Lazy Desugaring

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With the rapid development of computer science, domain-specific language (DSL) is quite useful in our daily life, not only for programmers or computer scientists, but for people from all walks of life. Syntactic sugar is a good way to implement embedded DSLs, because it can make good use of existing general-purposed language's feature. However, the evaluation sequences became unrecognizable after the sugar expression desugared.

Resugaring is an method to solve the problem above. In this paper, we purposed a lightweight approach of resugaring based on reduction semantics—getting evaluation sequences without fully desugaring the whole syntactic sugar expression. We implement a tool based on our method using PLT Redex and test our approach on some applications. The results show that our lightweight approach can even deal with more syntactic sugar's feature.

Additional Key Words and Phrases: Domain-specific Language, Syntactic Sugar, Interpreter, Rewriting System

1 INTRODUCTION

Domain-specific language[Fowler 2011] is becoming useful for people's daily tasks. For example, the IFTTT app and IOS's shortcuts designed DSLs describing some tasks to make our lives more convenient. So the users of DSL are no longer limited to programmers, but people from all walks of life.(to be completed)

Syntactic sugar[Landin 1964], as a simple way of implementing DSL, has an obvious problem. DSL based on syntactic sugars contains many components of its host language. Then its interpretation will be outside the DSL itself. The evaluation sequences of syntactic sugar expressions will contain many terms of the host language, which may confuse the users of DSL.

There is an existing work—resugaring[Pombrio and Krishnamurthi 2014][Pombrio and Krishnamurthi 2015], which aimed to solve the problem upon. It converted the evaluation sequences of desugared expression (core language) into representative sugar's syntax(surface language). The evaluation sequences shown by resugaring will not contain components of host language. But we found the existing resugaring approach using match and substitution is kind of redundant. The biggest deficiency of existing resugaring method is that the syntactic sugars in an expression have to fully desugar before evaluation. This limits the processing ability of the method. Moreover, it limits the complexity of getting the resugaring sequences. If we need to resugar a very huge expression, the match and substitution processes will cost so much. Also, processing of hygienic macros is complex due to the extra data structure.

In this paper, we propose an unidirectional resugaring approach by lazy dusugaring mixed with a dynamic approach and a static approach. The key idea of the whole approach is—syntactic sugar expressions only desugar at the point they have to desugar, which is what the word "lazy" means. It would be correct for resugaring if we can prove the whole sugar expression will keep the properties.

The dynamic approach use the reduction semantics of core language to decide whether desugaring the sugar. The static approach use the reduction semantics of core language to get reduction semantics of surface language based on sugars' syntax, then execute the syntactic sugar programs on the surface's semantics. The context rules of surface language decide which subexpression can be reduced, or desugaring is necessary because of the reduction rules.

Our main contribution is as follow:

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- **Mixture approach of resugaring.** We introduce an mixture of two different resugaring approachs 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 processing what existing work can process, the dynamic approach can handle recursive sugar easily, which makes the approach 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

In the rest of this paper, we present the technical details of our approach together with the proof of correctness. In details, the rest of our paper is organized as follow: todo:update

- An overview of our approach with mixture of dynamic and static approach.[sec 2]
- The technique of dynamic approach, with algorithm and evaluation.[sec 3]
- The technique of dynamic approach, with algorithm and evaluation.[sec **??**]
- Relative work and discussions.[sec 5]
- Conclusion and feature work.[sec 6]

2 OVERVIEW

2.1 Defination of resugaring

This subsection is partially similiar to original defination in[Pombrio and Krishnamurthi 2014].

Defination 2.1 (Resugaring). *Given core language (named **CoreLang**) and its evalation rules, together with surface language based on syntactic sugars of CoreLang (named **Surflang**). For any expression of Surflang, getting the evaluation sequences of the expression in terms of SurfLang.*

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

(1) **Emulation** The evaluation sequences reflect the actual execution process.
(2) **Abstraction** The resugaring sequences should only contains terms in SurfLang, and each term of SurfLang should originate from initial expression.
(3) **Coverage** No sequence is skipped during the process.

