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A Framework for Datatype Transformation

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ABSTRACT

We study one dimension in program evolution, namely the evolution of the datatype declarations in a program. To this end, a suite of basic transformation operators is designed. We cover structure-preserving refactorings, but also structure-extending and -reducing adaptations. Both the object programs that are subject to datatype transformations, and the meta programs that encode datatype transformations are functional programs.

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A Framework for Datatype Transformation

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Abstract

We study one dimension in program evolution, namely the evolution of the datatype declarations in a program. To this end, a suite of basic transformation operators is designed. We cover structure-preserving refactorings, but also structure-extending and -reducing adaptations. Both the object programs that are subject to datatype transformations, and the meta programs that encode datatype transformations are functional programs.

1 Introduction

We study operators for the transformation of the datatype declarations in a program. The presentation will be biased towards the algebraic datatypes in Haskell, but the concepts are of relevance for many typed declarative languages, e.g., Mercury and SML, as well as frameworks for algebraic specification or rewriting like ASF+SDF, CASL, Elan, and Maude. Our transformations are rather syntactical in nature as opposed to more semantical concepts such as data refinement. Our transformations contribute to the more general notion of *functional program refactoring* [TR01].

The following introductory example is about extracting a new datatype from constructor components of an existing datatype. This is illustrated with datatypes that represent the syntax of an imperative language. The following extraction identifies a piece of syntax to enable its reuse in later syntax extensions:

-- Datatypes with focus on two constructor components

```
data Prog    = Prog ProgName [Dec] [Stat]
data Dec     = VDec Id Type
data Stat    = Assign Id Expr | If Expr Stat Stat | ...
```

-- After extraction of [Dec] [Stat] to constitute a new datatype Block

```
data Prog    = Prog ProgName Block
data Block   = Block [Dec] [Stat]
```

In the present paper, we describe the design of a framework for datatype transformations including the operators for the above extraction. In Sec. 2, we identify all the concerns addressed by the framework. In Sec. 3, we describe all the basic operators for datatype transformations. In Sec. 4, these operators are lifted from datatypes to complete programs. Related work is discussed in Sec. 5. The paper is concluded in Sec. 6.

2 Concerns in datatype transformation

The central contribution of the present paper is a simple, well-defined, and ‘editing-complete’ suite of operators for datatype transformations. Before we embark on this suite, we identify the concerns addressed by our approach:

- Datatype transformations via scripting or interactive tool support.
- Well-defined primitives for datatype transformations.
- Generic meta-programming for conciseness of datatype transformations.
- Flexible means of referring to fragments of interest in datatype transformations.

We will now discuss these concerns in some depth.

2.1 *Scripting vs. interactive tool support*

From the point of view of a programmer, datatype transformations should be founded on intuitive scenarios for adaptation. To actually perform (datatype) transformations, there are two modes of operation. The first mode is *scripting*: the programmer encodes the desired transformation as an expression over basic or higher-level operators. The second mode is *interactive* transformation based on a corresponding GUI. The benefits of an interactive tool are rather obvious. Such a tool is useful to issue a transformation on the basis of an operator-specific dialogue, and to provide a tailored list of options for transformations that make sense in a given context. A crucial benefit of interactive transformation is that the GUI can be used to provide feedback to the programmer: Which locations were changed? Where is the programmer’s attention needed to complete the issued transformation scenario? The apparent benefits of scripting such as the opportunities to revise transformations and to replay them can be also integrated into an interactive setting.

In Fig. 1, we illustrate the interactive treatment of the introductory example using our prototypical tool *TH* — *Transform Haskell*. As the snapshot indicates, we use a designated *fold* dialogue to perform the extraction of the piece of syntax. (Folding is the basic transformation underlying extraction.) This dialogue combines several transformation steps and side conditions in a convenient way. The figure shows the following situation. The user has selected two consecutive types “[Dec] [Stat]” and initiated the *fold* dialogue. The user has also typed in “Block” in the “type name” field. The introduction check-box is marked automatically since the given type name does not yet exist. The user has also selected the “kind” radio-button to be “data” and filled in “Block” in the “cons name” field. After this, the user would press “Replace” to make the change. If there had been more than one occurrence, the user could replace them all with “Replace All”, or step through all occurrences with “Next”, and replace only specific ones with “Replace” as with ordinary *find and replace* in text editors.

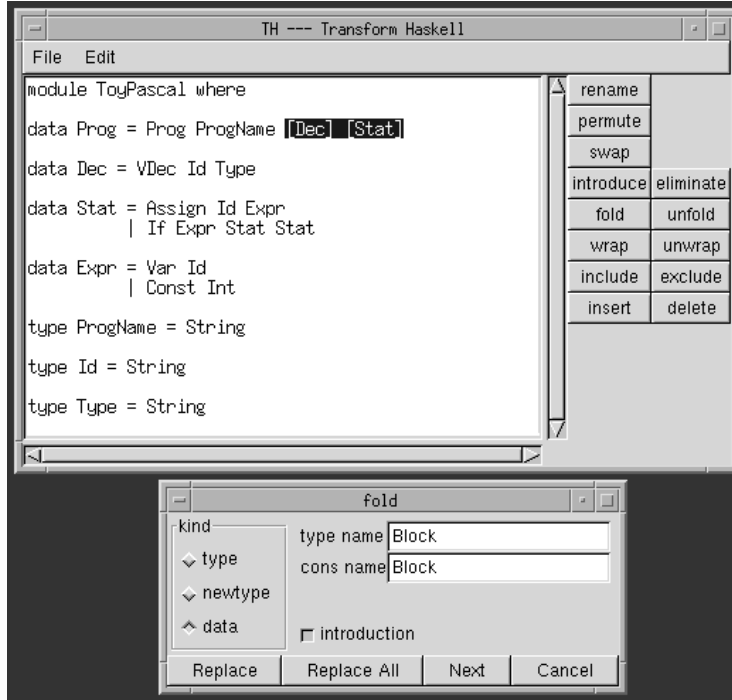


Fig. 1. A snapshot related to the interactive treatment of the introductory example

Here is an open-ended list of further common transformation scenarios:

- Renaming type and constructor names.
- Permuting type arguments and constructor components.
- The dual of extracting datatypes, i.e., inlining datatypes.
- Including a constructor declaration together with associated functionality.
- Excluding a constructor declaration together with associated functionality.
- Inserting a constructor component together with associated functionality.
- Deleting a constructor component together with associated functionality.

