Implementing Semantic Feedback in a Diagram Editor

Niklas Fors  
Department of Computer Science  
Lund University, Lund, Sweden  
niklas@cs.lth.se

Görel Hedin  
Department of Computer Science  
Lund University, Lund, Sweden  
gorel@cs.lth.se

ABSTRACT

In editors for visual languages it is often useful to provide interactive feedback that depends on the static semantics of the edited program. In this paper we demonstrate how such feedback can be implemented using reference attribute grammars. Because the implementation is declarative, it is easy to modularize compiler and editor computations, reusing the compiler’s program model in the editor. Furthermore, the declarative approach makes it easy to keep the program model and view consistent during editing. The approach is illustrated using a function block diagram language, with visual feedback on, for example, type checking and cyclic data flow.

Categories and Subject Descriptors

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General Terms

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Keywords

Visual languages, diagram, reference attribute grammars, jastadd

1. INTRODUCTION

In implementing language tooling, there is often the need for providing several related tools: textual editor, visual editor, compiler, program analyzers, etc. Developing such language tooling is typically very costly [22] [18], and there are many current efforts on providing meta-tooling to reduce these costs. Examples include both work based on meta-modeling, like the Eclipse Modeling Framework (EMF), and work based on grammars, e.g., Spoofax [13].

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While visual editors typically support structured editing, it is often useful to additionally provide semantic feedback, i.e., visualization and interaction that depends on static-semantic properties of the program. Examples include both visual display of static-semantic information, like displaying of type-checking errors, as well as interactive cues during editing gestures. An example could be to show if dragging a visual item to another location would change the semantics or not, or would introduce an error. If the underlying static-semantic analyses are done by a compiler, it is desirable to let the editor reuse this analysis, both in order to keep down development costs, and also to keep the tools consistent with each other.

We are currently exploring how reference attribute grammars (RAGs) [11] can be used in this context. RAGs are based on abstract syntax trees (ASTs), but provide reference attributes that link together AST nodes to form a graph. RAGs can also be integrated with EMF as shown by Bürger et al. [6], where containment relations correspond to the AST, and non-containment relations are mapped to reference attributes. RAGs have previously been shown useful for building extensible compilers for textual languages like Java [8] and Modelica [5].

We are applying RAGs for building tooling for a function block diagram language for control systems. The language, PicoDiagram, is based on existing languages in industrial use, and exhibits fairly advanced static-semantics, like diagram types, and data-flow based execution order. We have designed both a textual and visual syntax for PicoDiagram, and implemented both a compiler and a visual editor for it. The compiler is implemented in RAGs, using the metacompilation system JastAdd [12], and the editor is implemented using GEF, the Graphical Editing Framework in Eclipse.

In this paper, we investigate different opportunities for reusing static-semantics computations in the PicoDiagram compiler in order to provide semantic feedback during visual editing. In some cases, the compiler computations can be directly reused by the editor, and in other cases, they are modularly extended to provide specific feedback. This paper provides more details on the use of RAGs, compared to previous work [10].

The rest of this paper is organized as follows: Section 2 describes the PicoDiagram language, and Section 3 gives some background on RAGs. Sections 4, 5, and 6 describe different aspects of static-semantic analysis of PicoDiagram: name analysis, type checking, cyclic types, and cyclic connections. We explain how these aspects are implemented using RAGs, and how the implementation can be reused or
The example, a larger system may include several instances of thorough description on the use of RAGs.

This result by describing an algorithm to remove data flow affecting the execution order [10]. In this paper, we extend defined the execution order declaratively on diagrams with define an unambiguous total order. In a previous paper, weward data flow connections, and uses the positional order to correspond to the distance to the origin, i.e., the upper left corner of the diagram. For the textual syntax, it corresponds to the declaration order. The execution order follows the forward data flow connections, and uses the positional order to define an unambiguous total order. In a previous paper, we defined the execution order declaratively on diagrams with acyclic data flow, and described how to provide semantic feedback on how blocks in a diagram can be moved without affecting the execution order [10]. In this paper, we extend this result by describing an algorithm to remove data flow cycles in diagrams using the positional order and give a more thorough description on the use of RAGs.