Given an example below.

For syntactic sugar **and** and **or**, the sugar rules are:

(and e1 e2) $\longrightarrow$ (if e1 e2 #f)
(or e1 e2) $\longrightarrow$ (if e1 #t e2)

which forms a simple SurfLang.

The evaluation rules of **if** is:

$$\text{if}(\#t, e1, e2) \longrightarrow e1$$
$$\text{if}(\#f, e1, e2) \longrightarrow e2$$

Then for SurfLang's expression and(or($\#f$, $\#t$), and($\#t$, $\#f$)) should get resugaring sequences as fig1.

$$\begin{array}{c} \text{(and (or \#f \#t) (and \#t \#f))} \\ \downarrow \\ \text{(and \#t (and \#t \#f))} \\ \downarrow \\ \text{(and \#t \#f)} \\ \downarrow \\ \text{\#f} \end{array}$$

Fig. 1. resugaring example

The reason we should get the sequences above is because (and (or $\#f$ $\#t$) (and $\#t$ $\#f$)) should desugar to (if (if $\#f$ $\#t$ $\#f$) (if $\#t$ $\#f$ $\#f$) $\#f$). Then in the CoreLang, the evaluation sequences will be as fig2.

$$\begin{array}{c} \text{(if (if \#f \#t \#f) (if \#t \#f \#f) \#f)} \\ \downarrow \\ \text{(if \#t (if \#t \#f \#f) \#f)} \\ \downarrow \\ \text{(if \#t \#f \#f)} \\ \downarrow \\ \text{\#f} \end{array}$$

Fig. 2. evaluation sequences

The second item in the sequences can be desugared from (and $\#t$ (and $\#t$ $\#f$)), so resugars to it. So as the third item.

2.2 Mixture Approach Framework

We limit the language to s-expressions. Given an expression Exp = (Headid Exp∗), the process of mixture approach will as Fig 3.

Given an example here.

For syntactic sugar **and**, **or** and **map**, the sugar rules are:

(and e1 e2) ⟶ (if e1 e2 #f)
(or e1 e2) ⟶ (if e1 #t e2)
(f e lst) ⟶ (if (empty? lst) empty (cons (let x e (or x (and (first lst) x))) (f e (rest lst))))

which forms a simple SurfLang.

As we will see in Sec3, the dynamic approach could handle recursive syntactic sugar, and the static approach could not. If we execute (f #t (list #f #t)), the expression will Since the dynamic approach is more powerful and the static approach is more efficent, we should judge whether the input expression can be processed by static approach. If so, then use the static approach; if not, then use the dynamic approach to get (cons (let x #t (or x (and (first (list #f #t)) x))) (f #t (rest (list

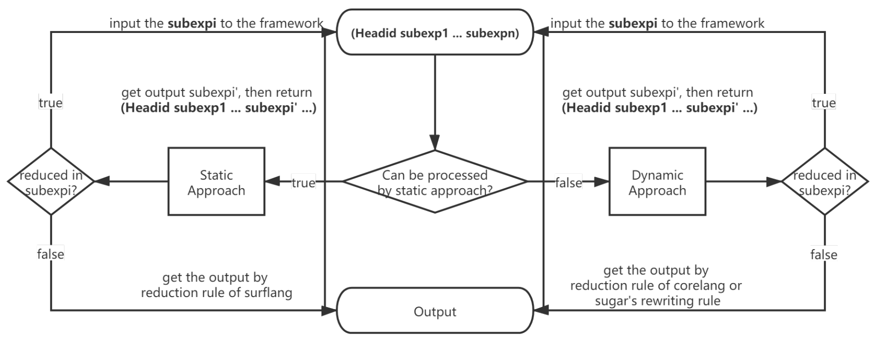


Fig. 3. One step in framework of mixture approach

#f #t)))). Then the expression with headid **cons** can be handled by static approach, which let the first subexpression reduced, so we get subsequences like (cons ... (f #t (rest (list #f #t)))), (cons #f (f #t (rest (list #f #t)))). At this time, the static approach will let the second subexpression reduced, so the expression with headid **f** will be processed by dynamic approach. (A recursive process it is.)