2.2 *Well-defined transformation primitives*

The core asset of our framework is a suite of *basic* operators, which can be either used as is, or they can be completed into more complex, *compound* transformations. In the design of this suite, we reuse design experience from a related effort on grammar adaptation [Läm01]. Indeed, there is an obvious affinity of grammar transformations and datatype transformations. A challenging problem that we did not need to address in this previous work, is the completion of datatype transformations to apply to entire (functional) programs in which evolving datatypes reside.

We list the required properties of our basic transformation operators:

Correctness Mostly, we insist on ‘structure preservation’, that is, the resulting datatype is of the same shape as the original datatype. This is enforced by the pre- and postconditions of the operators.

Completeness The operators are ‘editing-complete’, that is, they capture all scenarios of datatype evolution that are otherwise performed by plain text editors. Semantics-preserving adaptations are defined in terms of disciplined primitives.

Orthogonality The operators inhabit well-defined, non-overlapping roles. Higher-level scenarios for interactive transformation are derivable. Operators for datatype transformations are complementary to expression-level transformations.

Locality The basic operators operate on small code locations as opposed to ‘global’ or ‘exhaustive’ operators, which iterate over the entire program. Note that some operators are necessarily exhaustive, e.g., an operator to rename a type name.

Implementability The operators are implemented as syntactical transformations that are constrained by simple analyses to check for pre- and postconditions, but which otherwise do not necessitate any offline reasoning.

Universality While the present paper focuses on datatype transformations, the principles that are embodied by our operators are universal in the sense that they also apply to other abstractions than datatypes, e.g., functions or modules.

We do not list these properties to announce a formal treatment. This would be very challenging as we opt for the complex language setup of Haskell. The above properties provide merely a design rationale. A formal approach is an important subject for future work, but it does not contribute anything to the narrow goal of the present paper: to compile an inventory of the basic roles in datatype transformation.

2.3 *Generic meta-programming*

We implement transformation operators and compound meta-programs in Haskell. We reuse a publicly available abstract syntax for Haskell.¹ We rely on generic programming techniques to perform meta-programming on the non-trivial Haskell syntax in Haskell. We use the Strafunski-style² of generic programming that allows us to complete functions on specific syntactical sorts into generic traversals that process subterms of the specific sorts accordingly. This style of meta-programming is known to be very concise because one only provides functionality for the types and constructors that are immediately relevant for the given problem.

All our datatype transformations are of type *Trafo* which is defined as follows:

```
type Trafo = HsModule → Maybe HsModule
```

That is, a datatype transformation is a partial function on *HsModule* — the abstract syntactical domain for Haskell modules. Partiality is expressed by means of the *Maybe* type constructor that wraps the result type. Partiality is needed to model side conditions.

In Fig. 2, we illustrate generic meta-programming by giving the definition of a simple operator for replacing type names. The specification formalises the fact that

¹ The used abstract syntax is part of the Haskell Core Libraries — in the `haskell-src` package.

² <http://www.cs.vu.nl/Strafunski/>

Replace a type name

```
replaceTypeId :: TypeId → TypeId → Trafo
replaceTypeId n n' = full_tdTP (ad hocTP (ad hocTP idTP declSite) refSite)
```

where

Transform declaring occurrences of type names

```
declSite :: HsDecl → Maybe HsDecl
declSite (HsTypeDecl l n0 ps t) | n0 ≡ n      = return (HsTypeDecl l n' ps t)
declSite (HsDataDecl l c n0 ps cds d) | n0 ≡ n = return (HsDataDecl l c n' ps cds d)
declSite (HsNewTypeDecl l c n0 ps cd d) | n0 ≡ n = return (HsNewTypeDecl l c n' ps cd d)
declSite decl = return decl
```

Transform using occurrences of type names

```
refSite :: HsType → Maybe HsType
refSite (HsTyCon (UnQual n0)) | n0 ≡ n = return (HsTyCon (UnQual n'))
refSite tpe = return tpe
```

Fig. 2. Specification of the replacement operation underlying renaming of type names

type names can occur in two kinds of locations: either on a declaration site, when we declare the type, or on a using site, when we refer to the type in a type expression. So we need to synthesise a transformation which pays special attention to the syntactical domains for declaring and using sites. Indeed, in the figure, there are *two* type-specific ‘ad-hoc’ cases which customise the identity function *idTP*. In the given context, we choose the traversal scheme *full_tdTP* for ‘full top-down traversal in Type-Preserving manner’. This way, we will reach each node in the input tree to transform type names on declaring and using sites. The operator *replaceTypeId*, by itself, is a total function. (So the *Maybe* in its type is not really needed here.) Partiality would be an issue if we derived an operator for renaming type names. This necessitates adding a side condition to insist on a fresh new name.