A diagram type can be instantiated several times. For example, a larger system may include several instances of the Cascade diagram.

We have implemented two different tools for PicoDiagram: a visual editor where the user can edit programs using the visual syntax, and a compiler that translates the text representation to C code. The visual editor stores the programs in the text representation, and it is also possible to use a normal text editor to edit the programs. Both tools reuse the same parser and core RAG specification, but they can also extend the RAG specification with their own attributes.

2. PICODIAGRAM

PicoDiagram is an experimental language for control systems. It is inspired by a product from ABB, which in turn builds on the IEC-61131 standard for programmable logic controllers, including function block diagrams.

A PicoDiagram diagram consists of blocks and connections that model data flow. The blocks are instances of diagram types that may be defined either by other PicoDiagram diagrams, or by external C functions. We have designed PicoDiagram to have both a visual and a textual syntax. The textual syntax is a high-level model of a diagram, in the sense that visual properties such as shapes and colors are not part of the textual syntax. There are several benefits of having a textual syntax, for example, when generating diagrams or in concurrent development to allow the use of existing text-based merging tools.

Figure 1 shows an example PicoDiagram program in both the visual and textual syntax. The program is a cascade regulator that controls an actuator using two controllers: a master controller uses input from one sensor to control the setpoint of the slave controller. The slave controller reads another sensor and sets the actuator value. There is also feedback information that goes from the slave to the master (the orange connection).

A diagram is executed periodically, reading/setting sensors and actuators with a given frequency. In each period, the blocks are executed in a sequence. In the case of a loop, like in the example, the compiler automatically breaks the loop by considering a certain connection as a backwards connection. In the visual editor, backward connections are colored orange. This is an example of giving the user semantic feedback. For values coming via backward connections, the old value from the previous period will be used.

The algorithm for computing the backwards connections makes use of a positional order between the blocks, see Section 6. For the visual syntax, the positional order corresponds to the distance to the origin, i.e., the upper left corner of the diagram. For the textual syntax, it corresponds to the declaration order. The execution order follows the forward data flow connections, and uses the positional order to define an unambiguous total order. In a previous paper, we defined the execution order declaratively on diagrams with acyclic data flow, and described how to provide semantic feedback on how blocks in a diagram can be moved without affecting the execution order [10]. In this paper, we extend this result by describing an algorithm to remove data flow cycles in diagrams using the positional order and give a more thorough description on the use of RAGs.

A diagram type can be instantiated several times. For example, a larger system may include several instances of the Cascade diagram.

3. REFERENCE ATTRIBUTE GRAMMARS

We use the semantic formalism Reference Attribute Grammars (RAGs) [11] to define the meaning of a diagram in the PicoDiagram language. A diagram is represented as an attributed abstract syntax tree (AST), typically created by a parser or by an interactive visual editor. The attributes are derived values computed given a set of equations and the AST. Equations are directed, with an attribute on the left hand side, and an expression over other attributes on the right hand side. The attributes are declarative in the sense that each attribute will have a value that is equal to the right-hand side of its defining equation, and the expressions inside an equation are forbidden to have any externally observable side effects. An attribute evaluation engine automatically evaluates the attributes, according to their dependencies.

RAGs extends Knuth’s Attribute Grammars [14] with reference attributes, i.e., attributes whose values are references to other nodes in the AST. This makes it possible to superimpose graphs on top of the AST.

For implementation, we use the JastAdd metacompilation tool [12] which supports RAGs, object-oriented ASTs, and aspect-oriented modularization of RAG specifications. JastAdd also supports circular attributes [16], i.e., attributes that may transitively depend on themselves, and for which the evaluation engine uses fixed-point iteration to compute the value.