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 ...

(and (or #f #t) (and #t #f))
↓step1
(and (if #f #t #t) (and #t #f))
↓step2
(and #t (and #t #f))
↓step3
(if #t (and #t #f) #f)
↓step4
(and #t #f)
↓step5
(if #t #f #f)
↓step6
#f

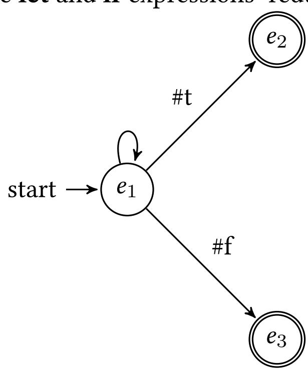
Fig. 4. core-algo example

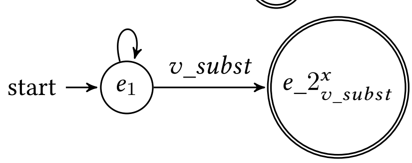
At step 1, we found the outermost *and* sugar don't have to expand, because its first sub-expression will reduce earlier. At step 2, the same as step 1. At step 3, the outermost *and* sugar have to expand, because no sub-expression will reduce after the whole expression desugar. At step 4, the inner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

The key idea of our dynamic 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.

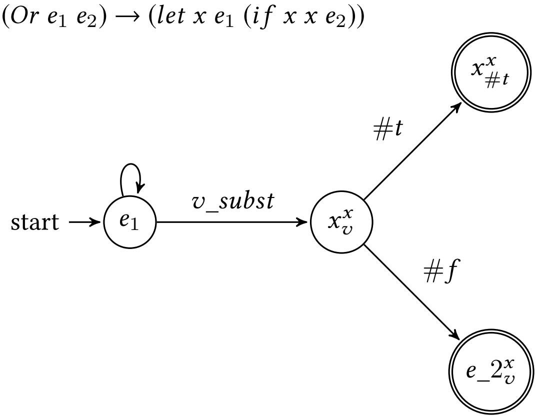
(or e1 e2) → (let x e1 (if x x e2))

The **let** and **if** expressions' reduction semantics can be represented as follow.





$(Or\ e_1\ e_2) \rightarrow (let\ x\ e_1\ (if\ x\ x\ e_2))$



3 DYNAMIC APPROACH

3.1 Language setting

3.1.1 Grammatical restrictions. Firstly, the whole language should be restricted to tree-structured disjoint expression.

DEFINATION 3.1 (DISJOINT). *For every sub-expression in a expression, its reduction rule is decided by itself.*

This restriction limits the scope of language. Every sub-expression must have no side effect. We will discuss more on side effect in section 5.1.1.

DEFINATION 3.2 (TREE-STRUCTURED). *The grammar of the whole language is defined as follow.*

$$\begin{array}{rcl} Exp & ::= & (Headid\ Exp*) \\ & | & Value \\ & | & Variable \end{array}$$

The grammatical restrictions give our language a similiar property as church-rosser theorem[Church and Rosser 1936] for lambda calculus.

3.1.2 Context restrictions. For expressions in CoreLang, the context rules should restrict it to have only one reduction path. The context rules can limit the order of evaluation. This restriction is normal, because a program in general-purposed language should have only one execution path.

For expressions in SurfLang, context rules should allow every sub-expressions reduced. It's the same as full-β reduction.

3.1.3 Restriction of syntactic sugar. The form of syntactic sugar is as follow.

$\boxed{(\text{Surfid } e_1\ e_2\ \ldots) \longrightarrow (\text{Headid } \ldots)}$

An counter example of this restriction is (Surfid $\ldots$ $(e1\ e2)\ldots$)) in LHS. It's for simpler algorithm form, and the expression ability of syntactic sugar will not be changed.

