Deriving program transformations by demonstration

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Abstract—Automatic code transformation in which transformations are tuned for specific applications and contexts are difficult to achieve in an accessible manner. In this paper, we present an approach to build application specific code transformations. Our approach is based on analysis of the abstract syntax representation of exemplars of the essential change to the code before and after the transformation is applied. This analysis entails a sequence of steps to identify the change, determine how to generalize it, and map it to term rewriting rules for the Stratego term rewriting system. The methods described in this paper assume programs are represented in a language-neutral term format, allowing tools based on our methods to be applied to programs written in the major languages used by computational scientists utilizing high performance computing systems.

I. INTRODUCTION

Automated program transformation is a method for changing programs for the purposes of porting, improving, and maintaining code. Such techniques are attractive because they can help prevent the introduction of bugs due to mistakes and the inefficiency of manual, repetitive changes to potentially huge source code bases. In the context of high performance computing, the necessity to perform extensive changes to programs has been brought to the front of developers minds due to the rapid change in architecture and corresponding programming models in petascale and emerging exascale systems. Any assistive technology to aid developers using those systems would improve their working lives.

The practice of refactoring [4], wherein behavior-preserving changes are applied to code, has been well established. This is due in large part to the inclusion of refactoring algorithms in popular tools such as integrated development environments (IDEs). These tools may be inadequate, however, when developers wish to customize transformations for application-specific purposes. Tools such as Stratego [13] that take a term rewriting approach to program transformation encourage customization, providing a domain specific rewriting language for expressing and composing transformations. The cost of this is the exposure of complex rewriting systems that are beyond the scope of knowledge (and often patience) of many programmers. Refactoring tools within IDEs hide this low level pattern matching and term manipulation from the user. Our research focuses on term rewriting-based tools, aiming to reduce the cost of entry to creating transformations. Our goal is to allow rewrite system rules to be generated in a semi-automated fashion with guidance from the user, insulating them as much as possible from the underlying term representation and rewriting mechanics.

The work described in this paper has been inspired by a popular tool called Coccinelle[1]. Coccinelle is used for describing and performing application-specific transformations on C code. The technique that we describe expands upon the concepts introduced by Coccinelle in three ways.

1) Broad language support: we seek to support all languages that are commonly used in computational science in addition to C, such as Fortran and C++.
2) Native language transformation specification: we use the original source language to specify the transformation using compiler directives and code annotations to guide the transformation generation. Coccinelle uses a C-like domain specific language called SmPL for transformation specification.
3) Structural difference driven rule generation: we employ a different algorithm for inferring the rewriting rules that are derived from the transformation specification based on previous work in the area of structural tree comparison for difference identification. The rules that we generate target the Stratego term rewriting system.

A. Motivating example

Consider the following transformation as a motivating example. Changing the way in which data is laid out is a relatively simple optimization that can result in significant performance benefits on modern massively multithreaded architectures [9]. The performance benefits are realized through improved data locality in the transformed code. A common transformation pattern for this sort of optimization transposes a structure of array-based fields into an array of structures containing singleton elements for each field. Implementing this kind of transformation is conceptually simple, but in practice can be quite tedious. In particular, implementations will require modification of at least the
following points within the program: data structure definition, allocation, deallocation, and both direct and indirect access to fields. Even though transformations of the structure definition are easily accomplished by hand, accesses to instances of the structure will appear throughout the source code and will require repetitive application of one or more transformations. These repetitive transformations are the motivator for automation.

B. Approach

Our approach uses a demonstration-based development workflow illustrated in Figure 1. Programmers write small programs that represent the “before” and “after” states of essential parts of the code under the desired transformation. Our tool infers from these demonstrations a set of rewrite rules that will carry out the transformation. The inference operates on a term representation derived from the abstract syntax tree (AST) of the code. Our technique uses a structural differencing algorithm to determine the set of tree edit operations necessary to carry the term representation of the code before the transformation to the term representation of the code after. The rewrite rules inferred by this process are parameterizable by heuristic-driven refinements. Thus, our approach allows for rules to be generalized into patch-like changes, and also to include context around changes that can control where the rule is applied. In this paper we will describe our methodology and algorithmic approach, as well as known limitations of our current implementation and areas of current and ongoing research and development.

