

Generalized Systematic Debugging for Attribute Grammars

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ABSTRACT

Attribute grammars (AGs) are known to be a useful formalism for semantic analysis and translation. However, debugging AGs is complex owing to inherent difficulties of AGs, such as recursive grammar structure and attribute dependency. In this paper, a new systematic method of debugging AGs is proposed. Our approach is, in principle, based on previously proposed algorithmic debugging of AGs, but is more general. This easily enables integration of various query-based systematic debugging methods, including the slice-based method. The proposed method has been implemented in Aki, a debugger for AG description. We evaluated our new approach experimentally using Aki, which demonstrates the usability of our debugging method.

KEYWORDS: Algorithmic Debugging; Attribute Grammars

1 Introduction

Debugging of attribute grammars (AGs) involves specific hurdles because of the language features of AGs, such as recursion of syntax structure and complex dependency between attributes. To attack these problems our group has developed two AG debugging methods, one applying algorithmic debugging [5] and the other with a slice-based debugging method for AGs [2], which works in a complementary manner with the algorithmic debugging-based method.

Although the previous methods are effective for debugging AGs, some limitations still exist. For example, the user may have to answer questions about a huge tree, depending on the location of the bug. Another limitation is that the user has no way to give information directly to the debugger other than by answering a question from the debugger. The most obvious problem of the previous methods is that they work independently of each other—that is, the user cannot switch to another method during debugging.

In this paper, we propose an AG debugging method that solves the abovementioned problems. Our approach is a generalization of algorithmic debugging of AGs [5]. Whereas queries performed by the previous methods have a single form, the new method allows several forms of query. This enables integration of various

query based methods, including the previous two methods, in a single framework. We implemented the new debugging method in our debugger. We showed the effectiveness of the proposed method experimentally.

2 Algorithmic Debugging of AGs

Attribute grammar is a formalization that integrates both syntax and semantics of languages. Fig. 1 is a simple example of attribute grammar description. This description calculates the value of a number in binary notation (including a bug).

$$\begin{array}{ll}
 F ::= . L & L_0 ::= B L_1 \\
 \{ L.pos = 1; & \{ L_1.pos = L_0.pos + 1; \\
 F.val = L.val \} & B.pos = L_0.pos + 1; (bug) \\
 B ::= 1 & L_0.val = B.val + L_1.val \} \\
 \{ B.val = 2^{-B.pos} \} & | B \\
 | 0 & \{ B.pos = L_0.pos; \\
 \{ B.val = 0 \} & L_0.val = B.val \}
 \end{array}$$

Figure 1: Attribute Grammar G_1

Attribute evaluation is a process that calculates semantics according to the attribute grammar. For G_1 , the attribute evaluation of “.101” is performed as follows: (1) construction of the parse tree for input “.101”, then (2) computation of the value of each attribute according to the attribute dependency. By this process, an attributed parse tree is constructed, as shown in Fig. 2. $F.val =$

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3/8 is the result of the evaluation, which is incorrect.

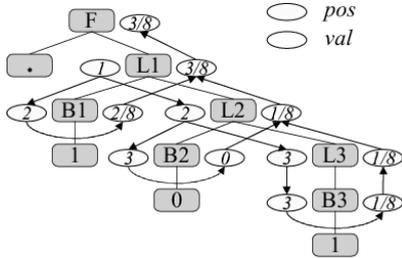


Figure 2: Attributed parse tree

Algorithmic debugging proposed by Shapiro [6] is formalized by *computation trees*. A computation tree represents the trace of program execution that corresponds to a proof tree for logic languages. To apply this method to AGs, we need a structure equivalent to the computation tree in AGs. Using fictitious functions called *synth-functions* [5], we can do this. By recursive application of synth-functions, we obtain a structure equivalent to the computation tree that can model execution in AGs, i.e. attribute evaluation. Fig. 3 represents the computation tree formed by the attribute evaluation of “101” for $G1$. Each node of the computation tree consists of a triplet including a function name (of a synth-function), arguments and the result. For example, node (a) represents the computation that the value of $L2.val$ is $1/8$ when $L2.pos = 2$ and the parse tree rooted at $L2$ (substring “01” of the input) are given. The user can confirm that this computation (relation) is correct and the debugger can prune the tree rooted at (a) from the search space.