Defination 3.3 (Unambiguous). *For every syntactic sugar expressions, it can only desugar to one expression in CoreLang.*

3.1.4 Grammar Description. In our language setting, we regard SurfLang and CoreLang as a whole language. The whole language is under restrictions above, and its grammar is defined as follow.

$$
\begin{array}{rcl}
\text{Exp} & ::= & \text{DisplayableExp} \\
 & | & \text{UndisplayableExp} \\
\text{DisplayableExp} & ::= & \text{Surfexp} \\
 & | & \text{Commonexp} \\
\text{UndisplayableExp} & ::= & \text{Coreexp} \\
 & | & \text{OtherSurfexp} \\
 & | & \text{OtherCommonexp} \\
\text{Coreexp} & ::= & (\text{CoreHead Exp}*) \\
\text{Surfexp} & ::= & (\text{SurfHead DisplayableExp}*) \\
\text{Commonexp} & ::= & (\text{CommonHead DisplayableExp}*) \\
 & | & \text{Value} \\
 & | & \text{Variable} \\
\text{OtherSurfexp} & ::= & (\text{SurfHead Exp}*\ \text{UndisplayableExp Exp}*) \\
\text{OtherCommonexp} & ::= & (\text{CommonHead Exp}*\ \text{UndisplayableExp Exp}*)
\end{array}
$$

The difference between CoreLang and SurfLang is identified by *Headid*. But there are some terms in CoreLang 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 **Coreexp** terms are terms with undisplayable CoreLang's Headid. The **Surfexp** terms are terms with SurfLang's Headid and all sub-expressions are displayable. The **Commonexp** terms are terms with displayable CoreLang's Headid, together with displayable sub-expressions. There exists some other expression during our resugaring process. They have Headid which can be displayed, but one or more subexpressions can't. They are UndisplayableExp.

Take some terms in CoreLang as examples.

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

We let **if**, **let**, λ_N, **empty**, **first**, **rest** as Coreexp's Headid, **Op**, λ, **cons** as Commonexp's Headid. Then we could show some useful intermediate steps.

3.2 Algorithm defination

Our lightweight resugaring algorithm is based on a core algorithm core-algo. For every expression during resugaring process, it may have one or more reduction rules. The core algorithm core-algo chooses the one that satisfies three properties of resugaring, then applies it on the given expression. The core algorithm core-algo is defined as 1.

We briefly describe the core algorithm core-algo in words.

For Exp in language defined as last section, try all reduction rules in the language, get a list of possible expressions ListofExp'={Exp'_1,Exp'_2,. . .}.

Line 2-9 deal with the case when Exp has a CoreLang's Headid. When Exp is value or variable (line 3-4), ListofExp' won't have any element (not reducible). When Exp is of Coreexp or Commonexp (line 5-6, due to the context restriction of CoreLang, only one reduction rule can be applied. When Exp is OtherCommonexp (line 7-8), due to the context restriction of CoreLang, only one sub-expression can be reduced, then just apply core algorithm recursively on the sub-expression.

Line 10-21 deal with the case then Exp has a SurfLang's Headid. When Exp only has one reduction rule (line 11-12), the syntactic sugar has to desugar. If not, we should expand outermost sugar and find the sub-expression which should be reduced (line 14-16), or the sugar has to desugar (line 17-18), because it will never be resugared.

Then, our lightweight-resugaring algorithm is defined as 2.

The whole process of the lightweight resugaring executes core algorithm core-algo, and output sequences which is of Surfexp or Commonexp.