2.4 Means of referring to fragments of interest

Both the basic operators for datatype transformation but also actual transformation scenarios in scripts or in interactive sessions need to refer to program fragments of interest. Recall our introductory example. Extracting a type necessitates referring to the constructor components that are meant to constitute the new type. In our framework, we use three ways to refer to fragments of interest:

Focus markers on subterms This approach is particularly suited for interactive transformations. Here, relevant fragments can be directly marked. In Fig. 3, we extend Haskell’s abstract syntax to include term constructors for focusing on relevant fragments in datatype transformations. That is, we are prepared to focus on names of types, on type expressions, and on lists of constructor components.

Selectors of subterms This approach is particularly suited for scripting transformations. Selectors for Haskell’s type expressions are defined in Fig. 4. The three forms of *TypeSel* represent the three kinds of declarations that involve types. The helper *TypeSel'* allows to select any part of a given type expression.

Focus on names

```
data HsName = ... | HsNameFocus HsName
```

Focus on type expressions

```
data HsType = ... | HsTypeFocus HsType
```

Focus on lists of constructor components

```
data HsConDecl = HsConDecl SrcLoc HsName [ HsFocusedBangType ]
              | HsRecDecl SrcLoc HsName [(HsName, HsBangType)]
data HsFocusedBangType = HsUnfocusedBangType HsBangType
                       | HsFocusedBangType [HsBangType]
```

Fig. 3. Kinds of focus for datatype transformation

```
data TypeSel = AliasRef TypeId TypeSel' -- Refer to a type alias
            | ConRef ConPos TypeSel'   -- Refer to a constructor component
            | SigRef [FunId] TypeSel'   -- Refer to a function signature

data TypeSel' = SelStop -- Reference stops here
              | SelDom TypeSel' -- Refer to domain of function type
              | SelCod TypeSel' -- Refer to co-domain of function type
              | SelIth ParaPos TypeSel' -- Refer to products component
              | SelFun TypeSel' -- Refer to type constructor
              | SelArg TypeSel' -- Refer to type argument

type TypeId = HsName -- Refer to a type
type ConId = HsName -- Refer to a constructor
type FunId = HsName -- Refer to a function name
type ConPos = (ConId, ParaPos) -- Refer to a component of a constructor
type ParaPos = Int -- Refer to a parameter position
data HsName = ... -- Syntactical sort for all kinds of names
```

Fig. 4. Selectors that refer to type expressions, and others

Predicates on subterms Such predicates typically constrain the type of a term or the top-level pattern. This approach is particularly suited for the repeated application of a transformation to different focuses that match a given predicate.

There are ways to mediate between these different ways of referring to subterms. For example, given a term with a focus marker on a type expression, one can compute the selector that refers to the focused subterm. Given a predicate on type expressions, one can compute the list of all selectors so that an operator that is defined on selectors can be used with predicates as well. Finally, given a selector, one can also add the corresponding focus marker in the input at hand.

3 Basic operators for datatype transformation

We will now describe the themes that constitute our operator suite:

- Renaming type and constructor names.
- Permutation of type parameters and constructor components.
- Swapping types on use sites.
- Introduction vs. elimination of type declarations.
- Folding vs. unfolding of type declarations.

Sample input datatype	
<code>data ConsList a</code>	<code>= Nil Cons a (ConsList a)</code>
Renamed and permuted datatype	
<code>data SnocList a</code>	<code>= Lin Snoc (SnocList a) a</code>

Fig. 5. Illustration of renaming and permutation

<code>renameTypeId :: TypeId → TypeId → Trafo</code>	-- Rename a type declaration
<code>renameConId :: ConId → ConId → Trafo</code>	-- Rename a constructor
<code>permuteTypeId :: TypeId → [ParaPos] → Trafo</code>	-- Permute type parameters
<code>permuteConId :: ConId → [ParaPos] → Trafo</code>	-- Permute constructor components

Fig. 6. Operators for renaming and parameter permutation

<code>renameTypeId (HsIdent "ConsList") (HsIdent "SnocList")</code>	<code>'seqTrafo'</code>
<code>renameConId (HsIdent "Nil") (HsIdent "Lin")</code>	<code>'seqTrafo'</code>
<code>renameConId (HsIdent "Cons") (HsIdent "Snoc")</code>	<code>'seqTrafo'</code>
<code>permuteConId (HsIdent "Snoc") [2,1]</code>	

Fig. 7. Script for the scenario in Fig. 5

- Wrapping vs. unwrapping of constructor components.
- Inclusion vs. exclusion of entire constructor declarations.
- Insertion vs. deletion of constructor components.

As this list makes clear, we group an operator with its inverse such as in “folding vs. unfolding”, unless the operator can be used to inverse itself. This is the case for renaming, permutation, and swapping. The operators from the first six groups are (almost) *structure-preserving*. The last two groups deal with *structure-extending* and *-reducing transformations*. We will now explain the operators in detail including illustrative examples. We will only explain the effect of the operators on datatype declarations while we postpone lifting the operators to the level of complete programs until Sec. 4.

3.1 Renaming and permutation

Let us start with the simplest datatype refactorings one can think of. These are transformations to consistently rename type or constructor names, and to permute parameters of type and constructor declarations. In Fig. 5, a simple example is illustrated. We rename the type name *ConsList*, the constructor names *Nil* and *Cons*, and we permute the two parameter positions of *Cons*. The resulting datatype specifies a *SnocList* as opposed to the *ConsList* before.