II. RELATED WORK

In the last decade, a number of customizable code transformation tools arose based on formal term rewriting methods [2]. Within the context of program transformation, term rewriting is applied by mapping an abstract representation of program code to a general term representation that can be manipulated by a term rewrite system. A generic rewriting engine that implements a specific rewriting system is then applied to combine the term representation of the program with a set of rewriting rules that capture the steps to implement in the overall program transformation. These techniques, while quite powerful and general, impose a significant burden on the programmer to learn the details of the rewriting system — expression of transformations as rewrite rules in a system like Stratego [14] or Maude [6] is challenging. This paper addresses this problem of defining these transformations in a way that reduces the necessary familiarity with the underlying rewrite technology and term representation used to perform the actual transformation.

The concept of program transformation based on some high-level specification is not new. Our work is directly inspired by the Coccinelle [1] program transformation tool for C code. The Coccinelle system uses the concept of a semantic patch to represent transformations using a format similar to that used by the familiar UNIX patch tool. The semantic patch specification language (SmPL [7]) that Coccinelle uses provides a combination of familiar C language syntax combined with additional information to identify metavariables, share metavariables between rules, and sequence rule application. Similar information is required by our tool to guide steps such as transformation generalization and context definition, and we are working to integrate it via structured comments in the language used to specify the before and after transformation code that are input to our tool. In the interim, our prototype implementation requires heuristic parameters to be specified separate from the before and after code specifications. The reason for this is that it allows us to use existing parsing and analysis infrastructure (such as ROSE) to support relevant languages for scientific programmers, with extraction of annotations performed as an analysis phase on the parse tree or AST.

The HERCULES [5] project states very similar goals as the work described in this paper. HERCULES focuses on specifying code patterns and transformations in such a way that they are accessible to the programmer. HERCULES also exposes compiler optimizations to the user of the tool, allowing them to include information to be used at compile time in the tuning process. Our work focuses on the specification of transformations via a patch-like definition of the code before and after the transformation has taken place. We rely on information provided via parameters (and eventually code annotations) similar to those that HERCULES specifies via compiler pragmas to communicate additional information to the transformation tools that cannot be inferred from the patch specification alone. Information about how the programmer expects the patch to be generalized, or to provide context to limit its scope of application, are examples of our use of annotations. The methods that we describe in this paper would complement systems such as HERCULES in adding automation to the process of pattern and transformation specification to lower the cost of entry for programmers unfamiliar with the inner workings of complex compilers or pattern matching systems.
III. METHODOLOGY

Our approach is based on the user providing a minimal input representing a specific example of a change that they wish build a rewrite rule for. Changes are expressed by specifying before and after code snippets that are an example of the change to capture. Adopting a format modeled on the UNIX patch tool, we can compactly view the before and after snippets where lines prefaced with a minus sign (−) exist only in the before code, lines prefaced with a plus sign (+) exist only in the after code, and all other lines appear in both. For example, if one wants to derive a rule to apply the distributive law for multiplication over addition, this could be expressed as:

```c
int x,y,z,a;
- x = a*(y+z);
+ x = a*y + a*z;
}
```

Listing 1. Distributive law of arithmetic.

The goal of the before/after versions of the code is to provide a minimal example that embodies only the change that a rewrite rule should be generated for. We are investigating methods to use annotations (either in the form of compiler pragmas or structured comments) that can communicate additional information that can be used by the rule generation algorithm. In the interim this information exists as parameters provided to our prototype tool. This additional information is necessary to aid in rule generalization, defining appropriate context for changes to be defined within, and defining relationships between multiple changes that result in a sequence of rules that must be applied in a specific sequence.

From this demonstration of the change(s), our algorithm infers one or more rewrite rules that implement the change in a generalized form. For example, a rewrite rule generated by our prototype of the algorithms described in this paper for the distributive example is:

```c
R1 : multiply_op(
    T_1, add_op(T_2, T_3, T_4, _),
    T_4, _)
->
add_op(
    multiply_op(T_1, T_2, T_4, gen_info()),
    multiply_op(T_3, T_4, T_4, gen_info()),
    T_4, gen_info())
```

Listing 2. Distributive law rewrite rule inferred from examples.