3.3 Proof of 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.

$Exp\ =\ (Headid\ Subexp_1\ Subexp_{\ldots}\ \ldots)$ 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 $(Headid_i\ Subexp_{i1}\ Subexp_{i\ldots}\ \ldots)$

Algorithm 1 Core-algorithm core-algo

Input:

Any expression Exp=($Headid\ Subexp_1\ \ldots\ Subexp_{\ldots}$) which satisfies Language setting

Output:

Exp' reduced from Exp, s.t. the reduction satisfies three properties of resugaring

Let $ListofExp' = \{Exp'_1, Exp'_2\ \ldots\}$
if Exp is Coreexp or Commonexp or OtherCommonexp **then**
  if Lengthof($ListofExp'$)==0 **then**
    return null; Case1
  else if Lengthof($ListofExp'$)==1 **then**
    return first($ListofExp'$); Case2
  else
    return $Exp'_i = (Headid\ Subexp_1\ \ldots\ Subexp'_i\ \ldots)$; //where i is the index of subexp which have to be reduced. Case3
  end if
else
  if Lengthof($ListofExp'$)==1 **then**
    return desugarsurf(Exp); Case4
  else
    Let $DesugarExp$ = desugarsurf(Exp)
    if $Subexp_i$ is reduced to $Subexp'_i$ during $f(DesugarExp)$ **then**
      return $Exp'_i = (Headid\ Subexp_1\ \ldots\ Subexp'_i\ \ldots)$; Case5
    else
      return $DesugarExp$; Case6
    end if
  end if
end if

Algorithm 2 Lightweight-resugaring

Input:

Surfexp Exp

Output:

Exp's evaluation sequences within DSL

while $tmpExp$ = f(Exp) **do**
  if $tmpExp$ is empty **then**
    return
  else if $tmpExp$ is Surfexp or Commonexp **then**
    print $tmpExp$;
    Lightweight-resugaring($tmpExp$);
  else
    Lightweight-resugaring($tmpExp$);
  end if
end while

- If the reduction process is Outer Reduction of $Subexp_i$ = $(Headid_i\ Subexp_{i1}\ Subexp_{i\ldots}\ \ldots)$, then it is called **Surface Reduction**.
- If the reduction process reduces $Subexp_{ij}$, then it is called **Inner Reduction**.

Example:

(if $\#t$ Exp_1 Exp_2) $\longrightarrow$ $Exp1$	Outer Reduction
(if (And $\#t$ $\#f$) Exp_1 Exp_2) $\longrightarrow$ (if (if $\#t$ $\#f$ $\#f$) Exp_1 Exp_2)	Surface Reduction
(if (And (And $\#t$ $\#t$) $\#t$) Exp_1 Exp_2) $\longrightarrow$ (if (And $\#t$ $\#t$) Exp_1 Exp_2)	Inner Reduction

Defination 3.4 (Upper and lower expression). *For* Exp=$(Headid\ Subexp_1\ Subexp_{\ldots}\ \ldots)$, 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.

Proof of Emulation.
For case 4 or 6, desugaring won't change Emulation property, because desugaring and resugaring are interconvertible.

For case 3 or 5, our core algorithm reduces the sub-expression which should be reduced. So if applying core algorithm core-algo on the subexpression satisfies emulation property, then this two cases satisfy. As we mentioned above, if the reduction is surface reduction, the subexpression is processed by case 2, 4 or 6, which have been proved to satisfy the emulation property; if the reduction is inner reduction, the subexpression is processed by case 3 or 5, which can be proved recursively, because the depth of expressions is finite, the subexpression will finally be reduced by an outer reduction. Thus, the reduction of the subexpression satisfies the emulation property, so it is for case 3 or 5.

□

Proof of Abstraction.
It's true, because we only display the sequence which satisfies abstraction property. □

Lemma 3.1. *If no syntactic sugar desugared before it has to, then coverage property is satisfied.*

Proof of Lemma. Assume that no syntactic sugar not necessarily expanded desugars too early, existing an expression in CoreLang
Exp = $(Headid\ Subexp_1\ Subexp_{\ldots}\ \ldots)$ which can be resugared to
$ResugarExp'$ = $(Surfid\ Subexp'_1\ Subexp'_{\ldots}\ \ldots)$, and $ResugarExp'$ is not displayed during lightweight-resugaring process. Then

