A Generic Projectional Editor for EMF Models

Johannes Schröpfer, Thomas Buchmann and Bernhard Westfechtel
Chair of Applied Computer Science I, University of Bayreuth, Universitätsstrasse 30, 95440 Bayreuth, Germany

Keywords: Model-driven Development, Projectional Editing, ALF, Java, Ecore, Syntax-directed Editor, Generic Framework.

Abstract: The Eclipse Modeling Framework (EMF) constitutes a popular ecosystem for model-driven development. In the technological space of EMF, a wide variety of model-based tools have been developed, including tools for transforming and editing models. Model editors may display models in different representations such as diagrams, trees, or tables. Due to the increasing popularity of human-readable textual syntax, there is a growing demand for textual model editors. In EMF, this demand is currently satisfied by syntax-based editors which persist models as text files. In contrast, we propose a projectional editor that persists models natively as EMF models; the textual representation constitutes a projection of the underlying EMF model. Projectional editing does not only exclude syntactic errors; in addition, maintaining the underlying model persistently facilitates tool integration. The projectional editor is generic; it may be instantiated for different modeling languages by declarative definitions of their concrete syntax. So far, model editors for subsets of Java and ALF (Action Language for Foundational UML) have been built to demonstrate the feasibility of the generic approach.

1 INTRODUCTION

The *Eclipse Modeling Framework* (*EMF*) (Steinberg et al., 2009) constitutes a popular ecosystem for model-driven development. In the technological space of EMF, a wide variety of tools for model-driven development have been implemented. EMF has established itself as a de facto standard for data models upon which many technologies and frameworks are based, including server solutions, persistence frameworks, UI frameworks, and support for transformations[1].

Model editors which provide tool support for creating, modifying, analyzing, and displaying models, constitute key components of environments for model-driven development. Probably the first EMF-based editor that has been provided is the tree editor belonging to the EMF core. Since then, a number of frameworks for building model editors have been developed for different model representations. For example, frameworks such as *GMF*[2] and *Sirius*[3] (Madiot and Paganelli, 2015) support the development of diagram editors while *EMF Parsley*[4] (Bettini, 2014) focuses on visualizations as trees, forms, or tables.

While diagrams have been frequently used for representing models, *human-readable textual syntax* has become more and more popular recently. The term "human-readable" excludes textual representations such as XML that have been designed for data exchange. Rather, human-readable syntax for models resembles the textual syntax of programming languages. The trend towards human-readable syntax may be exemplified by recent work on the *Action Language for Foundational UML* (*ALF*) (OMG, 2017a). While the *UML* standard (OMG, 2017b) originally defined only the abstract syntax of models and their representation as diagrams, ALF provides a textual language for both structural and behavioral modeling of a subset of UML (*Foundational UML* or *fUML* (OMG, 2018)) that features foundational execution semantics.

Textual editors may be divided roughly into two categories. *Syntax-based editors* (cf. Figure 1) treat the text as the primary artifact that is stored persistently. A command issued by the user results in the text being updated. Subsequently, the changes are propagated to the model – i.e., to the abstract syntax

[1]https://www.eclipse.org/modeling/emf
[2]https://www.eclipse.org/modeling/gmp/
[3]https://www.eclipse.org/sirius/
[4]https://www.eclipse.org/emf-parsley/index.html

Schröpfer, J., Buchmann, T. and Westfechtel, B.
A Generic Projectional Editor for EMF Models.
DOI: 10.5220/0008971003810392
In *Proceedings of the 8th International Conference on Model-Driven Engineering and Software Development (MODELSWARD 2020)*, pages 381-392
ISBN: 978-989-758-400-8; ISSN: 2184-4348

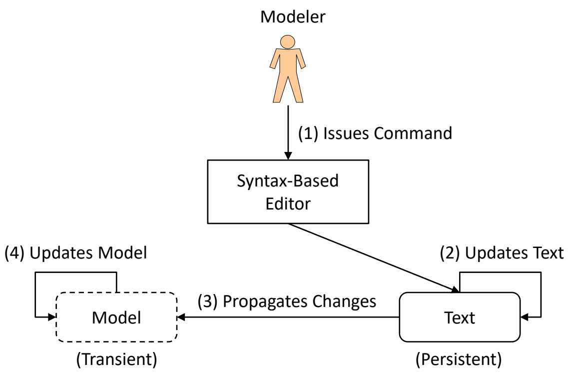


Figure 1: Syntax-based editing.