A rewrite rule is defined by two patterns (the left hand side to match and the right hand side to replace it with) separated by an arrow (→). In this case, the rule R1 has on its left hand side a term that represents a tree rooted at a multiplication operation, with two children - an arbitrary expression $T_1$, and a tree rooted at an addition operator. The addition operator itself has two children $T_2$ and $T_3$, which represent arbitrary expressions. Additional structure (such as the $T_4$ element) is a consequence of the AST representation that carries additional information related to typing and source locations. On the right hand side of the rule, we see the addition operator has been promoted to the root of the tree, with the multiplication distributed to the children appropriately. The bare underscores that appear in the pattern on the left hand side of the rule correspond to arbitrary subterms that are disregarded and replaced with the special `gen_info()` term. This term is used by the tool that maps the terms back to an AST representation to generate source locations for the AST elements created or moved as part of the transformation.

A. Algorithmic stages

Given an example in which the before and after states of the transformation are expressed, the algorithm for computing rewrite rules is structured in a sequence of steps.

1) **Term Generation**: Code is mapped to a term representation using the Annotated Term (aterm) format [12] used by Stratego/XT. We use the Minitermite tool included with the ROSE compiler framework for term generation.

2) **Structural difference calculation**: Identification of structural differences between the two examples in their term representation. This yields a patch that can be applied to implement precisely the change that was present in the examples.

3) **Difference generalization**: Examples are written in terms of specific program elements (e.g., variable and function names). Generation of more generally applicable structural patterns entails the introduction of metavariables to be used during pattern matching by the rewrite engine. Metavariables act as named “spaces” in the terms in which arbitrary legal subterms can reside, and can be referred to by the metavariable name in rewrite rule patterns.

4) **Context introduction**: Establishment of context allows the rewrite engine to distinguish common term substructures in order to apply the rule at the appropriate place in the tree. For example, function argument lists appear in both declarations and function calls: a transformation may be intended to only apply at call sites will require added context to the argument list to include parent nodes in the AST that represent the function call site. This eliminates unintended pattern matches and rule applications at function declarations.

5) **Rewrite rule generation**: Creation of Stratego rewrite rules. This phase combines traversals of the structures produced by the structural difference computation with information from annotations and parameters that are necessary to relate rules and control their order of application.
The second through fourth steps are the core of this work. The second step is focused on determining precisely what structures are present in both the before and after transformation representation of the program. The abstract representation of a program often contains more explicit detail about the structure of a program than the plaintext representation that the programmer works directly with. By using the source representation to express the code at both ends of a transformation step, the programmer is insulated from the abstract representation, and the relevant structures can be extracted automatically.

The third step is important in deriving abstract patterns to match from the concrete examples provided by the programmer defining the before and after transformation structure. For example, consider the code snippets discussed earlier expressing the distributive law. Looking only at the structural difference between the terms representing these examples, we find that the variables in the expression are bound to specific variable instances (a, x, y, and z). The rewrite rules that implement this change derived directly from the source code would apply only for this exact expression - any other example with other variable names, sub-expressions, or arithmetic operators would fail to pattern match in the rewrite engine.

On the other hand, the programmer may intend to generate a transformation that represents application of the distributive law for expressions of this form with arbitrary legal terms in place of concrete variables (e.g., function calls, sub-expressions, etc...). In this case, we would like to perform a refinement step on the terms corresponding to the structural difference between the examples to replace concrete named variables with metavariables that represent arbitrary legal terms within the arithmetic expression. Generalization is essentially the act of replacing specific AST node instances with named holes in which any legal AST structure can occur.