JastAdd attributes are accessed by calling them, like a method. In fact, the attributes are translated to Java methods by the JastAdd tool. For efficiency, the JastAdd attribute evaluator does not evaluate an attribute until its value is needed (i.e., until it is called), and evaluated attributes are cached for fast future access. The attribute caches are flushed whenever the AST is modified, for example after an edit action.
3.1 A Simple RAG Example

To illustrate how RAGs work, consider the following simple abstract grammar (written in JastAdd syntax):

\[
A ::= B1:B \ B2:B;
B ::= <ID: String>;
C : B;
\]

This abstract grammar corresponds to a Java class hierarchy, and defines that:

- A, B, and C are classes
- A has two children: B1 and B2, both of type B
- B has a token: ID of type String
- C is a subclass of B

The JastAdd RAG specification below defines attributes over this abstract grammar. Line 1 declares an attribute \( B.\text{otherB} \) of type B. I.e., \( \text{otherB} \) is a reference attribute in B nodes, and that will point to another B node. Lines 2 and 3 show two different equations defining \( \text{otherB} \): the first one holds for the B1 child of an A node, and the other one for the B2 child. The right-hand side of the equation is in the context of A. The attribute \( \text{otherB} \) is inherited in the attribute grammar sense, meaning that the B node does not know how the value is defined, but delegates this responsibility to the parent node, i.e., to the A node in this case.

1 \( \text{inh } B \ B.\text{otherB}(); \)
2 \( \text{eq } A.\text{getB1()}.\text{otherB}() = \text{getB2}(); \)
3 \( \text{eq } A.\text{getB2()}.\text{otherB}() = \text{getB1}(); \)

The result of this specification is that the two B children refer to each other, thus forming a cyclic data structure, as shown for the example AST in Figure 2. This AST corresponds to the expression \( \text{new } A(\text{new } B(“B”), \text{new } C(“C”)) \). Note that one of the B nodes is actually of the subclass C, illustrating that attributes are inherited (in the usual object-oriented sense) by subclasses.

Because RAGs are declarative, the order of specification of individual attributes and equations is irrelevant, and they can be split up into different modules based on what is practical to reuse in different tools. The following small RAG module illustrates the modular addition of an attribute \( B.\text{name} \) of type String. This is a synthesized attribute, meaning that there must be an equation defining its value in the same node. Line 5 gives a definition of the attribute value for B nodes. Line 6 illustrates how this definition is overridden for C nodes, relying on the usual object-oriented features of inheritance and overriding. The equation on line 6 also illustrates how information in distant nodes can be accessed: the ID of the other B node is accessed via the reference attribute \( \text{otherB} \).

4 \( \text{syn } \text{String } B.\text{name}(); \)
5 \( \text{eq } B.\text{name}() = \text{getID}(); \)
6 \( \text{eq } C.\text{name}() = \text{otherB}().\text{getID}(); \)

The RAG corresponds to the UML diagram depicted in Figure 3. The class hierarchy, the parent-child relations (i.e., containment relations), and UML attributes like ID, are specified in the abstract grammar. Non-containment relations like otherB, and methods like name, are specified as RAG attributes, and their values are computed automatically by the underlying RAG evaluation engine.

Additional JastAdd/RAG mechanisms used in this paper include parameterized attributes and circular attributes, and are explained as part of our discussion of the PicoDiagram compiler and editor.

4. NAME AND TYPE ANALYSIS

The name analysis is concerned with binding name uses to name declarations. For PicoDiagram, we have two separate namespaces, one for types and one for variables. Type uses and type declarations are represented by the classes TypeUse and TypeDecl, respectively, and VarUse and VarDecl represent variables. The bindings are implemented by a reference attribute decl in TypeUse and VarUse, referring to the appropriate declaration node.

An example of an attributed AST is shown in Figure 3. The structure of this AST is defined by the core abstract grammar of PicoDiagram, which is shown in Figure 4. In this grammar, we can see that a Program consists of a list of DiagramTypes, which in turn consists of a name, Parameters, Blocks and Connections. The classes Parameter and Block are subclasses to VarDecl and have a TypeUse each. The Connection class has at least one VarUse.

Figure 6 illustrates a simple diagram type S, using the textual syntax. It has one input parameter p, a block t of type T and a connection between the local parameter p and the parameter p2 in type T. There are three type uses in this example: the parameters p and p2 use the primitive type Int and the block t uses the diagram type T. The variable uses

---

Note 1: JastAdd also supports inheritance in the object-oriented sense, and if there is a risk on confusion, we will comment on what kind of inheritance we mean. Both uses of the term originate from the late 60s when both OO and AGs were invented.

Note 2: The full PicoDiagram language contains additional constructs like structs, floats, bools, etc.