- Or existing
$ResugarExp$=$(Surfid\ Subexp'_1\ \ldots\ Subexp_i\ Subexp'_{\ldots}\ \ldots)$ 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 $ResugarExp'$ is not displayed, then the sugar not necessarily expanded desugars too early, which is contrary to assumption.
- Or existing
$ResugarExp$=$(Surfid'\ \ldots\ ResugarExp'\ \ldots)$ in resugaring sequences, such that the expression after $ResugarExp$ desugaring reduces to Exp, and Exp is desugared from $ResugarExp'$'s sub-expression. If $ResugarExp'$ 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*.

□

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.

□

3.4 Implementation

Our lightweight resugaring approach is implemented using PLT Redex[Felleisen et al. 2009], which is an semantic engineering tool based one reduction semantics[Felleisen and Hieb 1992]. The whole framework is as Fig5.

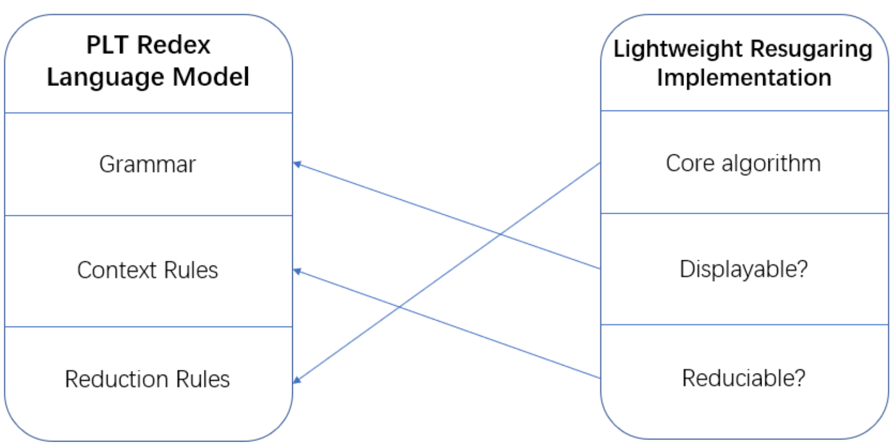


Fig. 5. framework of implementation

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 Evaluation

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 process 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.

$S \longrightarrow (\lambda_N\ (x_1\ x_2\ x_3)\ (x_1\ x_2\ (x_1\ x_3)))$
$K \longrightarrow (\lambda_N\ (x_1\ x_2)\ x_1)$
$I \longrightarrow (\lambda_N\ (x)\ x)$

Althought SKI combinator calculus is a reduced version of lambda calculus, we can construct combinators' sugar based on call-by-need lambda calculus in our CoreLang. For expression $(S\ (K\ (S\ I))\ K\ xx\ yy)$, we get the following resugaring sequences as Fig 6.

$$\begin{array}{c} \text{(S (K (S I)) K xx yy)} \\ \downarrow \\ \text{(((K (S I)) xx (K xx)) yy)} \\ \downarrow \\ \text{(((S I) (K xx)) yy)} \\ \downarrow \\ \text{(I yy ((K xx) yy))} \\ \downarrow \\ \text{(yy ((K xx) yy))} \\ \downarrow \\ \text{(yy xx)} \end{array}$$

Fig. 6. SKI's resugaring sequences

For existing approach, the sugar expression should firstly desugar to
$((\lambda_N(x_1x_2x_3)(x_1x_3(x_2x_3)))((\lambda_N(x_1x_2)x_1)((\lambda_N(x_1x_2x_3)(x_1x_3(x_2x_3)))(\lambda_N(x)x)))(\lambda_N(x_1x_2)x_1)xxyy)$

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

So the unidirectional resugaring algorithm makes our approach lightweight, because no attempts for resugaring the expression take place.

