Program Transformation: Functional Programming Perspective.

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Abstract

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Program transformation is used in a wide range of applications including compiler constructions, optimization, program synthesis, refactoring, software renovation, among others. Complex program transformation are achieved though a number of consecutive modifications of a program, Transformations rules define basic modifications. A transformation strategy is an algorithm for choosing a path in a rewrite relation induced by a set of rules.

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Program Transformation in a more general framework

Table 1: Taxonomy

Translation	Rephrasing
Migration	Normalization
Synthesis	◦ Simplification
◦ Refinement	◦ Desugaring
◦ Compilation	◦ Weaving
Reverse engineering	Optimization
◦ Decompilation	◦ Specialization
◦ Architecture extraction	◦ Inlining
◦ Documentation generation	◦ Fusion
◦ Software visualization	Refactoring
Analysis	◦ Design improvements
◦ Control-flow analysis	◦ Obfuscation
◦ Data-flow analysis	Renovation

Program Transformation in a more general framework

Table 2: Translation

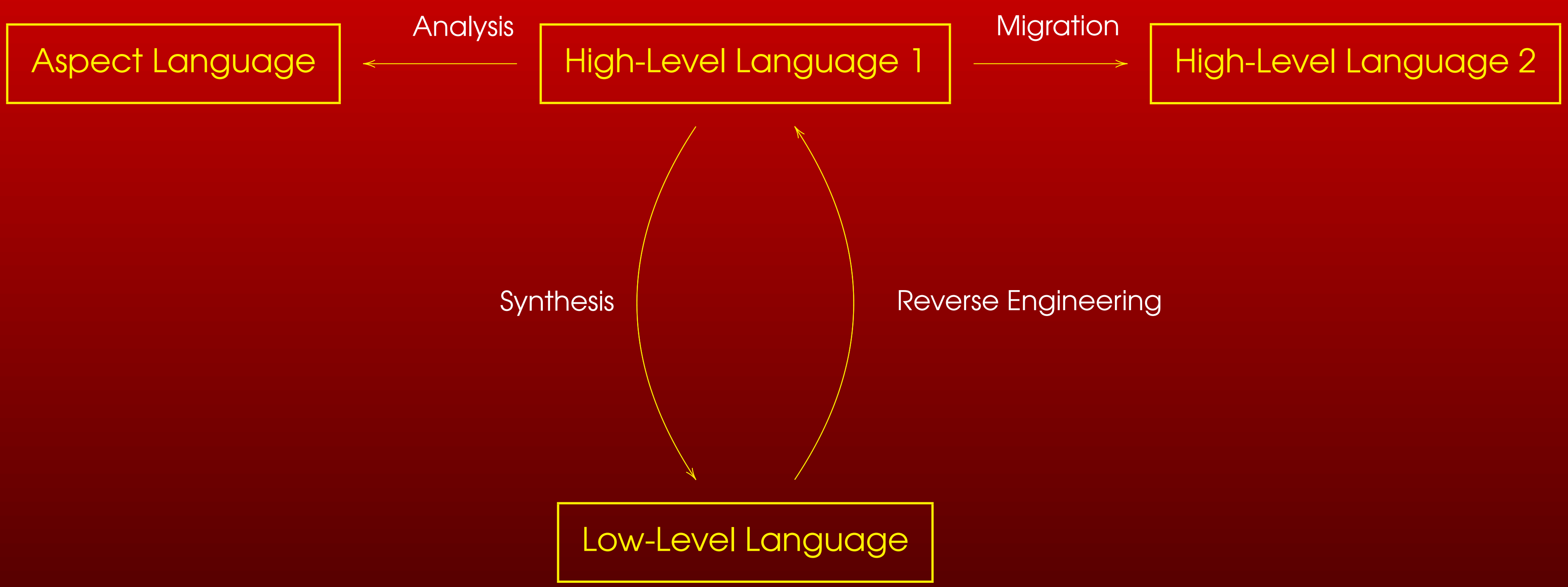

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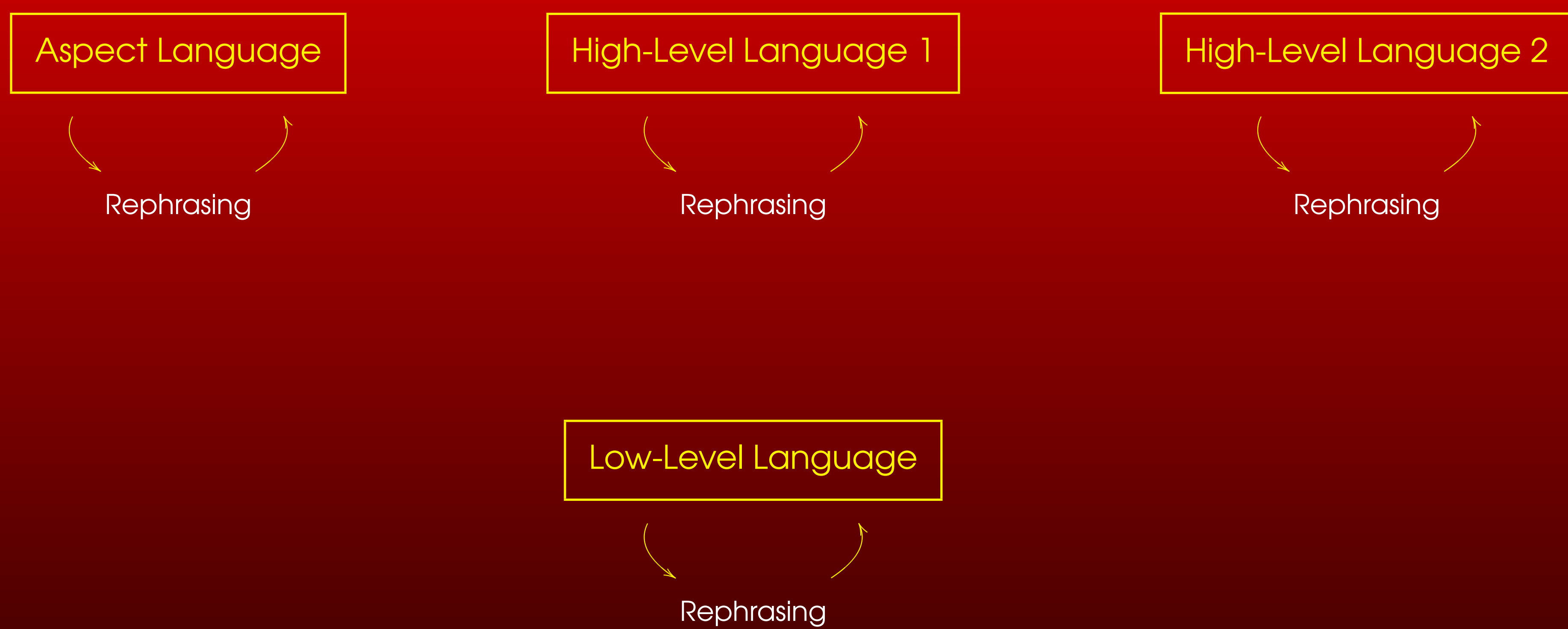
Table 3: Rephrasing



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Motivation.

Gérard Huet and **Bernand Lang** (1978) *"Proving and Applying Program Transformations Expressed with Second-Order Patterns"*

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" There is a huge gap between software certification techniques and the theoretical tool defined for formal proofs of programs.."

Example 1.

Structural Recursion:

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fact(x) = if (x==0) return 1 else return x * fact (x-1)
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Iteration:

```
fact(x) = if (x==0) return 1
      else {
        result = x;
        x = x-1;
        While ( x !== 0) do {
          result = result * x;
          x = x-1};
        return result * 1 }
```

Example 2.