In Fig. 6, we declare the operators for renaming names and permuting parameter lists. In Fig. 7, we include the script that encodes the *ConsList*-to-*SnocList* sample as a sequence of basic renaming and permuting transformations. To this end, we assume a sequential composition operator *seqTrafo* for datatype transformations. (In the script, *seqTrafo* is used as an infix operator ‘*seqTrafo*’.)

```

data HsDecl = ... -- Syntactical sort for (type) declarations
introTypes  :: [HsDecl] → Trafo -- Introduction of type declarations
elimTypes   :: [TypeId] → Trafo -- Elimination of type declarations

```

Fig. 8. Operators for introduction and elimination of datatypes

```

type TypeHdr = (TypeId, [TypeVar]) -- Header (LHS) of type declaration
type TypeVar = HsName -- Type variables
foldAlias    :: TypeSel → TypeHdr → Trafo -- Folding the referred type
unfoldAlias :: TypeSel → Trafo -- Unfolding the referred type

```

Fig. 9. Operators for folding and unfolding

3.2 Introduction vs. elimination

The next group of operators deals with the introduction and elimination of type declarations (see Fig. 8). Introduction means that the supplied types are added while their names must not be in use in the given program. Elimination means that the referenced types are removed while their names must not be referred to anymore in the resulting program. The two operators take *lists* of types as opposed to single ones because types can often only be introduced and eliminated in groups, say mutually recursive systems of datatypes. All kinds of type declarations make sense in this context: aliases, newtypes, and proper datatypes. The operators for introduction and elimination are often essential in compound transformations. This will be illustrated below when we reconstruct the introductory example in full detail (see Sec. 3.4).

3.3 Folding vs. unfolding

Instantiating the folklore notions of unfolding and folding for datatypes basically means to replace a type name by its definition and vice versa. Extra provisions are needed for parameterised datatypes. The prime usage scenarios for the two operators are the following:

- *extraction* = *introduction* of a type followed by its *folding*.
- *inlining* = *unfolding* a type followed by its *elimination*.

To give an example, the introductory example basically *extracts* the structure of imperative program blocks. To actually reconstruct this example, we need a few more operators. So we postpone scripting the example (see Sec. 3.4).

The operators for folding and unfolding are declared in Fig. 9. The operators make a strict assumption: the type which is subject to folding or unfolding is necessarily a type alias as opposed to a proper datatype. This assumption simplifies the treatment of the operators considerably since type aliases and their definitions are equivalent by definition. Extra operators for so-called wrapping and unwrapping allow us to use proper datatypes during folding and unfolding as well. This will be addressed below. In the type of the *foldAlias* operator, we do not just provide a type

type <i>ConRange</i>	=	(<i>ConPos</i> , <i>Int</i>)	-- Refer to consecutive components
group <i>ConRange</i>	::	<i>ConRange</i> → <i>Trafo</i>	-- Group constructor components
ungroup <i>ConPos</i>	::	<i>ConPos</i> → <i>Trafo</i>	-- Inline product
alias2newtype	::	<i>TypeId</i> → <i>ConId</i> → <i>Trafo</i>	-- Turn type alias into newtype
newtype2data	::	<i>TypeId</i> → <i>Trafo</i>	-- Turn newtype into datatype
data2newtype	::	<i>TypeId</i> → <i>Trafo</i>	-- Turn datatype into newtype
newtype2alias	::	<i>TypeId</i> → <i>Trafo</i>	-- Turn newtype into type alias

Fig. 10. Operators for wrapping and unwrapping

0. Original syntax			
data <i>Prog</i>	=	<i>Prog ProgName</i> [<i>Dec</i>] [<i>Stat</i>]	
data <i>Dec</i>	=	<i>VDec Id Type</i>	
data <i>Stat</i>	=	<i>Assign Id Expr</i> <i>If Expr Stat Stat</i>	
data <i>Expr</i>	=	<i>Var Id</i> <i>Const Int</i>	
1. After grouping [<i>Dec</i>] and [<i>Stat</i>]			
data <i>Prog</i>	=	<i>Prog ProgName</i> (<u>[<i>Dec</i>], [<i>Stat</i>]</u>)	
2. After introduction of <i>Block</i> to prepare folding			
data <i>Prog</i>	=	<i>Prog ProgName</i> ([<i>Dec</i>], [<i>Stat</i>])	
type <i>Block</i>	=	([<i>Dec</i>], [<i>Stat</i>])	
3. After folding away the type expression ([<i>Dec</i>], [<i>Stat</i>])			
data <i>Prog</i>	=	<i>Prog ProgName</i> <u><i>Block</i></u>	
type <i>Block</i>	=	([<i>Dec</i>], [<i>Stat</i>])	
4. After turning <i>Block</i> into a proper datatype with the constructor <i>Block</i>			
data <i>Prog</i>	=	<i>Prog ProgName</i> <i>Block</i>	
data <i>Block</i>	=	<u><i>Block</i> ([<i>Dec</i>], [<i>Stat</i>])</u>	
5. After ungrouping the product ([<i>Dec</i>], [<i>Stat</i>])			
data <i>Prog</i>	=	<i>Prog ProgName</i> <i>Block</i>	
data <i>Block</i>	=	<u><i>Block</i> [<i>Dec</i>] [<i>Stat</i>]</u>	

Fig. 11. Illustration of wrapping, unwrapping, and extraction

name but also a list of type variables (cf. helper type *TypeHdr*). This is needed for parameterised datatypes, where we want to specify how the free type variables in the selected type expression map to the argument positions of the type alias.

The preconditions for the operators are as follows. In the case of *foldAlias*, we need to check if the referenced type expression and the right-hand side of the given alias declaration coincide. In the case of unfolding, we need to check that the referenced type expression corresponds to an application of a type alias.