Note 3: The source of a connection can be an integer constant.
Figure 4: Example AST. Dashed lines are references from type uses to type declarations. Dotted lines are references from variable uses to variable declarations. The type Int and references to it have been omitted.

```plaintext
Program ::= DiagramType*;

abstract TypeDecl;
DiagramType : TypeDecl ::= <ID> Parameter* Block* Connection*;
IntType : TypeDecl;
BoolType : TypeDecl;
UnknownType : TypeDecl;

abstract VarDecl;
abstract Parameter : VarDecl ::= TypeUse <ID>;
InParameter : Parameter;
OutParameter : Parameter;
Block : VarDecl ::= TypeUse <ID>;

Connection ::= Source:Expr Target:VarUse;

abstract Expr;
IntConst : Expr ::= <Value:int>;
abstract VarUse : Expr;
SimpleVarUse : VarUse ::= <ID>;
DotVarUse : VarUse ::= VarUse <ID>;

TypeUse ::= <ID>;
```

Figure 5: Core abstract grammar for PicoDiagram. Abstract classes (like in Java) use the keyword abstract. Kleene star means a list of children.

```plaintext
diagramtype S(Int p =>) {
    T t;
    connect(p, t.p2);
}
diagramtype T(Int p2 =>) { ... }
```

Figure 6: Simple example for name analysis

```plaintext
syn TypeDecl TypeUse.decl() = lookupType(getID());
inb TypeDecl TypeUse.lookupType(String name);
eq Program.getDiagramType()
    .lookupType(String name) {
        TypeDecl typeDecl = lookupPredefType(name);
        if (typeDecl == null)
            typeDecl = lookupDiagramType(name);
        return typeDecl;
    }
```

Figure 7: Name binding for types

are found in the connection: p and t.p2. Note that the binding of p2 depends on the type of t. The corresponding AST of this example and the name bindings are shown in Figure 4.

As described earlier, both TypeUse and VarUse have a reference attribute decl that refers to the corresponding declaration. The RAGs implementation follows a typical pattern for name analysis where the decl attribute delegates the searching for the declaration to an inherited attribute lookup that is defined by the context in the AST. The lookup attributes are examples of parameterized attributes, that can be thought of as functions, but where the results are cached (i.e., memoized).

Figure 7 shows the name binding for types, where the decl attribute uses the inherited attribute lookup which in turn is defined by the Program node for its diagram types. The attribute first searches among the predeclared types (integer and boolean) using the attribute lookupPredefType and then continues among the user defined diagram types using the attribute lookupDiagramType. See the appendix on how these helper attributes are defined.

The implementation of name bindings for variables is shown in Figure 8. For SimpleVarUse, the attribute decl uses the lookup attribute directly. The enclosing diagram type defines the lookup attribute for all its children. It first searches among its parameters and then continues with searching among its blocks. The definitions of the helper attributes can be seen in the appendix. For DotVarUse, the attribute
syn VarDecl VarUse.decl();

eq SimpleVarUse.decl() = lookup(getID());

inh VarDecl VarUse.lookup(String name);
eq DiagramType.getChild().lookup(String name) {
    VarDecl decl = localParameterLookup(name);
    if (decl == null)
        decl = localBlockLookup(name);
    return decl;
}

eq DotVarUse.decl() = getVarUse().decl() == null? null: getVarUse().decl().findMember(getID());

diagramtype T() {
    S s;
}
diagramtype S() {
    T t;
}

Figure 10: Cyclic diagram types (a compile-time error)

syn Set<TypeDecl> TypeDecl.reachable()
circular[new HashSet<TypeDecl>()];
eq TypeDecl.reachable() = new HashSet<TypeDecl>();
eq DiagramType.reachable() {
    Set<TypeDecl> set = new HashSet<TypeDecl>();
    for (Block b: getBlocks()) {
        if (b.type().isDiagramType()) {
            set.add(b.type().reachable());
        }
    }
    return set;
}

Figure 11: Type reachability

since it would lead to endless unfolding of blocks. Figure 10 illustrates this error.