Structural Recursion:

```
(rev x) = if (x== nil) return nil
     else return (append (rev (tail(x)), [head(x)]))
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         result = (append [(head x)] result);
         x = (tail x)};
       return (append result nil) }
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Σ:

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f(x) = if a(x) return b(x)
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f(x) = if a(x) return b(x)
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        result = d(x);
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          x = c(x)};
        return h(result, b(x)) }
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Instantiating patterns.

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f(x) = if a(x) return b(x)
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$$\sigma_1 \begin{cases} \mathtt{f}(\mathtt{x}) \leftarrow \mathtt{fact}(\mathtt{x}); \\ \mathtt{a}(\mathtt{x}) \leftarrow (\mathtt{x} == 0); \\ \mathtt{b}(\mathtt{x}) \leftarrow 1; \\ \mathtt{c}(\mathtt{x}) \leftarrow \mathtt{x} - 1; \\ \mathtt{d}(\mathtt{x}) \leftarrow \mathtt{x}; \\ \mathtt{h}(\mathtt{u}, \mathtt{v}) \leftarrow \mathtt{u} * \mathtt{v}; \end{cases}$$

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$$\sigma_2 \begin{cases} \mathtt{f}(\mathtt{x}) \leftarrow (\mathtt{rev}\,\mathtt{x}); \\ \mathtt{a}(\mathtt{x}) \leftarrow (\mathtt{x} == \mathtt{nil}); \\ \mathtt{b}(\mathtt{x}) \leftarrow \mathtt{nil}; \\ \mathtt{c}(\mathtt{x}) \leftarrow (\mathtt{tail}\,\mathtt{x}); \\ \mathtt{d}(\mathtt{x}) \leftarrow [(\mathtt{head}\,\mathtt{x})]; \\ \mathtt{h}(\mathtt{u}, \mathtt{v}) \leftarrow (\mathtt{append}\,\mathtt{v}\,\mathtt{u}); \end{cases}$$

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  1. associative
  2. has unity, i.e. `h(x ,*) = h(* ,x) = x`
- The Paradigm:
  1. recognize a pattern $(\Sigma, \Sigma^{'}, \mathcal{X})$
  2. validate such pattern.
  3. recognize whether or not a pattern is applicable to a given program.
  4. organize a system applying automatically those patterns.

Huet's Proposal.

Let $(\Sigma, \Sigma^{'}, \mathcal{X})$ be a transformation, and let $\mathcal{P}[t]$ be a program which contains t as subterm. We say the transformation is *applicable* in $\mathcal{P}[t]$ at t if and only if there exists a substitution σ for the free variable of Σ and $\Sigma^{'}$ such that:

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- Replace in the program $\mathcal{P}$, t by $\sigma(\Sigma^{'})$

A problem occurs when for a certain context two different transformations are available, leading to two different programs, this is a well known problem for *Rewriting Systems*. In some cases it will possible to prove that our set of transformations is *confluent*.

Glasgow Haskell [1] Compiler: Compilation by transformation.

Compiler' Structure:

- The front end parses the source, does scope analysis and type inference, and translates the program into a small intermediate language called the *Core Language*.

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- The middle consists of sequences of Core to Core [2] transformations
- The back end translates the resulting Core program into C, whence it is compiled to the machine code.

---

[1] Haskell is a non-strict, typed, pure functional language
[2] Most of the "optimizations" appears at this level

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```
data Boolean = True | False

data List a = Nil | Cons a (List a)

data Tree a = Leaf a | Branch (Tree a) (Tree a)
```

Glasgow Haskell Compiler: Compilation by transformation.

"Desugarer":

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"Desugarer":

Haskell Code	$\Longrightarrow$	**Core Code**
`f (sin x ) y`		`let v = sin x in f v y`
`if C E1 E2`		`case C of {True -> E1; False -> E2}`

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Deforestation/Fusion laws are program transformation by means of which intermediate data structures can be eliminated.

The interest in this particular technique is due to the fact that programs are often implemented in a compositional fashion, using intermediate data structures to connect such a components. This compositional style is suitable for modular programming, however may be inefficient both time and space.