3.4 Wrapping vs. unwrapping

We will now consider operators that facilitate certain forms of wrapping and unwrapping of datatype constructors (see Fig. 10). There are operators for grouping and ungrouping, that is, to turn consecutive constructor components into a single component that is of a product type, and vice versa. There are also operators to mediate between the different kinds of type declarations, namely type aliases, newtypes and datatypes. This will allow us to toggle the representation of datatypes in basic ways. As a result, the normal forms assumed by other operators can be established; recall, for example, the use of type aliases in folding and unfolding. This separation of concerns serves orthogonality.

```

groupConRange ((HsIdent "Prog", 2), 2)                                'seqTrafo'
introTypes [HsTypeDecl noLoc "Block" []]
(HsTyTuple [
  HsTyApp (HsTyCon (UnQual (HsIdent "List")))
  (HsTyCon (UnQual (HsIdent "Dec"))),
  HsTyApp (HsTyCon (UnQual (HsIdent "List")))
  (HsTyCon (UnQual (HsIdent "Stat")))]])                                'seqTrafo'
foldAlias (ConRef (HsIdent "Prog", 2) SelStop) ((HsIdent "Block"), []) 'seqTrafo'
alias2newtype (HsIdent "Block") (HsIdent "Block")                    'seqTrafo'
newtype2data (HsIdent "Block")                                         'seqTrafo'
ungroupConPos ((HsIdent "Block"), 1)

```

Fig. 12. Script for the scenario in Fig. 11

data <i>Maybe</i>	<i>a</i> = <i>Nothing</i> <i>Just</i> <i>a</i>	
data <i>Maybe'</i>	<i>a</i> = <i>Nothing'</i> <i>Just'</i> <i>a</i>	
data <i>Maybe'</i>	<i>a</i> = <i>Nothing'</i> <i>Just'</i> <i>a</i>	<i>(Maybe' a)</i>
data <i>ConsList</i>	<i>a</i> = <i>Nil</i> <i>Cons</i> <i>a</i> (<i>ConsList</i> <i>a</i>)	

Fig. 13. Illustration of the generalisation of *Maybe* to *ConsList*

In Fig. 11, we show the steps that implement the introductory example. As one can see, we basically implement extraction, but extra steps deal with grouping and ungrouping the two components subject to extraction. Also, the extracted type should be a proper datatype as opposed to a type alias (see transition from 3. to 4.). For completeness' sake, the transformation script is shown in Fig. 12. The script precisely captures the steps that underly the interactive transformation in Fig. 1.

Some of the operators are not completely structure-preserving, that is, strictly speaking, the structures of the datatypes before and after transformation are not fully equivalent. For example, a newtype and a datatype are semantically distinguished, even if the defining constructor declaration is the very same. (This is because a constructor of a datatype involves an extra lifting step in the semantical domain, i.e., there is an extra 'bottom' element.) The operators for grouping and ungrouping also deviate from full structure preservation.

3.5 Swapping types on use sites

We will now deal with transformations that eliminate or establish type distinctions by what we call *swapping* types on use sites. In Fig. 13, we illustrate a typical application of swapping. In the example, we want to generalise the standard datatype *Maybe* to allow for lists instead. In fact, we do not want to change the general definition of the library datatype *Maybe*, but we only want to change it on one use site (not shown in the figure). This is where swapping helps: as an intermediate step, we can replace *Maybe* on the use site by a newly introduced datatype *Maybe'* with equivalent structure. The figure illustrates how subsequent adaptations derive

```

type DataNames    = (TypeId, [ConId])
type DataUnifier  = (DataNames, DataNames)
swapAlias         :: TypeSel → TypeId → TypeId → Trafo
swapData         :: TypeSel → [DataUnifier] → Trafo

```

Fig. 14. Operators for swapping types on use sites

```

type ConDecl = (ConId, [HsType])    -- Constructor declaration
data HsType  = ...                  -- Syntactical sort for type expressions
includeConDecl :: TypeId → ConDecl → Trafo
excludeConDecl :: ConId → Trafo

```

Fig. 15. Operators for inclusion and exclusion of constructor declarations

```

Syntax as of Fig. 11
data Prog    = Prog ProgName Block
data Block   = Block [Dec] [Stat]
data Dec     = VDec Id Type
data Stat    = Assign Id Expr | If Expr Stat Stat
data Expr    = Var Id | Const Int

After syntax extension by statement blocks
data Stat     = Assign Id Expr | If Expr Stat Stat | SBlock Block

```

Fig. 16. Illustration of constructor inclusion

the *ConsList* datatype from the clone of the *Maybe* datatype. In particular, we add the boxed constructor component.

The swapping operators are declared in Fig. 14. There is one operator for type aliases and another for datatype declarations. In the case of proper datatypes, one needs to match the constructors in addition to just the names of the types. This is modelled by the helper datatype *DataUnifier*. The type of the operator *swapData* clarifies that we are prepared to process a list of *DataUnifiers*. This is necessary if we want to swap mutually recursive systems of datatypes.

3.6 Inclusion vs. exclusion

We now leave the ground of structure-preserving transformations. That is, we will consider transformations where input and output datatypes are not structurally equivalent. In fact, we consider certain ways to extend or reduce the structure of the datatype. The first couple of structure-extending and -reducing transformations is about inclusion and exclusion of constructor declarations (see Fig. 15). These operators are only feasible for proper datatypes and not for type aliases or newtypes. (This is because a type alias involves no constructor at all, and a newtype is defined in terms of precisely one constructor declaration.)