The fourth step addresses a similar problem, but involving the parent and higher nodes in the tree relative to the detected change. Generalization is primarily concerned with children of the nodes where changes appeared. The parents of a changed node are necessary to establish context such that the scope of matching for the rule is constrained to the subtrees where the change is meaningful. For example, introduction of a statement requires us to define a pattern for the portion of the AST where the code does not yet exist, but will after the rule is applied. This pattern will include the parent node as well as some set of sibling nodes nearby the change in order to give the rewrite system a frame of reference for finding precisely where we wish to make the change. As we will discuss in more detail in Section IV-D, this choice is not well defined and the manner by which we define what constitutes sufficient context to define a rewrite rule pattern is a component of our ongoing research work.

B. Term generation

Everything that we describe in this paper is based on our ability to map programs to and from a term representation that can be analyzed to infer rewrite rules, as well as fed into a rewriting engine such as Stratego in order to apply these rules to transform code. We achieve this term mapping via the ROSE compiler framework\footnote{http://www.rosecompiler.org/} and a tool called Minitermite originally developed as part of the SATIrE (Static Analysis Tool Integration Engine) project\footnote{\cite{cite}}. Minitermite is able to traverse the ROSE Sage AST and map AST nodes to and from a term representation. By taking this approach, we are able to leverage the fact that ROSE supports numerous languages in its Sage AST format and handles the challenging task of parsing and generating code in each supported language. By using ROSE and Minitermite, we are able to bypass much of the tedium of the language front-end and code generation process and focus our algorithms on transformations applied to the generic Sage AST in term form.

IV. ALGORITHMS

In this section we will discuss the algorithms that implement the stages of the rule generator. During processing, the representation of the code changes depending on the operations being performed on it. These representations correspond to data types used to represent the tree structure, which are defined in Haskell for this paper and our corresponding implementation. The initial term representation that is used for the before and after versions of the program is simply a labeled tree in which the root of the term is stored as a label, and subterms are stored as a list of children.

data LabeledTree =
  Node String [LabeledTree]

The algorithm for computing the edit distance between the two trees requires more information to indicate not only what resides within the tree but what edit operations occur at the nodes.

data EditTree =
  ENode String [(EditOp,EditTree)]
  ELeaf LabeledTree

data EditOp = Keep | Delete

The result of the computation is a pair of edit trees representing the sequence of operations necessary to turn each tree into the other. In order to generate rewrite rules that represent the changes between the sides, we must establish a relation between the elements of each edit tree. This relation between each node within the edit tree represents one of four interpretations of a pair of edit operations on a node: the node matches between the two trees, the node does not

\[ \text{data LabeledTree} = \]

\[ \text{Node String [LabeledTree]} \]

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match, the node is not present in the “before” tree but is in the “after” tree, and the node is not present in the “after” tree but is in the “before” tree. Adopting the convention that “before” and “after” correspond to the left- and right-hand sides of the rule respectively, we represent the absence on one side or the other as a hole indicating the side.

data WeaveTree =
  WNode Label [WeavePoint]
  | WLeaf LabeledTree

data WeavePoint =
  Match WeaveTree
  | Mismatch WeaveTree WeaveTree
  | LeftHole WeaveTree
  | RightHole WeaveTree

It is important to note that edit operations are computed from the root towards the children. When a mismatch or hole is detected, no further comparison is attempted below that point. This is why both edit and weave tree nodes have a leaf case from which we hang the original labeled subtree.

A. Structural difference calculation

Rewrite systems operate on graph structures, most often in the form of trees representing the abstract syntax of programs. As such, naive string differencing algorithms (such as edit distance) are not easily applied to compare structured data. We instead started our work using algorithms for computing an edit distance between two tree structures derived from the abstract syntax representation of the code. From the tree distance computation we obtain both an edit distance metric as well as a sequence of edit operations that can be performed to the given trees to transform one into the other. The choice of algorithms for computing such a difference is broad, as the need for reasoning about changes in structured data arises in many contexts beyond program AST understanding such as comparing XML documents [11].

In this work, our goal is to determine for two trees the simplest set of operations necessary to map one to the other. We restrict ourselves to the simple set of edit operations: add, delete or keep. The algorithm that we implemented represents additions implicitly as a hole on one side and a delete operation that is paired with the hole on the other side. Richer sets of edit operations have been studied for representing tree edit distances (such as whole-subtree movement), which often can be represented as a sequence of the simpler add/delete/keep operations. The basis of our work is the algorithm presented by Yang [15] that was used to visualize source differences where the differences were informed by the syntactic structure of the programs.