Deforestation/fusion

From an example: "Sum of the square of n integers"

```
Version(1) Modular
```

```
SquareList ::  [Int] -> [Int]
SquareList [] = 0
SquareList (x :xs ) = [x^2] ++ SquareList(xs)
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SumSqr ::  [Int] -> Int
SumSqr = Sum ∘ SquareList
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Version(2) UnModular

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Deforestation/fusion

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SumSquare ::  [Int] -> Int
SumSquare [] = 0
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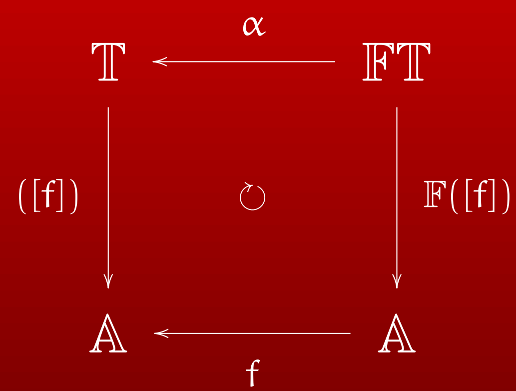
```

A generalization? Where could we get it?

Deforestation/fusion

Answer: Category theory!!, datatypes [3] as initial algebra for a given functor.



[3] $\alpha : \mathbb{F} \leftarrow \mathbb{F}\mathbb{T}$, is called the *initial algebra* for $\mathbb{F}$. Exists a unique $(\![f]\!)$ called *catamorphism*

Deforestation/fusion

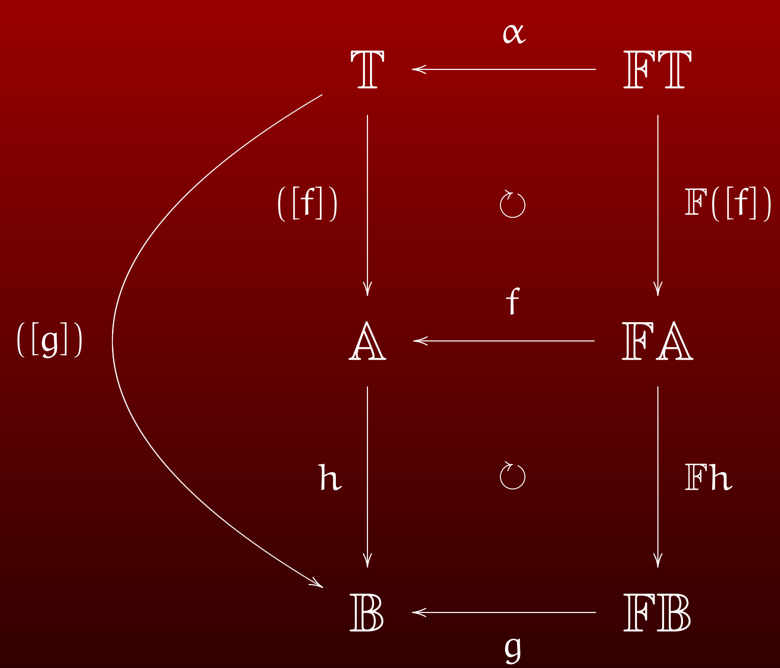
Fusion Law

- $(\![\alpha]\!) = \mathrm{id}$ and $h \circ (\![f]\!) = (\![g]\!) \Leftarrow h \circ f = g \circ \mathbb{F}h.$

Deforestation/fusion

Fusion Law

- $([\alpha]) = id$ and $h \circ ([f]) = ([g]) \Leftarrow h \circ f = g \circ \mathbb{F}h$.