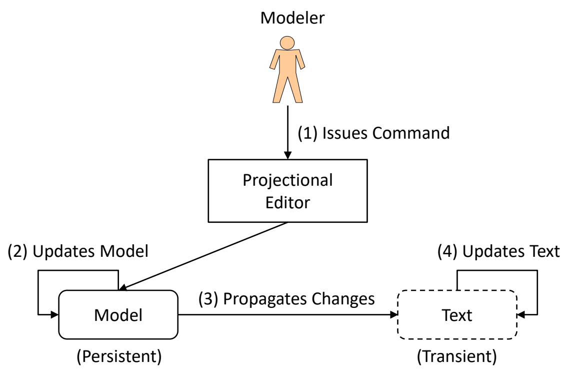


Figure 2: Projectional editing.

tree that is represented by the plain text. The model is maintained only transiently, during an editing session, and is used primarily for incremental syntactic and semantic analysis.

In the technological space of EMF, among several tools for building syntax-based editors, e.g., *EMF-Text*[5] (Heidenreich et al., 2011) for textual languages that can be easily extended and integrated with other languages, the framework *Xtext*[6] (Bettini, 2016) is the most prominent one. The editors are generated from a grammar definition that refers to an underlying metamodel. Grammar rules in Xtext are based on the *Extended Backus-Naur Form* (*EBNF*) (Yue, 2014). Either the starting point is the grammar from which the metamodel is generated (*concrete syntax first*) or the grammar is specified for an existing metamodel (*abstract syntax first*) which has been built using any tool in the EMF context (e.g., the Ecore tree editor). The generated editor artifacts can be augmented with *Xtend*[7] classes describing the custom scoping rules, validation constraints, hovering information, highlighting, etc. The (customized) editor plug-ins for the specific language may be used by arbitrary EMF-based projects.

Syntax-based editors are flexible since they allow the modeler to issue arbitrary text-based commands. For the same reason, they are easy to learn (usually, the modeler is familiar with the operation of text editors). On the other hand, they suffer from the following shortcomings:

- There is a high risk of *syntactic errors* since the modeler may type arbitrary text. This may be problematic for beginners who are not familiar with the respective modeling language.
- *Tool integration* may be hampered by storing models as text files. For example, models may be related by inter-model links, e.g., traceability links connecting models at different levels of abstraction or links between features and domain model elements in software product lines. Since text files do not provide for reliable identifiers of model elements, inter-model links may be easily corrupted.

Projectional editors (cf. Figure 2) invert the syntax-based approach to model editing. Rather than the text (concrete syntax), the model (abstract syntax) is persisted. In the context of product line engineering, a great importance is attached to projectional editors, e.g., the *PEoPL* approach (Behringer et al., 2017) combines different representations. Commands issued by the modeler affect the model rather than the text. After the model has been updated, the changes are propagated to the text which is updated accordingly in turn. For experienced users, projectional editors may feel less natural and comfortable than syntax-based editors (Völter et al., 2014). On the other hand, projectional editors solve the problems mentioned above:

- A projectional editor guarantees *syntactic correctness* by offering only commands that perform correctness-preserving in-place model transformations. For example, a command for inserting some syntactic unit is allowed only at locations where this unit is legal and ensures syntactic correctness of the inserted syntactic unit.
- A projectional editor facilitates tool integration by providing reliable means for identifying model elements. While line numbers in text files are subject to change, elements may be assigned *universally unique identifiers* (*UUIDs*) that are immutable.

This paper fills a gap in the EMF tool landscape by providing a *generic projectional editor for EMF models* that is distinguished by the following key properties:

[5]https://marketplace.eclipse.org/content/emftext
[6]https://www.eclipse.org/Xtext/
[7]a Java dialect, see https://www.eclipse.org/xtend/

- The projectional editor stores the abstract syntax of some model as an ordinary *EMF model*, enabling integration with any EMF-based tool for model transformations, code generation, etc.
- The projectional editor is *generic* inasmuch as an EMF model may be instantiated from an arbitrary metamodel (defining the abstract syntax of some modeling language) that provides universally unique identifiers for objects.
- So far, the projectional editor supports *textual representations*. However, its underlying design is extensible such that support for other representations (e.g., diagrams) may be added in the future.
- Deviating from Figure 2, *representations* are *persisted*, as well – again as EMF models. This approach allows to persist representation-specific information such as layout of text or diagrams (which may be improved manually by the modeler).
- The editor may be adapted to a specific modeling language by providing a *declarative syntax definition* which is used to map abstract to concrete syntax. No programming is required to this end.