Yang’s algorithm is similar to previously described algorithms by Tai [10] and Selkow [8], with allowances for the concept of “comparable symbols”. The ability to support comparable symbols allows difference calculations to be made more or less sensitive to parts of the abstract syntax tree that can be considered interchangeable. The use of these flexible comparison operators is an aspect of our ongoing research work. For example, a transformation on a structure that requires precedence of operators to be respected regardless of which operators are present could benefit from an comparison operator that treats binary operators of equal precedence as equivalent.

B. Weaving edit trees

Once we have obtained two EditTree structures from the algorithm, we then wish to determine how the two trees related such edit operations can be associated with the paired before/after AST objects. This algorithm differs from that presented by Yang, as Yang’s work was only concerned with printing the difference between the programs and not maintaining the computed edit structure for further computation. Our algorithm takes the two EditTree structures and yields a single WeaveTree, named such due to its role as representing the two edit trees as essentially overlain and woven together to form a unified tree of edit operations.

Weaving a pair of nodes together requires consideration of the table of possible pairings as shown in Table I. The cases are rather straightforward to break down. The base case (1) states that weaving two empty lists is itself empty. Case 2 handles the situation where we have two matching nodes indicated by paired Keep edit operations. This results in a Match node being created in which the children of the matching nodes are woven together, followed by the remaining siblings of the matched node. Case 3 is the opposite of this in which both nodes are not the same have a Delete edit operation indicating a mismatch. A Mismatch node is created in that case, with the two deleted subtrees attached, followed by the siblings of the mismatching nodes being processed.

Case 4 represents the deletion of an element from the before code when no nodes remain in the after code. This occurs when deleting elements from the end of a list, where the list on the before side would be longer. This results in a RightHole node being created indicating that the right-hand side of the comparison was missing nodes. Case 5 is the symmetric instance of this where the deletion operation appears in the after code, resulting in a LeftHole being created. Cases 6 and 7 are similar, except they appear when the side without the deletion operation still have elements remaining. An example of this occurring would be the deletion or insertion of an element in a list at a position before the end. Finally, cases 8 and 9 are the symmetric error cases that are impossible to encounter in practice but are included to complete the set of patterns to match. Both cases represent the situation in which one side is the empty list, yet the other side has a Keep operation. Keep operations must be paired on both sides since they represent matches between the two trees being compared. Clearly it is not possible
Table I

| Pre-EditTree | Post-EditTree | Woven Tree |
|--------------|---------------|------------|
| 1. [1]       |               |            |
| 2. (Keep tL):restL | (Keep tR):restR | (Match (weave tL tR)):weaveHandle restL restR |
| 3. (Delete tL):restL | (Delete tR):restR | (MisMatch tL' tR'):weaveHandle restL restR |
| 4. (Delete, t):rest | []           | (RightHole t') :weaveHandle rest [] |
| 5. [ ]        | (Delete, t):rest | (LeftHole t') :weaveHandle [] rest |
| 6. (Delete tL):restL | r             | (RightHole tL') :weaveHandle restL r |
| 7. l          | (Delete tR):restR | (LeftHole tR') :weaveHandle l restR |
| 8. [ ]        | (Keep t):rest  | error |
| 9. (Keep t):rest | [ ]          | error |

Weaving operations for edit tree node pairs. The function weaveHandle recursively implements this table. Subtrees with a prime (’) annotation correspond to unmodified LabeledTree instances that are attached to the Woven Tree.

Figure 2. Term without variable reference generalization.

C. Term generalization

The result of computing the structural difference between two programs is a sequence of edit operations in which subtrees are deleted, inserted, or replaced. These edit operations correspond specifically to the ASTs of the input programs and do not generalize without additional processing. Consider again the simple case of the distributive law in which the pre-transformation example is the expression \( x = a \ast (y + z) \). When the right hand side of the assignment is identified as the location of the change by the structural differencing algorithm, we would see a term that has a structure similar to the tree shown in Figure 2. This tree will match not only the desired arithmetic expression structure, but will also require a match to contain the exact variable references as well.