3.5.2 hygienic macro. The second work[Pombrio and Krishnamurthi 2015] mainly processes hygienic macro compared to first work. We try a *Let* sugar , which is a common hygienic sugar example, on our tool. Our algorithm can easily process hygienic macro without special data structure. The *Let* sugar is define as follow

$(Let\ x\ v\ exp) \longrightarrow (Apply\ (\lambda\ (x)\ exp)\ v)$

Take $(Let\ x\ 1\ (+\ x\ (Let\ x\ 2\ (+\ x\ 1))))$ for an example. First, a temp expression
$(Apply\ (\lambda\ (x)\ (+\ x\ (Let\ x\ 2\ (+\ x\ 1))))\ 1)$
is needed. (case 5 or 6)Then one-step try on the temp expression, we will get
$(+\ 1\ (Let\ 1\ 2\ (+\ 1\ 1)))$ which is out of the whole language's grammar. In this case, it is not a good choice to desugar the outermost *Let* sugar. Then we just apply the core-algo f on the sub-expression

where the error occurs ($(+\ x\ (Let\ x\ 2\ (+\ x\ 1)))$ in this example). So the right intermediate sequence $(Let\ x\ 1\ (+\ x\ 3))$ will be get.

In practical application, we think resugaring for a unhygienic rewriting system is not interesting at all, because hygienic macro can be easily processed by rewriting system. So in the finally implementation of our tool, we just use PLT Redex's binding forms to deal with hygienic macros. But we did try it on the version without hygienic rewriting system.

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

$(Odd\ e) \longrightarrow (if\ (>\ e\ 0)\ (Even\ (-\ e\ 1)\ \#f))$

$(Even\ e) \longrightarrow (if\ (>\ e\ 0)\ (Odd\ (-\ e\ 1)\ \#t))$

are typical recursive sugars. The previous works can 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 start resugaring as Fig7 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))
↓
...

Fig. 7. Odd2's desugaring process

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 as Fig 8 of the former example using our tool.

(Odd 2)
↓
(Even (- 2 1))
↓
(Even 1)
↓
(Odd (- 1 1))
↓
(Odd 0)
↓
#f

Fig. 8. Odd2's resugaring sequences

We also construct some higher-order syntactic sugars and test them. The higher-order feature is important for constructing practical syntactic sugar. And for syntactic sugar's feature, it is of recursive sugar. Giving the following two higher-order syntactic sugar as examples.

$(map\ e\ (list\ v_1 \ldots)) \longrightarrow$
$(if\ (empty\ (list\ v_1 \ldots))\ (list)\ (cons\ (e\ (first\ (list\ v_1 \ldots)))\ (map\ e\ (rest\ (list\ v_1 \ldots)))))$
$(filter\ e\ (list\ v_1\ v_2 \ldots)) \longrightarrow$
$(if\ (e\ v_1)\ (cons\ v_1\ (filter\ e\ (list\ v_2 \ldots)))\ (filter\ e\ (list\ v_2 \ldots)))$
$(filter\ e\ (list)) \longrightarrow (list)$

These two syntactic sugars use different sugar forms to implement. For *Map* sugar, we use if expression in CoreLang to constrain the boundary conditions. For *Filter* sugar, we use two different parameters' form, which is another easy way for constructing syntactic sugar. The testing results show as Fig9 10.

(map (λ (x) (+ 1 x)) (list 1 2 3))
↓
(cons 2 (map (λ (x) (+ 1 x)) (list 2 3)))
↓
(cons 2 (cons 3 (map (λ (x) (+ 1 x)) (list 3))))
↓
(cons 2 (cons 3 (cons 4 (map (λ (x) (+ 1 x)) (list)))))
↓
(cons 2 (cons 3 (cons 4 (list))))
↓
(cons 2 (cons 3 (list 4)))
↓
(cons 2 (list 3 4))
↓
(list 2 3 4)