Projectional editors are not a new invention. Rather, they were devised several decades ago as components of integrated programming environments; see (Medina-Mora and Feiler, 1981; Habermann and Notkin, 1986; Bahlke and Snelting, 1986; Ballance et al., 1992; Klint, 1993) for some early approaches. In this context, they were called *syntax-directed editors*. Currently, the *Meta Programming System* (*MPS*)[8] by *JetBrains* (Campagne, 2015) constitutes a contemporary framework for developing projectional editors – not just for text but also for other representations such as two-dimensional math notations, tables, or forms. MPS also provides support for language modularization as well as composition (Voelter, 2011). In (Ratiu et al., 2017), experiences with teaching MPS in industry are outlined. Recent research deals with support for incremental model transformations (Voelter et al., 2019).

While this framework is powerful, it comes with a proprietary data model. Instead of an open ecosystem, MPS provides a closed language workbench that requires its users to commit to the MPS data model and tool set. For defining languages, MPS uses hierarchies of concepts and their implementations: While in the world of EMF, the abstract syntax of a language may be defined by metamodels using arbitrary editors (e.g., the standard Ecore tree editor but also graphical editors), in MPS one concept is defined textually for each type in a separate file – similar to defining Java classes. Furthermore, instead of specifying the concrete syntax similar to a grammar, each concept provides an additional text file to describe the notation of the respective element. For defining custom scoping, validation, building a type system, etc. also a special textual notation is used instead of providing artifacts in a common general-purpose language.

[8]https://www.jetbrains.com/mps/

The rest of this paper is structured as follows: Section 2 provides an overview of our approach to projectional editing. Section 3 explains the functionality and the user interface of the projectional editor by outlining an exemplarily editing process within a sample ALF editor. Section 4 describes its underlying software architecture. Section 5 introduces the language that is used for context-free syntax definitions while Section 6 illustrates implementing static semantics by means of respective extension points. Finally, Section 7 concludes by an outlook on current and future work.

2 APPROACH

As stated above, projectional (syntax-directed) editing differs significantly from syntax-based editing since the abstract syntax rather than the concrete syntax serves as the primary artifact.

In the current implementation of our framework, we assume that the abstract syntax, i.e., the metamodel of the language to be developed, has been specified yet in terms of an Ecore model. In order to be used for arbitrary Ecore models, our framework has to be as generic as possible. Figure 3 depicts an overview of our basic editing approach within the EMF context. Two different kinds of users are distinguished: While the DSL Developer defines the context-free syntax of the language as well as the static semantics including scoping rules and type checking, the Modeler uses the configured editor for

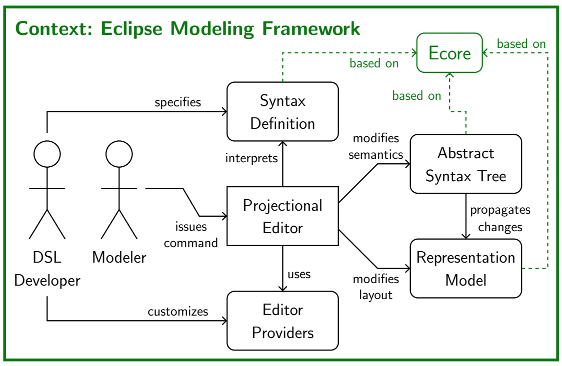


Figure 3: The editing approach of the framework.

creating and modifying models.

First, the DSL developer is considered. This actor defines the concrete syntax (cf. Section 5) as well as static semantics (cf. Section 6). From the metamodel describing the abstract syntax of the language, an incomplete editor plug-in is generated. It contains one (initially empty) text file where the DSL developer defines the context-free syntax; to this end, an intuitive textual language is used that allows for declarative syntax definitions. The projectional editor works with generic commands that are executed by interpreting the persisted syntax definition. In order to provide further customizations, in particular static semantics, code stubs are generated in which the DSL developer can override the default behavior, e.g., by specifying custom scoping rules and validation constraints. Our primary design decision was to generate only the most essential parts (i.e., a minimum number of lines of code) and to provide the main functionality, especially the edit commands, in global modules. As a result, the DSL developer is not bothered with a large number of generated code lines including technical details concerning the editing commands and the possible extension points which allow for customizing the default behavior become clearly visible.