In Fig. 16, we show an example for constructor inclusion. In fact, we just continue the introductory example to make use of the extracted block structure in a language extension for statement blocks. That is, we include a constructor application for *Stat* to capture *Block* as another statement form. This continuation of the

```

insertConComp  ::  ConPos → HsType → Trafo
deleteConComp  ::  ConPos → Trafo

```

Fig. 17. Operators for insertion and deletion of constructor components

```

A datatype for a transition relation/function, and helpers
type TransRel a    =  a → Maybe a
data Maybe a      =  Nothing | Just a
data ConsList a   =  Nil | Cons a (ConsList a)

Introduction of a substitute for Maybe
data Maybe' a     =  Nothing' | Just' a

Swapping Maybe and Maybe' in TransRel
type TransRel a   =  a → Maybe' a

Extension of Maybe' to fit with shape of ConsList
data Maybe' a     =  Nothing' | Just' a (Maybe' a)

Swapping Maybe' and ConsList in TransRel
type TransRel a   =  a → ConsList a

```

Fig. 18. Illustration of component insertion and type swapping

introductory example amplifies the intended use of our operator suite: for program evolution in the sense of datatype refactoring and adaptation.

3.7 Insertion vs. deletion

Inclusion and exclusion of constructor declarations is about the *branching* structure of datatypes. We will now discuss operators that serve for the insertion or deletion of constructor *components* (see Fig. 17). Insertion of a component c into a constructor declaration $C\ c_1 \cdots c_n$ proceeds as follows. Given the target position for the new component, be it $i \leq n + 1$, the new constructor declaration is simply of the form $C\ c_1 \cdots c_{i-1}\ c\ c_i \cdots c_n$. In general, c might need to refer to type parameters of the affected datatype. Deletion of a constructor declaration relies on the identification of the obsolete component.

In Fig. 18, we elaborate on the earlier example for generalising ‘maybies’ to lists (recall Fig. 13). At the top of Fig. 18, we see three datatypes *TransRel*, *Maybe*, and *ConsList*. The idea is indeed to replace *Maybe* by *ConsList* in the using occurrence in *TransRel*. (That is, we want to allow for a function from a to a list of a s instead of a partial function from a to a .) We call this adaptation a generalisation because a list is more general than an optional. In the initial phase of the generalisation of *Maybe*, we disconnect the relevant occurrence of *Maybe* in *TransRel* from other possible occurrences in the program. So we introduce a copy *Maybe'* of *Maybe*, and we perform type swapping so that *TransRel* refers to *Maybe'* instead of the ‘read-only’ *Maybe*. Now we need to make *Maybe'* structurally equivalent to *ConsList*. This amounts to adding a recursive component to the second constructor *Just'*. Then, we can again swap types to refer to *ConsList* in the co-domain of *TransRel*.

4 Datatype transformation meets program transformation

We will now re-iterate over the groups of operators to investigate their impact on functional programs. It would be utterly complex to formalise the link between datatype and program transformation. The mere specification of the transformations is already intractable for a publication because of its size, and the number of details. So we will describe the implied program transformations informally while omitting less interesting details.

4.1 *Renaming*

Type names only occur inside type declarations and type annotations. So there is no need to adapt expressions or function declarations except for their signatures, or the type annotations of expressions. Constructor names can very well occur inside patterns and expressions that contribute to function declarations. Renaming these occurrences is completely straightforward.

4.2 *Permutation*

The permutation of type parameters does not necessitate any completion at the level of function declarations. The permutation of constructor components, however, needs to be realized in patterns and expressions as well. This is particularly simple for pattern-match cases because all components are matched by definition. Hence, we can directly permute the sub-patterns in an affected constructor pattern. Witnessing permutations of constructor components in expression forms is slightly complicated by currying and higher-order style. Instead of permuting components in possibly incomplete constructor applications, we could first get access to all components by ‘ λ -pumping’: given a constructor C with say n potential components according to its declaration, we first replace C by $\lambda x_1 \cdots x_n. C\ x_1 \cdots x_n$ as justified by η -conversion. Then, we witness the permutation by permuting the arguments x_1, \dots, x_n in the pumped-up expression. In the presence of a non-strict language with an evaluation order on patterns, the permutation of constructor components might actually change the behaviour of the program regarding termination. We neglect this problem. We should also mention that it is debatable if the described kind of η -conversion is really what the programmer wants because it obscures the code.

4.3 *Introduction vs. elimination*

Introduction does not place any obligations on the functions defined in the same program. In the case of elimination, we have to ensure that the relevant types are not used by any function. If we assume that all function declarations are annotated by programmer-supplied or inferred signatures, then the precondition for elimination can be checked by looking at these signatures. There is an alternative approach that does not rely on complete type annotations: we check that no constructor of the relevant types is used.

4.4 *Folding vs. unfolding*

The restriction of folding and unfolding to type aliases guarantees that these operators do not necessitate any adaptation of the function declarations. This is simply because interchanging a type alias and its definition is completely structure- and semantics-preserving, by definition. This is extremely convenient: despite the crucial role of the operators for folding and unfolding, they do not raise any issue at the level of function declarations.

4.5 *Wrapping vs. unwrapping*

Grouping and ungrouping These operators are handled using the same overall approach as advocated for the permutation of constructor components. That is, in patterns we witness grouping or ungrouping by inserting or removing the enclosing “(...)”; in expressions, we perform η -conversion to access the relevant components, and then we group or ungroup them in the pumped-up constructor application.

Mediation between newtypes and datatypes These datatype transformations do not imply any adaptations of the functions that involve the datatype in question. (As we indicated earlier, the extra bottom value of a datatype, when compared to a newtype, allows a program to be ‘undefined’ in one more way.)

Newtype to alias migration We simply remove all occurrences of the associated constructor both in pattern and expression forms. We require that the relevant newtype is not covered by any instance declaration of some type class or constructor class. Otherwise, we had to inline these members in a non-obvious way prior to the removal of the constructor. If we neglected this issue, the resulting program either becomes untypeable, or a different instance is applied accidentally, which would be hazardous regarding semantics preservation.