We use a circular attribute to identify such cycles. The value of a circular attribute is computed using a fixed-
point iteration. We define the circular attribute reachable that is the set of all reachable diagram types from a dia-
gram type, as can be seen in Figure 11. If the diagram

type is in this set, the diagram type is circular, otherwise it is not. The attribute is defined on TypeDecl, to avoid explicit type casts. The attribute returns an empty set for all other types than diagram types. For diagram types, it returns the types of its blocks and the reachable types from
these types. The attribute isCircular on DiagramType tells whether the diagram type is circular or not, by using the attribute reachable.

5.1 Semantic Feedback

We can now provide semantic feedback for cyclic diagram types by coloring blocks red that are in a type cycle. For example, in viewing the diagram type T from the example in Figure 10 the component block s would be colored red as follows:

To aid the implementation of this visual semantic feedback, an attribute isCircular is defined for Block as follows:

syn boolean Block.isCircular() = type().reachable().contains(diagramType());

5. CYCLIC DIAGRAM TYPES

If a diagram type contains a block of its own type (di-
rectly or transitively), this constitutes a compile-time error

Because decl is defined by asking the declaration of its child if it has a member using the attribute findMember. For example, in the expression t.p2, we use the declaration of t to define p2. In this example, the declaration of t is a block, and Block defines findMember by searching among the parameters of its type, that is, p2.

Types of expressions and declarations are represented by type attributes that refer to TypeDecl AST nodes. They are straightforward to define with the help of the decl attributes, as shown in Figure 9 Predeclared types, like intType, are represented using attributes in the program root. Semantic feedback on errors, for example, connections that connect incompatible types, can be shown in the visual editor using, for instance, colors or icons and associated error messages.
6. CYCLIC CONNECTIONS

The connections define data flow between blocks, transferring values from source blocks to target blocks. Normally, a connection’s source block should therefore execute before the target block. However, this becomes problematic when the connections form a cycle, since we do not know which block to execute first. We solve this by constructing a graph where edges corresponding to certain connections are removed, so that the resulting graph becomes acyclic. All blocks are executed periodically, so for a connection corresponding to a removed edge, we use the source block value from the previous period and feed it into the target block.

The idea behind the algorithm for removing edges is to only remove those corresponding to connections that usually go backwards, meaning that the source block is further away from the origin than the target block. If there are several such connections in a cycle, we choose the one whose target is closest to the origin. This is simple to understand for a user of the visual editor, and fits with the way control diagrams are usually laid out.

We model the diagram as a directed graph. In the diagram, the connections go between specific ports on the blocks, representing different variables. For the constructed graph, we abstract this to edges between the blocks, since we are only interested in ordering complete blocks. So if there are more than two connections between two specific blocks, they will be represented by a single edge in the graph.

The algorithm for breaking cycles is shown in Figure 12 and uses strongly connected components (SCCs) to detect cycles. An SCC is the maximal set of vertices where there is a path from all vertices in the SCC to all other vertices in the SCC, and can be computed in linear time using Tarjan’s algorithm [21]. The cycle-breaking algorithm is iterative and removes edges until the graph is acyclic. For each iteration, all SCCs are computed. For each SCC consisting of more than one vertex, we select the vertex \( v \) that is closest to the origin. This is simple to understand for a user of the visual editor, and fits with the way control diagrams are usually laid out.

An example of a cyclic graph is shown in Figure 13. Running the algorithm on this graph, two SCCs are computed during the first iteration: \( \{a, b, c, d, e\} \) and \( \{a, b, c, e\} \). We are only interested in SCCs with more than one vertex, that is, the latter SCC. In this SCC, vertex \( a \) is closest to the origin. We thus remove all edges from vertices in the same SCC to \( v \), where \( v \) is the vertex \( \{a, b, c, d, e\} \). During the second iteration, we compute the SCC \( \{e, c\} \) and therefore remove the edge \( (e, c) \). The graph is now acyclic and we are finished.

The algorithm is implemented as a method `breakCycles` on `DiagramType` and uses attributes to obtain the information needed to construct the original cyclic graph. The method returns a wrapper object consisting of all predecessors and successor sets for the corresponding acyclic graph. The attribute `DiagramType.predSucc` is defined by calling `breakCycles`, as can be seen in Figure 14. This is fine since although `breakCycles` is implemented imperatively, it does not result in any externally observable side-effects. Note that `breakCycles` is only computed once for each diagram type, since JastAdd caches attribute values. The wrapper object consists of two maps: `pred` maps a `Block` to its predecessors and `succ` maps it to its successors. We use these two maps to define the attributes `pred()` and `succ()` on `Block`.