On the other hand, if we use heuristics that define term processing rules such as “all variable reference expressions should be replaced with meta-variables”, then we can create a tree that represents a more general pattern as shown in Figure 3. This generalized pattern then allow any legal subterm to match in place of the metavariables.

Generalization of patterns for rule generation presents two tasks to solve: the algorithm to process the terms and replace substructures with generic patterns, as well as the specification rules that represent legitimate generalizations.

1) Generalization algorithm: The algorithm that we have implemented approaches generalization by establishing terms to seek out in which specific subterms are replaced with metavariables. For example, consider the case where we are seeking to generalize arithmetic expressions to build a pattern that matches on the operator structure and is oblivious to the specific operands (e.g., variable references or function calls). This could be implemented by matching all subtrees that are rooted at one or more arithmetic operators (\( \text{multiply\_op} \), \( \text{add\_op} \), and so on). For each subtree that matches these roots, we could then seek out further subtrees contained within them that are rooted at terms that we wish to replace, such as \( \text{var\_ref\_exp} \) and \( \text{binary\_op\_annotation} \) nodes. These nodes correspond to specific variables being referenced, or metadata that ROSE uses internally to indicate information such as the inferred type of a binary operator. In both cases, if we replace these subtrees with metavariables, then when the original binary operator that triggered the search for those terms is matched, the pattern matcher will focus on the operator structure of the expression and allow arbitrary legal operands to be matched.
2) Term processing specification: We currently specify a generalization as a pair \( g = (R, S) \) where \( R \) is a set of labels corresponding to the roots of subtrees that we wish to traverse in the interest of generalizing. The set \( S \) is the set of labels corresponding to terms within subtrees rooted at an element of \( R \) that we wish to replace with metavariables. All elements of \( R \) are treated as equivalent in their interpretation during generalization. Generalizations are specified via parameters independent of the before/after code, and are represented within our prototype as an ordered sequence \( G = (g_1, g_2, \ldots) \) that dictates their order of application. This allows certain generalizations to be applied before others in the event that the order of application matters. Enforcing the order ensures that their application will be predictable.

D. Context generation

In addition to meta-variable introduction, we also require the introduction of context in the rules. This is most apparent when considering transformations that do not replace AST with new AST parts, but introduce new AST from nothing or delete AST without replacement. Common examples of this include the addition or deletion of a parameter to a function call, statement within a block, or else-clause within a conditional. Context can also be used to control the scope of application for rules that could be applied in undesirable places absent context.

Consider the following case in which a status argument is to be added to a function call. This involves the introduction of the status variable declaration as well as the inclusion of an additional parameter in the function invocation.

```c
void bar(void) {
    int x,y,z;
    + int a;
    - x = foo(y,z);
    + x = foo(y,z,a);
}
```

Listing 3. Addition of a variable declaration and function parameter.

The differencing algorithm will correctly identify that an insertion was performed by identifying a hole in the input tree. Unfortunately, to build a usable rewrite rule, the hole must be given context to allow a pattern to be defined that can be matched. This context can be found by looking at the parents of the AST where the hole appears. The challenge is that the number of AST nodes towards the root of the tree that are required for sufficient context requires some thought. Consider the tree shown in Figure 4 in which a single argument called \( a \) is added to the parameter list for the function call to \( \text{foo()} \).

In this case, we see that the variable reference expression added to the list of arguments is indicated by the dashed line. This line originates from the aterm list node that represents the list of expressions that form the argument list for the function call expression at the root. When traversing the woven tree, the insertion appears as a left-hole indicating that something present in the right hand tree (the post tree) is paired with an absent element in the left hand tree. This is illustrated in Figure 5 in which we see the match weave points for the two arguments that are common to both the pre and post versions of the code.