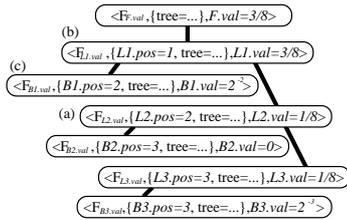


Figure 3: Computation tree

3 Debugging Algorithm

3.1 Problems with the previous approach

There are difficulties with the previous algorithmic debugging of AGs [5]. One problem is that it is hard for the user to answer a question near the root of the computation tree because the user requires information from the large subtrees (e.g. Fig. 4).

Another problem is the limitation on flexible debugging. We have developed another systematic debugging for AGs, which is based on par-

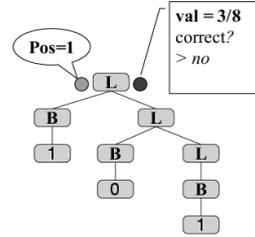


Figure 4: Query with a large subtree

tion of program slicing [2]. However, after the user starts debugging using program slicing, he or she generally must use that method throughout the remainder of the debugging process, and cannot switch to the algorithmic debugging (and vice versa). Other problems exist: the previous algorithmic debugging is hard to apply to a program that leads to run-time errors, and algorithmic debugging generally may only indicate a plurality of semantic rules as candidates for the bug.

3.2 Debugging Algorithm

As shown above, the sole use of the previous algorithmic debugging of AGs is not effective. To solve these problems, we have developed a generalized version of algorithmic debugging for AGs, which enables integration of various query based debugging methods, including slice-based debugging. Compared with the method of Kamkar et al. [3], which employs a combination of interprocedural slicing and algorithmic debugging, we aim at a more generalized method for AGs that allows users to switch between various debugging methods.

We have formalized several theorems for the generalization. Details of these theorems are presented in [4].

Fig. 5 is a summary of the debugging method. This algorithm localizes a bug using recursive functions: GAD_{init} is the function that gives an initial condition, and GAD is the actual function that performs the recursive applications of the bug localization process. The argument ACC of GAD represents an attribute computation composition the behavior of which is incorrect. Here an “attribute computation composition” in a general sense means a sub-computation in the attribute evaluation. The second argument $\{ACC_1, \dots, ACC_m\}$ represents a set of attribute computation compositions the behaviors of which are correct.

Function $getNextACC$ selects an ACC' and m for the next query. Here we should select ACC' and m that are subject to certain properties: ACC' should include ACC_i ($1 \leq i \leq m$), and ACC' should not have an intersection with ACC_i ($m < i$). This function determines the form of query to the user. That is, by changing the realization

```

GADinit(ACC){
  return GAD(ACC, {});
}
GAD(ACC, {ACC1, ..., ACCn}){
  bugACs = ACC - ∪1 ≤ k ≤ n ACCk;
  if size(bugACs) ≤ ε
    /* report the candidates of a bug */
    return bugACs;
  /* select ACC' and m */
  ACC', m =
    getNextACC(ACC, {ACC1, ..., ACCn});
  if Query(ACC') == correct
    /* if the behavior is correct, then add ACC'
    to correct ACC set */
    return
      GAD(ACC, {ACC', ACCm+1, ..., ACCn});
  else
    /* narrow the search space to ACC' */
    return GAD(ACC', {ACC1, ..., ACCm});
}
    
```

Figure 5: Algorithm *GAD*

of *getNextACC*, various debugging methods can be induced in this algorithm, which gives the debugger flexibility.

If *ACC'* takes a form equivalent to a synth-function, the algorithmic debugging above can be realized. Slice-based debugging can also be realized by selecting *ACC'* that is equivalent to a program slice—that is, sub-computations ranging from the start of the attribute evaluation to some execution point. To resolve the problem of huge trees (Fig. 4), we can select *ACC'* that generates a query such as Fig. 6 that is not a form of synth-functions. Therefore, we can easily realize and integrate several debugging methods in a single framework.

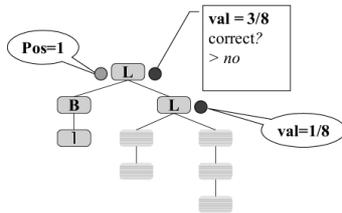


Figure 6: Query with an incomplete subtree

4 Debugger Aki

We have implemented the debugger known as Aki [2], as a part of our compiler development environment with AGs. In this environment, each phase of the compiler is described in AG. The debugger Aki assists debugging of the descriptions of the compiler phases written in AGs.