Deforestation/fusion

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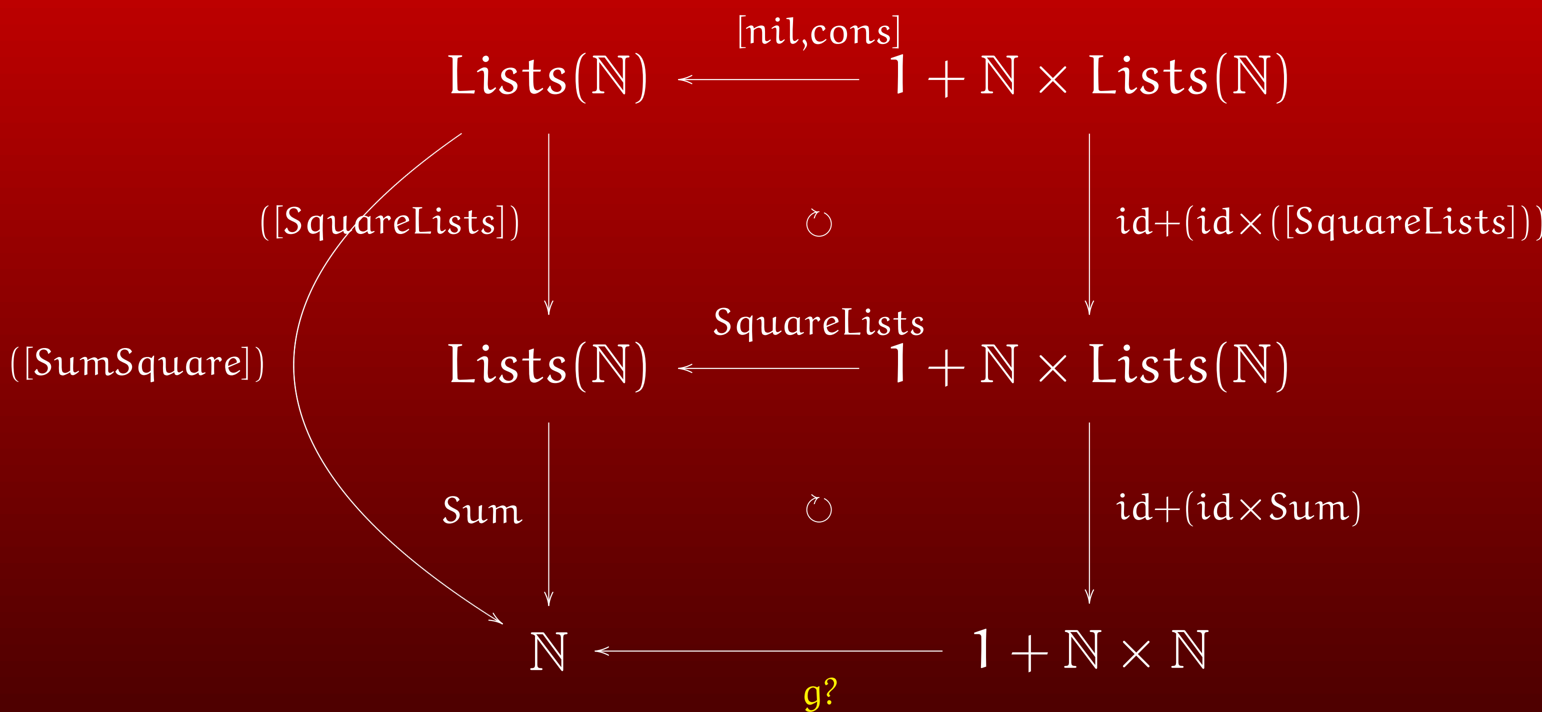