6.1 Semantic Feedback

Connections corresponding to a removed edge will have a different meaning than normal edges, since their values will be delayed one period. To help the user in understanding this, we provide semantic feedback by coloring these connections orange, as can be seen in Figure 1. To aid this implementation, an attribute `isBroken` is defined on `Connection`. A connection is defined as broken if both its source and targets are blocks, and if the target block is not a successor to the source block in the acyclic graph, see Figure 14.

We also provide interactive semantic feedback while the user moves a block, since this could affect how cycles are broken, see Figure 16. Here, the user is dragging the `Slave` block, and the green box shows its current position. The block is in a type cycle. The enclosing diagram type is accessed by the inherited attribute `DiagramType`.

```java
syn PredSucc DiagramType.predSucc() = breakCycles();

inh Set<Block> Block.pred();
eq DiagramType.getBlock(int i).pred() = predSucc().pred.get(getBlock(i));

inh Set<Block> Block.succ();
eq DiagramType.getBlock(int i).succ() = predSucc().succ.get(getBlock(i));
```

Figure 14: Attributes `predSucc()`, `pred()` and `succ()`

```java
syn boolean Connection.isBroken() {
    if (getSource().isBlock() && getConnection().isBlock()) {
        Block src = getSource().block();
        return !src.succ().contains(getTarget());
    } else {
        return false;
    }
}
```

Figure 15: Attribute `isBroken`
The focus of this paper is on reusing static semantics between different tools and providing semantic feedback in the visual editor.

In the Eclipse world, there are several ways to create a visual editor, such as using the Graphical Editing Framework (GEF) [1], the Graphical Modeling Framework (GMF) [2], or Graphiti [2]. The visual editor for PicoDiagram has been created using GEF. GMF is built on top of GEF and requires an EMF model to define a visual editor. These projects focus on lowering the burden for creating visual editors, and they focus less on semantic analysis and semantic feedback.

One interesting work by Bürger et al. [6] combines RAGs and EMF, to define the static semantics of EMF models using RAGs. By building on their work, one possible future direction would be to use GMF instead of GEF to create the visual editor for PicoDiagram, in order to decrease the effort spent on the visual editor.

The blocks in PicoDiagram are instantiations of diagram types, and the appearance of these blocks depends on their types. A diagram type defines how many parameters it has and the visual representation of a block of this type reflects this. The language workbench MetaEdit+ [3] supports, since version 5.0, something they call dynamic ports, which they have created to support situations like this.

Another tool is xText [9] that is used for creating textual domain specific languages. It supports name binding for languages with simple name rules, otherwise the user needs to provide a Java implementation of the name binding. Also in the Spoofax language workbench, which has been used for graphical languages [23], a DSL is developed for name binding [15]. While such specific support can be useful in many cases, it is limited, both in what domain is supported (for example, name analysis), and in the generality of how that domain is supported (for example, limited to certain known kinds of scope rules). In contrast, RAGs is a general declarative formalism for defining any static-semantic analysis, and has been successfully used to implement complex name and type analyses for languages like Java [8] and Modelica [5].

Many metamodelling-based tools, including EMF, MetaEdit+, and xText, use constraint languages like OCL (Object Constraint Language) for specifying static-semantic constraints on the model. RAGs serve a similar purpose, but in addition supports building derived parts of the model itself, through the use of the reference attributes. Some of these derived parts, e.g., name bindings, may correspond to explicitly defined non-containment relations in EMF, whereas others go beyond EMF+OCL, like the representation of the broken cycles in section [6].

Schmidt et. al. [19] have used attribute grammars to implement visual editors. They use something called visual patterns that are predefined reusable implementations of common visual representations, such as lists, graphs, tables and line connections. These patterns have been implemented using attribute grammars. The user can refine these patterns and also create new visual patterns. The focus of their work is on using attribute grammars to define visual languages. A difference is that we use reference attributes and they do not. It would, however, be interesting to combine visual patterns with our approach.