Alias to newtype migration This operator requires a non-trivial treatment for function declarations. The crucial issue is how to know the following:

- What expressions have to be wrapped with the newtype constructor?
- In what patterns does the newtype constructor need to be stripped?

Our approach is as simple as possible. We observe that the new newtype might be used in the declarations of other datatypes. The corresponding patterns and expressions can be easily located and adapted as in the case of permutation, grouping, and ungrouping (recall η -conversion etc.). We also need to adapt function declarations if their argument or result types are known to refer to the relevant alias. This basically means that we need to access the affected arguments and result expressions in all relevant equations to unwrap the arguments and wrap the result expressions. These adaptations are slightly complicated by the fact that the affected type alias can occur in arbitrarily nested locations.

In Fig. 19, we illustrate the effect of the *alias2newtype* operator in the introductory example. We show the top-level interpreter function that maps over the statements

Top-level interpreter function before the illustrative extraction

```
run :: Prog → State ()
run (Prog name decs stats) = mapM interpret stats
```

The same function after extraction

```
run :: Prog → State ()
run (Prog name (Block decs stats)) = mapM interpret stats
```

Fig. 19. Function adaptation triggered by alias-to-newtype migration

Input program

```
type TransRel a = a → Maybe a
data Maybe' a = Nothing | Just a
deadEnd :: TransRel a → a → Bool
deadEnd r a = case r a of Nothing → True
                  Just _ → False
```

Output program

```
type TransRel a = a → Maybe' a
data Maybe' a = Nothing | Just a
deadEnd :: TransRel a → a → Bool
deadEnd r a = case toMaybe (r a) of Nothing → True
                  Just _ → False
```

Induced helper for type swapping

```
toMaybe :: Maybe' a → Maybe a
toMaybe Nothing' = Nothing
toMaybe (Just' a) = Just a
```

Fig. 20. Function adaptation triggered by type swapping

of the program. (The program name and the declarations do not carry any semantics here.) The type of the function *run* exhibits that the meaning of a program is a computation that involves a *State* for the program variables. The adapted version of *run* refers to the extra constructor *Block*, which resulted from extraction.

4.6 Swapping types on use sites

This operator relies on the same techniques as *alias2newtype*. However, instead of wrapping and unwrapping a constructor. We invoke conversion functions that mediate between the two structurally equivalent types. These mediators merely map old to new constructors and vice versa, and hence they are immediately induced by the datatype transformation itself, namely by the *DataUnifiers* passed to the swap operator. This approach implies that we only perform very local changes. The program code will still work on the old datatypes thanks to the mediators.

The impact of swapping types at the function level is illustrated in Fig. 20. We deal with the initial steps of the *Maybe*-to-*ConsList* migration in Fig. 18, where we replace the occurrence of *Maybe* within *TransRel* by a structurally equivalent *Maybe'*. We show an illustrative function *deadEnd* which performs a test if the given transition relation allows for a transition in the presence of a given state *a*. The adapted function *deadEnd* refers to the conversion function *toMaybe* prior to performing pattern matching on the obsolete *Maybe* type.

```

Input program
data Stat = Assign Id Expr | If Expr Stat Stat
interpret :: Stat → State ()
interpret (Assign i e) = envLookup i >>= λr → ...
interpret (If e s1 s2) = reval e >>= λv → ...

Output program
data Stat = Assign Id Expr | If Expr Stat Stat | SBlock Block
interpret :: Stat → State ()
interpret (Assign i e) = envLookup i >>= λr → ...
interpret (If e s1 s2) = reval e >>= λv → ...
interpret (SBlock _) = ⊥

```

Fig. 21. Inclusion of a constructor declaration

4.7 Inclusion vs. exclusion

Intuitively, the inclusion of a constructor should be complemented by the extension of all relevant case discriminations. This normally means to add a pattern-match equation (or a case to a case expression) for the new constructor. Dually, exclusion of a constructor should be complemented by the removal of all pattern-match equations (or cases) that refer to this constructor. In the case of added pattern-match equations, we view the right-hand sides of these equations as a kind of ‘hot spot’ to be resolved by subsequent expression-level transformations. To this end, we use “undefined”, i.e., “ \perp ”, as a kind of to-do marker. Dually, in the case of removed constructors, we also need to replace occurrences of the constructor within expressions by “ \perp ”. When using interactive tool support, these to-do markers are useful to control further steps in a transformation scenario.

In Fig. 21, we progress with our running example of an interpreter for an imperative language. We illustrate the step where blocks are turned into another form of statements. Hence, the shown output program involves a new pattern-match equation that interprets statement blocks. This added equation reflects that the meaning of such blocks is as yet undefined, subject to subsequent adaptations.

4.8 Insertion vs. deletion

Inserting a component into a declaration for a constructor C means that all patterns with C as outermost constructor must be adapted to neglect the added component, and all applications of C must be completed to include “ \perp ” for the added component. Dually, deletion of a component from C means that all applications of C and all patterns with C as outermost constructor need to be cleaned up to project away the obsolete component. Any reference to a pattern variable for the obsolete component is replaced by “ \perp ”. As in the case of permutation and others, η -conversion is needed to actually get access to constructor components in expressions.