Aki provided two debugging methods: the previous (i.e. naive) algorithmic debugging and a method based on the partition of slices. In addition, the generalized method in Section 3 is im-

Figure 7: Debugger Aki

plemented for this research.

Aki performs systematic debugging using information on attribute dependency that can be obtained from the AG description, an input parse tree, and the trace of the evaluation of attribute values. To help the user understand its questions, Aki implements several mechanisms. For example, for questions concerning values with large data structures (such as symbol tables), Aki highlights the difference between the two values, which helps the user to understand the value intuitively.

Fig. 7 shows a screen shot of debugging of an AG description using Aki. The panes display the AG description, the source program, attribute values and the input tree. Queries are presented in a dialog window, as shown in Fig. 8. When Aki detects a semantic rule that includes a bug, Aki highlights the rule as shown in Fig. 9.

Figure 8: Query

Figure 9: An erroneous rule inferred by Aki

5 Experimental Results

We performed user tests of the debugger Aki presented in the previous section. Three test users tried to find erroneous positions in six programs using three methods—i.e., slice-based, pure algorithmic and our generalized method. The example attribute grammar is a description of static semantics checking of the “Tiger language” in a

compiler text [1]. The description consists of 25 productions and 105 semantic rules. The three users were all familiar with the language.

Table 1: Comparison of the number of queries

	# attrs	# nds	Slice	AD	GAD
A	78	52	7(1)	8(3)	4(1)[6(1)]
B	146	103	6(1)	9(4)	5(1)
C	60	43	4(1)	8(3)	4(1)
D	56	34	9(1)	6(4)	7(1)
E	45	32	5(1)	5(2)	7(2)
F	104	69	7(1)	6(2)	2(2)

Table 1 shows the number of the queries that the users required to identify an erroneous portion in each description. In this table, “# attrs” and “# nds” denote the number of attribute instances and parse tree nodes, respectively. “Slice”, “AD” and “GAD” represent the slice-based method, pure algorithmic debugging and the method proposed in this paper, respectively. Rows E and F are the cases for runtime error. The numbers in parentheses are the numbers of candidates of semantic rules identified as bugs.

In this experiment, we could not conclude that a method with fewer queries is more efficient, because some questions are difficult to answer and others are easy. We discuss this in the next section. In the table, the numbers in brackets in row A mean that one user had a different result from other users. This is because users can freely indicate erroneous values of inherited attributes in GAD.

6 Discussion

We discuss the advantages of the proposed debugging method. Some features can be realized in the previous methods by ad-hoc extension. However, our method is advantageous because these features can be realized in a single framework.

Easy question to answer: In the previous two methods, to answer the question is the only way the user can give debuggers information for bug localization. On the other hand, in the proposed method, the user can indicate some attribute values that are found to be wrong. This enables the focus of the search to be nearer the user’s interest, which leads to efficient debugging.

Runtime error: When attribute evaluation produces a runtime error, the previous algorithmic debugging of AGs forces the user to answer such difficult question as, “is it correct that an attribute value should be undefined for this premise?”. In the proposed method, the debugger never asks a question including undefined attributes. This can be realized by the integration of both pure algorithmic debugging and slice-based debugging.

Reduce questions on big trees: In the previous algorithmic debugging of AGs, a subtree that is a premise of a query should be a complete subtree with all descendant nodes. On the other hand, in the proposed method, trees in a query may be incomplete, in the sense that some part of the subtrees may be pruned (e.g. in Fig. 6).

Identification of bug: When employing the previous algorithmic debugging of AGs, semantic rules identified as erroneous are not, in general, single rules. On the other hand, the proposed method can identify just one semantic rule as erroneous.

7 Concluding Remarks

This paper presents a systematic debugging method for AGs. We generalized the algorithmic debugging of AGs, which allows various forms of questions and unifies the previous two methods. We also developed a new debugging method using the proposed framework. This method is implemented in the debugger Aki, and experimental results are shown.

In the future we intend to develop a more effective method using the generalized algorithmic debugging proposed in this paper. We will also investigate the combination of the proposed method and other debugging methods, such as assertion, as well as the user interface of the debugger for questions that are easier to answer.

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