After the context-free syntax and the static semantics have been specified completely, the modeler uses the editor (cf. Section 3) in order to alter a persisted, underlying model while the editor visualizes its representation that is also persisted such that view-specific information can be stored. After the abstract syntax tree has been modified by means of appropriate commands, the changes are propagated to the representation model. Apart from commands modifying the abstract syntax tree, several commands are provided in order to customize the representation (e.g., inserting layout elements) without having any impact on the abstract syntax tree.

The editing process in projectional editors is based upon commands which alter the underlying model. Consequently, free text editing is no longer possible even for textual representations (editing commands have to be used instead). However, we strive for an editing experience which comes close to free text editing. While our primary focus is a textual representation of the model, we do not want to limit ourselves to plain text. Instead the framework is designed in a way which allows for adding other model representations (diagrams, tables, etc.) in a later stage.

3 PROJECTIONAL EDITING

This section outlines the functionality of our framework from the modeler's point of view. After a general description, a sample scenario using the framework is demonstrated; the example considers the textual modeling language ALF for which a projectional editor is developed.

3.1 General Aspects

Figure 4 depicts a screenshot of the user interface of the editor. The major part of the editor constitutes the main pane (cf. part 1) that presents the representation of an underlying abstract syntax tree. The editor provides two modes from which the user may choose (cf. part 2): the *data mode* and the *view mode*. Depending on the chosen mode, adequate operations are provided by means of buttons (cf. part 3) when the user performs a selection within the main pane. For a representation element that is selected within the data mode, summarizing information about the underlying model element is provided (cf. part 4). Additionally, some independent operations – e.g., Undo and Redo – can be invoked (cf. part 5).

The data mode supports commands in the form of button events (cf. Figure 4, part 3) for editing the abstract syntax tree. After modifying the underlying model, the changes are propagated to the representation model and become visible at the user interface. The list of available commands depends on the selection performed by the user; besides single cells representing values, also representation elements of objects or structural features of them – which consist of several cells that are logically connected – can be selected. Editing commands comprise setting values and links, adding and removing objects, as well as adding and removing optional representation elements based on (boolean) structural features (e.g., the keyword abstract is visible if and only if the respec-

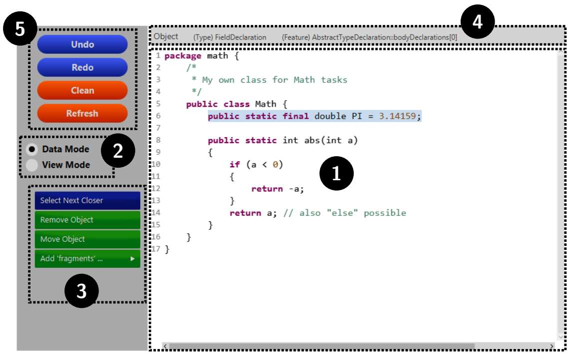


Figure 4: The editor user interface and its components.