The question that we are faced with is determining how far up the tree is necessary to build context in order to control where this pattern is matched. For example, without context the rule would simply state that in the absence of any term, insert the variable reference expression. This is clearly wrong, as it is ambiguous and could lead to a proliferation of insertions all over the AST. If we look up at the parent of the inserted AST elements, we see the aterm list. This is slightly better, but still will cause uncontrolled insertion of variable reference expressions all over the program wherever a list containing the other two parameters appears. As we move up the tree, we include more context that narrows down the set of potential pattern matches that will be found by the rewrite engine. In this case, if we are interested in only rewriting function calls, we need to traverse from the hole until we hit an ancestor that is a function call expression.

Specification of context is currently a work in progress. Our current prototype traverses the weave tree from the root and for subtrees whose root is in a prespecified set of labels of interest (e.g., function declarations), we perform further processing. This processing involves determining whether or not these subterms contain hole nodes, determining that code is removed or deleted and requires context to be added to the rule. While this has proven to be useful to generate legitimate rule patterns with sufficient context, we ultimately wish to drive this process not from a set of subtree roots to seek, but information provided with the before/after code specification by the user. This would be consistent with the method used by Coccinelle in the SnPPL language.

E. Stratego rewrite rule generation

The bulk of the work related to rule generation is performed in the previous steps, such as the replacement of terms with metavariables and pairing of pre/post terms that correspond to the left and right hand side of rewrite rules.
The set of term constructors that are necessary for establishing the structure of terms that Stratego will work with will be provided by Minitermite. These term constructors define the legal structure of terms, which must match the structure that Minitermite produces from the ROSE Sage AST. The Sage AST contains a great number of nodes, with a tiny representative subset shown below for illustrative purposes.

**signature**

**sorts** E F A

**constructors**

- gen_info : F
- file_info : S * N * N -> F
- add_op : E * E * A * F -> E
- multiply_op : E * E * A * F -> E

These term constructors establish the set of term sorts that terms are composed of. For example, both gen_info and file_info correspond to term constructors that map AST constructs to concrete source locations, both of which yield the sort F. The binary operators add_op and multiply_op represent AST nodes that appear in arithmetic expressions (with sort E). We can see that the binary operators have associated with them terms of sort F since they have some location within the source files. The full set of sorts and constructors is independent of any specific rule set, but serves as a common definition that are used for any transformation rules generated by our algorithms.

Given this boilerplate, term generation currently is implemented as a simple traversal of the AST terms identified (with generalization and context) by the structural differencing algorithm. The traversal serializes the structures as strings that are aggregated in a Stratego .str specification file. This file is then compiled with the Stratego compiler to yield an executable that consumes programs to be transformed in aterm form, yielding another aterm that Minitermite can then reconstruct as ROSE Sage AST nodes for code generation.

Future work in Stratego rule generation includes potential use of Stratego strategies in order to relate rules and control their order of application. We are specifically looking at how to use program annotations and other directives provided by the user to generate this additional information in the Stratego rule sets beyond that which can be derived from the processed structural differencing computation.

**V. Conclusion**

Automatic code transformation techniques that can be driven by application programmers with minimal knowledge of the underlying transformation and code analysis tools are very important for maintaining and evolving complex simulation codes. The results and techniques that we show in this paper build upon techniques that have been developed for the C language community, but focus on applying them to languages that are commonly used in high performance and scientific computing. Our prototype implementations of these techniques have been able to be applied to simple cases to demonstrate their utility in lowering the cost of entry for programmers to use automated transformation tools. We have a number of ongoing lines of research related to this work to address questions that arise in supporting more complex and nuanced transformations than discussed in this paper.

**A. Current work and prototype**

This paper discusses the core algorithms used in our prototype. The major areas of ongoing work at submission time include:

- Moving parameters currently specified via configurations separate from the before/after code specification into code annotations either via structured comments or compiler directives.
- Techniques for specifying points in the ancestors of holes to identify the required context for transformations. This will augment or fully replace our current heuristic approach.
• Use of Stratego strategies to coordinate the application of multiple rules that constitute a single complex transformation.

All of the tools and techniques used in this work are available as open source software available via the source control repository at [http://sf.net/projects/compose-hpc]. We hope that interested readers will try our evolving prototypes, and contributions to advance the work are always welcome.

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