Where $\mathsf{SquareLists} = [\mathsf{nil}, \mathsf{cons}(\_^2, \mathsf{id})]$

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Deforestation/fusion

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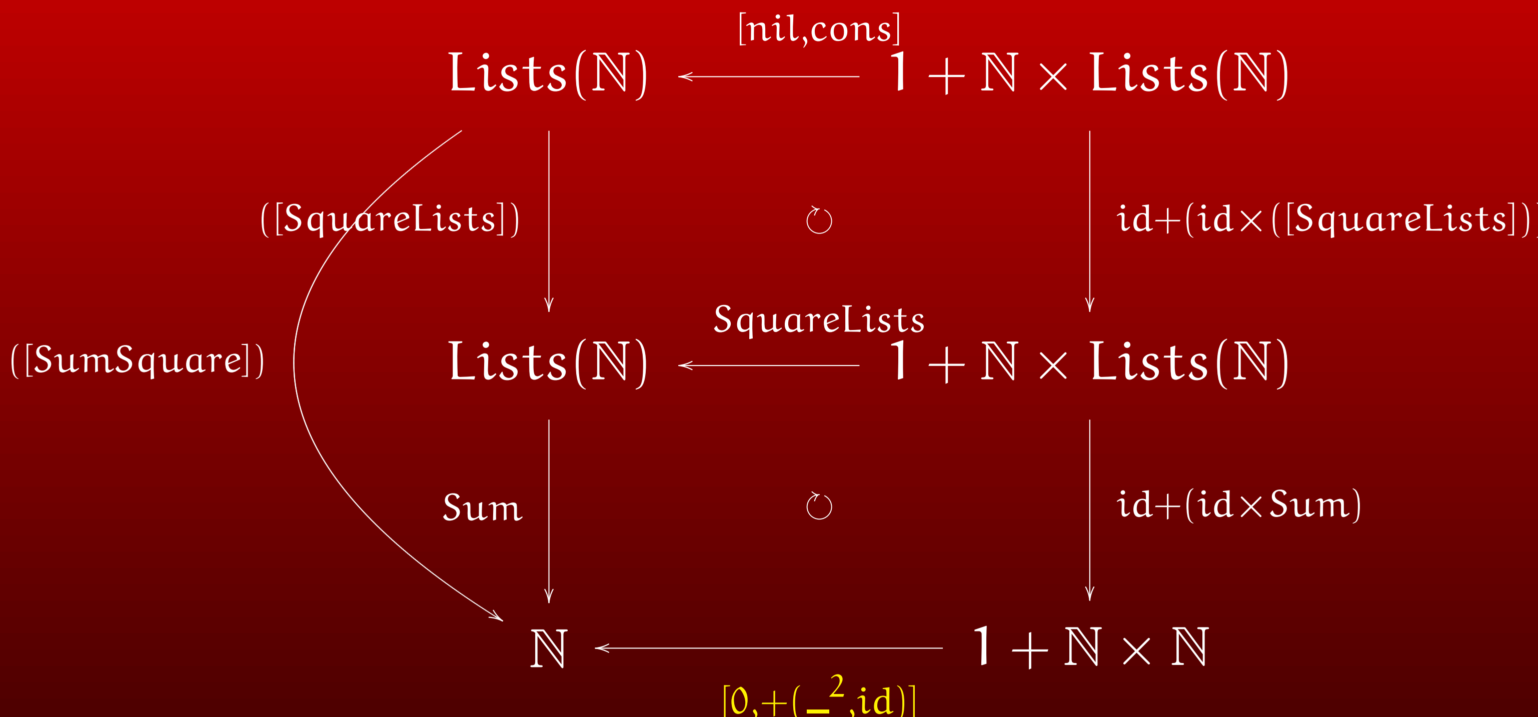

Where $\mathsf{SquareLists} = [\mathsf{nil}, \mathsf{cons}(\_^2, \mathsf{id})]$

Deforestation/fusion

The key: observe that we found an appropriate $g = [0, +(\_^2, id)]$ such that the diagram commute i.e. we answer the question.

Is there some g such that $h \circ f = g \circ \mathbb{F}h$.?