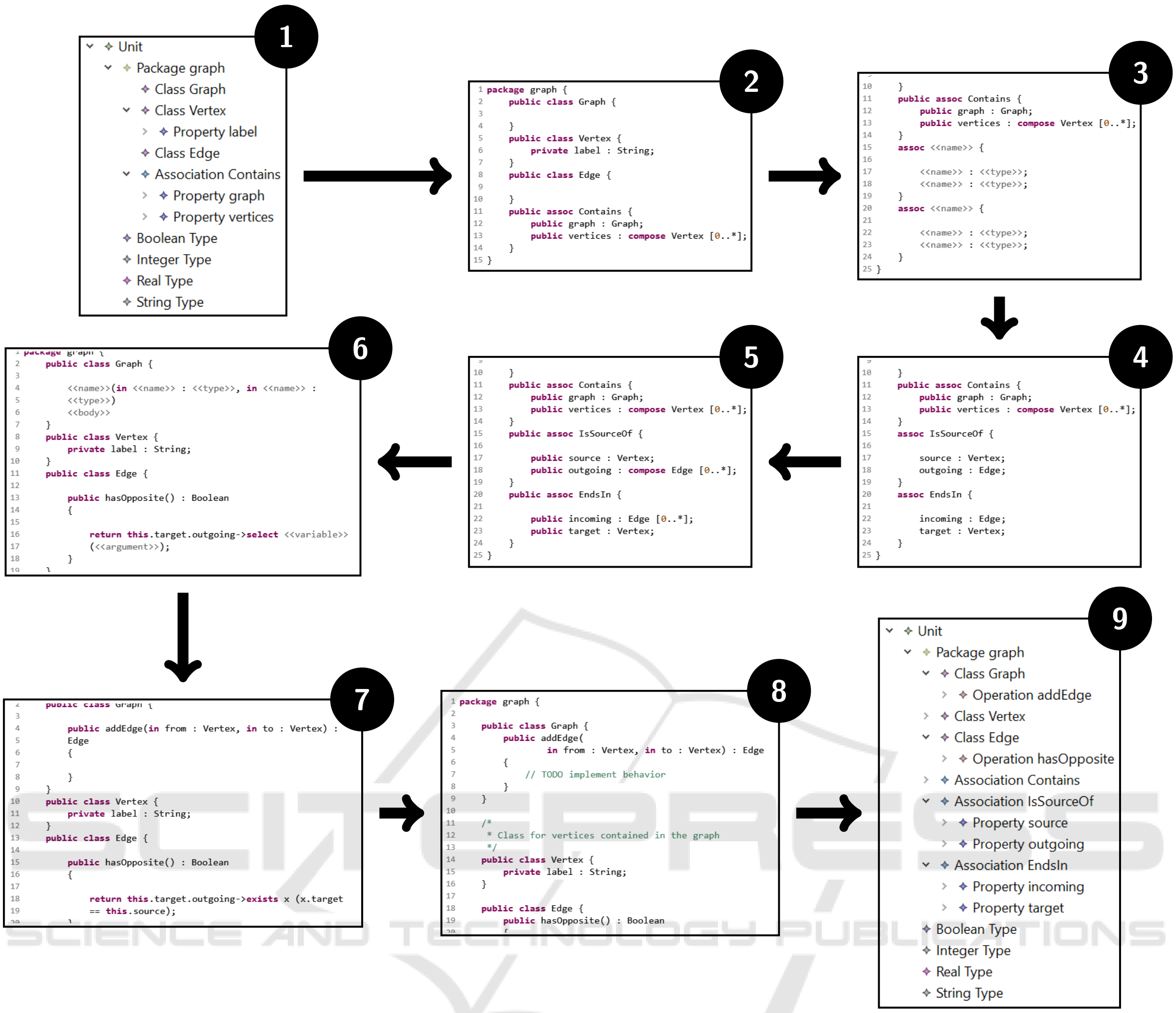


Figure 5: Exemplary editing workflow for an ALF model.

tive attribute isAbstract is set to true). Future work will deal with extensions and additional keyboard actions in order to provide a more comfortable look-and-feel when using the editor. In addition, the view mode supports commands which affect the representation only and do not affect the underlying abstract syntax tree. For instance, in order to modify the layout, space characters, tabulators, and line breaks can be inserted using keyboard events.

While the commands described above only consider an editing process that is performed completely within the editor, an independent evolution of the abstract syntax tree outside the editor is also captured. This facilitates a pretty flexible integration with other frameworks, e.g., the abstract syntax tree can be the target of a model transformation. For an incremental synchronization, a Refresh button is provided (cf. Figure 4, part 5). This process is also used for generating an initial representation model for a given abstract syntax tree; this action can be executed by means of a right-click operation on the model file containing the abstract syntax tree.

3.2 Example Scenario

We demonstrate the functionality of our framework for the textual modeling language ALF that allows for specifying models comprising structural as well as behavioral elements. An example workflow is shown in Figure 5. The general case is considered that the modeler starts with an initial abstract syntax tree which is modified and extended using the projectional editor within several subsequent editing steps. The initial abstract syntax tree (cf. step 1; the model is shown within the generic EMF model tree editor) has a package containing several classes and one association describing the structure of graphs. This model could also constitute the result of a model transformation with a UML model (class diagram) as its source model. Invoking the initial synchronization command results in creating the representation model for the given abstract syntax tree (cf. step 2; the model is displayed now in the projectional editor).

Next, two additional associations containing properties as their association ends are added. Neither values nor cross links have been specified yet (cf. step 3, gray placeholders represent representation elements for missing values, links, or child objects). Thereupon, the names of the association and its properties as well as the missing types are specified (cf. step 4). Currently, the objects are still not complete. After invoking commands for setting optional elements (e.g., visibilities and multiplicities), the missing information is added (cf. step 5).

During the next steps, operations are added. First, the objects are created. The operation hasOpposite() is also augmented with several values and child objects (name, return type, parameters, and body); for its implementation, a SequenceExpansionExpression instance is used that applies a functional operation to a collection (cf. step 6). Aside from the behavior of the operation addEdge(...), the objects are defined completely (cf. step 7).