In Fig. 22, the insertion of a constructor component is illustrated by continuing the scenario from Fig. 20. The adapted equation of *toMaybe* involves an extended pattern. As the don’t care pattern “ $_$ ” indicates, the definition of *toMaybe* does not make use of the added component. In fact, the definition of the function *deadEnd* does not need to be adapted; it only tests for the availability of a transition step.

```

Output program
type TransRel a = a → Maybe' a
data Maybe' a = Nothing' | Just' a (Maybe' a)
deadEnd :: TransRel a → a → Bool
deadEnd r a = case toMaybe (r a) of Nothing → True
                                     Just _ → False

Induced helper for type swapping
toMaybe :: Maybe' a → Maybe a
toMaybe Nothing' = Nothing
toMaybe (Just' a _) = Just a

```

Fig. 22. Illustration of the insertion of a constructor component

Normally, other functions will start to rely on the richer pattern.

5 Related work

Transformational program development Formal program transformation [BD77] separates two concerns: the development of an initial, maybe inefficient program the correctness of which can easily be shown, and the stepwise derivation of a better implementation in a semantics-preserving manner. Partsch's textbook [Par90] describes the formal approach to this kind of software development. Pettorossi and Proietti study typical transformation rules (for functional and logic) programs in [PP96]. Formal program transformation, in part, also addresses datatype transformation [dRE98], say data refinement. Here, one gives different axiomatisations or implementations of an abstract datatype which are then related by well-founded transformation steps. This typically involves some amount of mathematical program calculation. By contrast, we deliberately focus on the more syntactical transformations that a programmer uses anyway to adapt evolving programs.

Database schema evolution There is a large body of research addressing the related problem of database schema evolution [BK87] as relevant, for example, in database re- and reverse engineering [HTJC93]. The schema transformations themselves can be compared with our datatype transformations only at a superficial level because of the different formalisms involved. There exist formal frameworks for the definition of schema transformations and various formalisms have been investigated [MP97]. An interesting aspect of database schema evolution is that schema evolution necessitates a database instance mapping [BCN92]. Compare this with the evolution of the datatypes in a functional program. Here, the main concern is to update the function declarations for compliance with the new datatypes. It seems that the instance mapping problem is a special case of the program update problem.

Refactoring The transformational approach to program evolution is nowadays called refactoring [Opd92,Fow99], but the idea is not new [ABFP86,GN90]. Refactoring means to improve the structure of code so that it becomes more comprehensible, maintainable, and adaptable. Interactive refactoring tools are being studied and used extensively in the object-oriented programming context [Moo96,RBJ97]. Typical examples of *functional* program refactorings are described in [Läm00], e.g., the introduction of a monad in a non-monadic program. The precise inhabitation of

the refactoring notion for functional programming is being addressed in a project at the University of Kent by Thompson and Reinke; see [TR01]. There is also related work on type-safe meta-programming in a functional context, e.g., by Erwig [ER02]. Previous work did not specifically address datatype transformations. The refactorings for object-oriented class structures are not directly applicable because of the different structure and semantics of classes vs. algebraic datatypes.

Structure editing Support for interactive transformations can be seen as a sophistication of structure editing [RT88,Koo94,KS98]. This link between transformation and editing is particularly appealing for our “syntactical” transformations. Not surprisingly, concepts that were developed for structure editing are related to our work. For example, in [SdM99], primitives of structure editing are identified based on the notion of focus to select subtrees, and on navigation primitives left, right, up and down. Trees, subtrees and paths are here defined as follows:

```

data Tree      = Fork Label [Tree]
type SubTree   = (Path, Tree)
type Path      = [Layer]
type Layer     = (Label, [Tree], [Tree])

```

The t in a subtree (p, t) is the currently selected tree and it is between the left and right trees in the top layer (the head of the p). This approach does not account for the heterogeneous character of language syntaxes, but it shows that the fact if a focus resides in a term can be encoded in types.

6 Concluding remarks

Contribution We identified the fundamental primitives for datatype transformation. These operators are meant to support common scenarios of program adaptation in functional programming, or other settings where algebraic datatypes play a role. In fact, all the identified operators are universal in the sense, that they are also meaningful for other program abstractions than just datatypes, e.g., function declarations. We deliberately focused on adaptations of datatypes because a vast body of previous work addressed fold/unfold transformations for recursive functions. Despite the focus on datatype transformations, we had to consider program transformations that are necessitated by the modification of datatypes. Regarding the executable specification of the operator suite, we adhered to the formula: meta-programs = object-programs = Haskell programs. We employed generic functional programming in the interest of conciseness. We also employed designated means of referring to fragments of interest, e.g., a focus concept.

Partial project failure We are confident that the identified operators are sufficient and appropriate for actual datatype transformations. We have attempted to complement this framework development by actual interactive tool support. We initially thought that using Haskell for this interactive tooling as well would be a good idea. Since the actual transformation operators are implemented in Haskell anyway, and the interactive dialogues need to cooperate with the operator framework to perform analyses, Haskell indeed seems to be the obvious choice. To make a long story

short, there are many GUI libraries for Haskell, but none of them is suitable for developing a sophisticated GUI for interactive program transformation at the moment. It seems that environments for interactive language tools would provide a better starting point, e.g., environments based on attribute grammars [RT88,KS98].

Perspective To cover full Haskell, a few further operators would have to be added to our suite, in particular, operators that support type and constructor classes. We should also pay full attention to some idiosyncrasies of Haskell; cf. refutable vs. irrefutable patterns. Then, there are also transformation techniques that seem to go beyond our notion of program evolution but it is interesting to cover them anyway. We think of techniques like turning a system of datatypes into functorial style, or threading a parameter through a system of datatypes. The ultimate perspective for the presented work is to integrate the datatype transformations into a complete, well-founded, and user-friendly refactoring tool for functional programming along the lines of Thompson’s and Reinke’s research project [TR01]. Another perspective for our research is to further pursue the intertwined character of datatype and program transformations in the context of XML format and API evolution.

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