In this paper, we handle cyclic data flows by removing connections based on the layout. In Simulink, a diagram can contain loops, which are called algebraic loops, that Simulink tries to solve mathematically [17]. If a loop contains a block with a discrete value as output, then Simulink cannot solve that loop. When Simulink cannot solve an algebraic loop, the user can add a so-called delay block to explicitly break the loop. In PicoDiagram, when a connection is removed due to a cycle, a delay is added implicitly, which corresponds to a delay block in Simulink.

Modelica is a language for modeling and simulating physical systems [4]. It has also a textual and a visual syntax, like PicoDiagram. However, in contrast to PicoDiagram, its semantics is not layout-dependent.

**8. DISCUSSION**

The declarative nature of attribute grammars allows attributes to be reused by different tools, for example, by the visual editor to provide semantic feedback. The attributes are declarative in the sense that they always compute the same value and no externally visible side-effects are allowed. This means that we can reuse the attributes in the visual editor without thinking about in what order they are computed. By reusing attributes between different tools, it is easier to keep the tools consistent with each other and the semantics is only required to be specified once.
Figure 17 shows the overall architecture of how the RAG specification defines the attributed AST which is reused by both the compiler and the editor. In addition to this, the compiler and the visual editor can modularly add new attributes.

Attributes are computed values given a set of equations and an AST. When the user changes something in the visual editor, for example, adding a connection or a block, attribute values may become invalid, since the AST has changed. When the AST changes, we currently flush all attribute values, and they are recomputed again when they are needed (due to on-demand evaluation). In industry, large problems are modularized to many smaller diagrams, often limited to at most 50 blocks, since larger diagrams are difficult to understand and to fit on screen or paper. For PicoDiagram, there are no performance problems with individual diagrams: feedback is immediate even when interacting with diagrams with 500 blocks and 500 connections. However, further studies are needed to see how our approach scales to large libraries of diagrams. If performance needs to be improved, a possibility is to apply incremental evaluation for RAGs, where flushing is limited to attributes that depend on the AST change. Such incremental evaluation is currently investigated by Söderberg et al. [20].

The base structure in EMF is a graph, whereas for RAGs it is a tree (the AST). With reference attributes, a graph can be super-imposed on the tree. We think having a high-level textual syntax also for a visual language has huge benefits. It makes the stored programs independent of tooling, and allows all existing text-level tools to be used. At the same time, the trees created by the parser are automatically decorated with attributes representing graphs, making the representation suitable for visual editors. However, the visual editor cannot change the reference attributes directly, but needs to transform visual editing operations to corresponding tree changes.

9. CONCLUSION

In this paper we have shown how to implement semantic feedback in a visual editor by reusing the static semantic specification. To only specify the static semantics once, and reuse the attributed AST in different tools, makes it easy to keep the tools consistent with each other. As a case study, we have created a language called PicoDiagram that is similar to function block diagrams. The language has both a textual and a visual syntax, and we define its semantics using reference attribute grammars (RAGs), which is a declarative, but executable, formalism. For PicoDiagram, we have created a compiler and a visual editor that both reuse the same semantic specification including name analysis, type analysis, detection of cyclic diagram types and removal of cyclic connections based on layout. Then we showed examples of semantic feedback in the visual editor, for example, coloring blocks red that form a cyclic diagram type and displaying how a block can be moved without changing how the cyclic connections are broken.

In the future we would like to generate the visual editor from a specification, instead of coding it manually using GEF. It would be interesting to combine RAGs with EMF and GMF to create a visual editor, by building on the work by Bürger et al. It would also be interesting to use incremental evaluation [20] in the visual editor.

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11. REFERENCES

APPENDIX

The attributes `lookupPredefType` and `lookupDiagramType` that are used in the name analysis for type names are shown in Figure 18. These attributes access their children to find the corresponding declaration.

![Figure 18: Helper attributes for looking up type names](image)

The attributes `localParameterLookup` and `localBlockLookup` that are used in the name analysis for variable names are shown in Figure 19. These attributes access their children to find the corresponding declaration.

![Figure 19: Helper attributes for looking up variable names](image)