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Ref: **O. de Moor** and **G. Sittampalam**(1999) *Generic Program Transformation* (1999)

Deforestation/fusion

From Example:

$$
\begin{array}{ccc}
\mathsf{Lists}(\mathbb{N}) & \xleftarrow{\mathsf{SquareLists}} & 1 + \mathbb{N} \times \mathsf{Lists}(\mathbb{N}) \\
\Big\downarrow \mathsf{Sum} & \circlearrowright & \Big\downarrow \mathsf{id}+(\mathsf{id}\times\mathsf{Sum}) \\
\mathbb{N} & \xleftarrow[g=[g_0,g_1]]{} & 1 + \mathbb{N} \times \mathbb{N}
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Translated to:

$\mathtt{SquareLists} \Longrightarrow \mathtt{if\ (y\ =\ 1)\ nil\ cons(\ \_^{2},\ id)y}$

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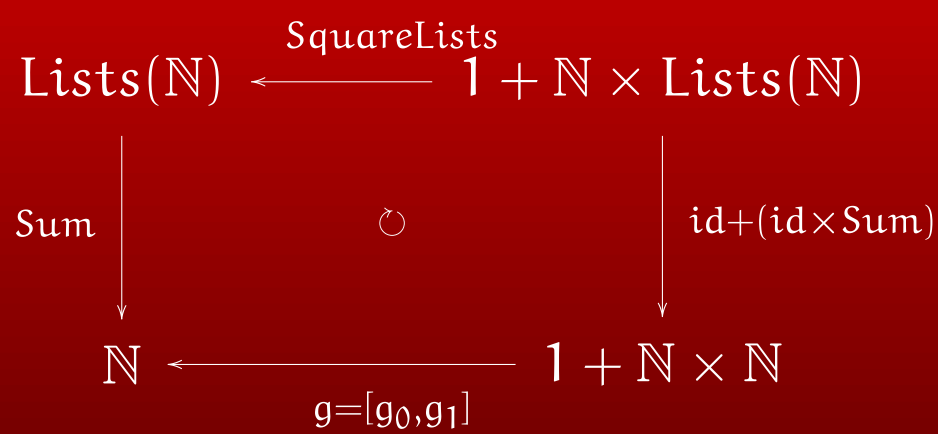

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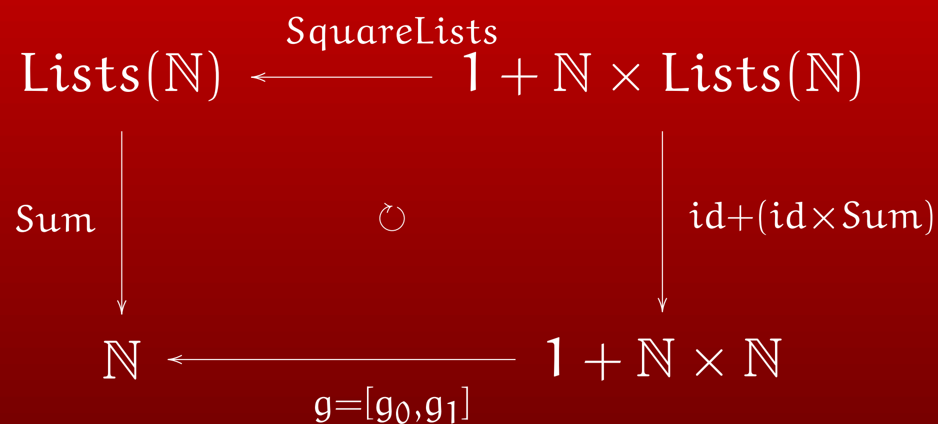

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$\texttt{g} \Longrightarrow \texttt{if (y = 1)}\ g_0\ g_1$

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Higher Order Matching and HOAS

From this it's not hard to see that those programs can be encoded as a lambda terms (HOAS) i.e. the fusion law can be expressed as:

$$(t_{Sum}\ \ t_{SquareLists}) =^{?} (t_g\quad [id, \langle id, t_{Sum}\rangle])$$

Higher Order Matching and HOAS

Results on Matching

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- More coming...

References

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(4) **Simon P. Jones**, **André M. Santos**(1998);
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(5) **O. de Moor** and **G. Sittampalam**(1999);
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(5) **O. de Moor** and **G. Sittampalam**(1999); *Generic Program Transformation.* Proceedings of the 3rd International Summer School on Advanced Functional Programming. Springer Lecture Notes in Computer Science, Vol 1608, pages 116–149.

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