Fig. 9. Map's resugaring sequences

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 expresssion 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 searchs all intermediate sequences many times. It will cause huge cost for a large program. So out 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.
- **lazy expansion for recursive sugar** The ability of processing 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 lazy expanding the syntactic sugars. Higher-order functions, as an important feature of functional programming, was supported by many daily programming languages, and many higher-order functions should run recursively. So it's an important feature of our dynamic approach.
- **Rewriting rules based on reduction semantics** Any syntactic sugar that can expressed by reduction semantics can be used in our approach. It will give more possible forms for constructing syntactic sugars. todo:example?

```
(filter (λ (x) (and (> x 3) (< x 6))) (list 1 2 3 4 5 6 7))
↓
(filter (λ (x) (and (> x 3) (< x 6))) (list 2 3 4 5 6 7))
↓
(filter (λ (x) (and (> x 3) (< x 6))) (list 3 4 5 6 7))
↓
(filter (λ (x) (and (> x 3) (< x 6))) (list 4 5 6 7))
↓
(cons 4 (filter (λ (x) (and (> x 3) (< x 6))) (list 5 6 7)))
↓
(cons 4 (cons 5 (filter (λ (x) (and (> x 3) (< x 6))) (list 6 7))))
↓
(cons 4 (cons 5 (filter (λ (x) (and (> x 3) (< x 6))) (list 7))))
↓
(cons 4 (cons 5 (filter (λ (x) (and (> x 3) (< x 6))) (list))))
↓
(cons 4 (cons 5 (list)))
↓
(cons 4 (list 5))
↓
(list 4 5)
```

Fig. 10. Filter's resugaring sequences

The most obvious shortage compared to existing approach is that our approach needs a whole semantic of core languages. The reason is because in case 5 and 6, we need to expand the outermost syntactic sugar and try one step, which may contain unexpanded sugars. Theoretically, our dynamic approach would also work with only a core language's stepper, by totally expand all sugar expressions and marked where each term is originated from. Simple modifications are needed in core-algo. But we did not try it, because of the intent we would discussed in Sec5.1.3.

4 ZC

5 RELATED WORK

The most related work is the series of resugaring[Pombrio and Krishnamurthi 2014, 2015, 2018; Pombrio et al. 2017]. The first two work is about resugaring evaluation sequences, the third one is about resugaring scope rules, and the last one is about resugaring type rules. The whole series is for better syntactic sugar. Our approach considered to implement a method for better DSLs, then regarded core language and surf language as a whole language.

Macrofiction[Schuster et al. 2016] is for generating macros for programs automatically to refactor the codes. Our work may try resugaring some macros generated automatically to test the practicality of resugaring method. Since the setup of our tools is simple, it will be easy to intergrate the two tools.

Galois slicing for Imperative Functional Programs[Ricciotti et al. 2017] is a work for analyzing functional programs during execution. Our approach used a similiar idea on slicing programs and processing on sub-programs.

Dynsem[Vergu et al. 2015] is

5.1 Comments on resugaring

5.1.1 Side effects in resugaring. The previous resugaring approach used to tried a *Letrec* sugar and found no useful sequences shown. We explain the reason from the angle of side effects. We also used to try 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.

5.1.2 hygienic resugaring. As mentioned in Sec3.5.2, our approach can deal with hygienic resugaring without much afford (just another case in core algorithm). Compare to existing hygienic resugaring[Pombrio and Krishnamurthi 2015], our approach is a more general approach. As we learned from the existing approach, it will also work if the rewriting system itself is hygienic, so is our approach. During implementing our tools, we found using $\#refers-to$ keyword of PLT Redex would get more concise intermediate process, so we just use it.

5.1.3 assumption on CoreLang's evaluator. As mentioned in Sec , the work "resugaring" originated from has weaker assumption on the core language—it just required a stepper of core languages' expression, when our approach needed the whole reduction semantics. Thus, the intent of our resugaring is not a tool for supporting resugaring for languages, but a tool for implementing DSL better. We will discuss this in feature work for details.

6 CONCLUSION

Summarize the paper, explaining what you have shown, what results you have achieved, and what future work is.

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A APPENDIX

Text of appendix ...