Before finishing the editing process, representation commands are used in order to customize the layout by means of additional line breaks, whitespaces, etc. (cf. step 8). The commands modify the representation model while the underlying abstract syntax tree is not affected. In addition, some comments are inserted. Finally, the changes performed using the projectional editor are saved which stores the underlying abstract syntax tree as displayed in the EMF tree editor (cf. step 9).

4 ARCHITECTURE

This section describes the architecture of the framework. After a brief overview of involved (internal and external) components and their dependencies, the foundations of the representation metamodel are presented. Finally, details about the presentation within the editor are given.

4.1 Overview

Figure 6 depicts an overview of the models involved in a general editing workflow and the relationships between them. Currently, the framework works with exactly one model that contains the abstract syntax tree (AST Model). The metamodel of the AST model (AST Metamodel) may be an arbitrary Ecore model; besides the prerequisite that it constitutes an instance of Ecore using universally unique identifiers (UUIDs) for objects, there are no further assumptions or restrictions. For a specific metamodel, its concrete syntax is stored within the Syntax Definition Model (cf. Section 5). The editor (Editor GUI) shows a representation of the AST model (Representation Model, cf. Section 4.2). At runtime, a data structure (Representation/Presentation Mapping) stores the traces connecting graphical elements of the user interface with persisted representation elements (cf. Section 4.3).

Elements from the abstract syntax tree, the representation, and the syntax definition are connected by means of a Mapping Model. It persists the traces between the involved models storing different information and therefore serves as the technical background enabling the functionality of the editor and its commands. The structure of a model system containing mapping model, abstract syntax tree, representation model, and syntax definition model is depicted in Figure 7. Two kinds of mappings are distinguished: the *object mappings* and the *feature mappings* (where features refer to structural features). For each object within the abstract syntax tree (an EObject instance),

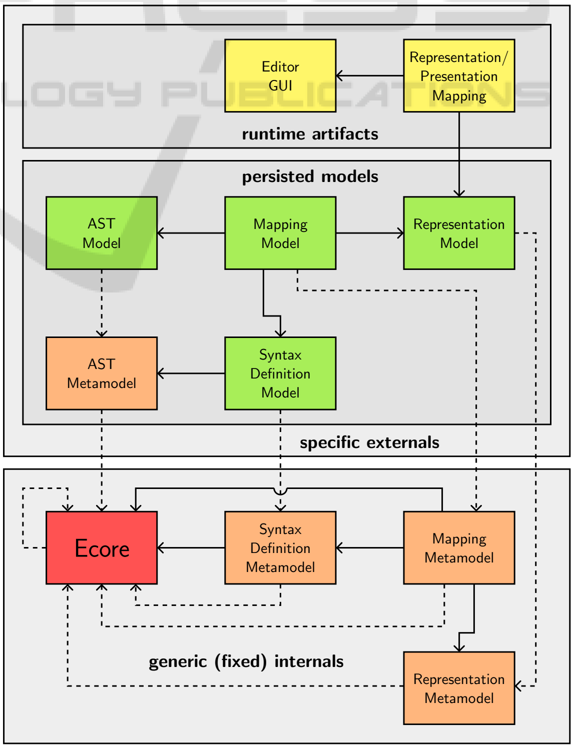


Figure 6: Overview of the underlying architecture. Solid arrows visualize dependencies in terms of references while dashed arrows indicate instanceOf-relationships.

the mapping model contains an object mapping. Each object mapping provides traces between the AST element, the respective representation element, and the underlying pattern within the syntax definition. Furthermore, elements within the syntax definitions that refer to structural features of the considered metamodel (e.g., the feature reference for the list of parameters within the pattern for operations) of the abstract syntax tree are connected with respective representation elements by means of feature mappings.

The mapping model contains its elements within a containment hierarchy corresponding to the objects within the abstract syntax tree as well as their representation objects. If an AST object o_1 is contained in the object o_2, the representation element r_1 (that represents o_1) is contained in r_2 (that represents o_2) and the object mapping m_1 (that maps o_1 to r_1) is contained in m_2 (that maps o_2 to r_2). Feature mappings are contained in the object mappings that refer to the respective objects within the abstract syntax tree.

4.2 Representation Concepts

The representation metamodel allows for instances that represent arbitrary abstract syntax trees. Currently, a purely textual representation is supported. The metamodel is designed in a way that allows for extensions with additional forms of representation, e.g., graphical representation. The concepts referring to textual representation are inspired by programming languages as Java. The model elements possess block or line structures: While a for-loop or a switch-statement in Java constitute block patterns containing head lines and bodies, assignments or arithmetic expressions are line patterns.

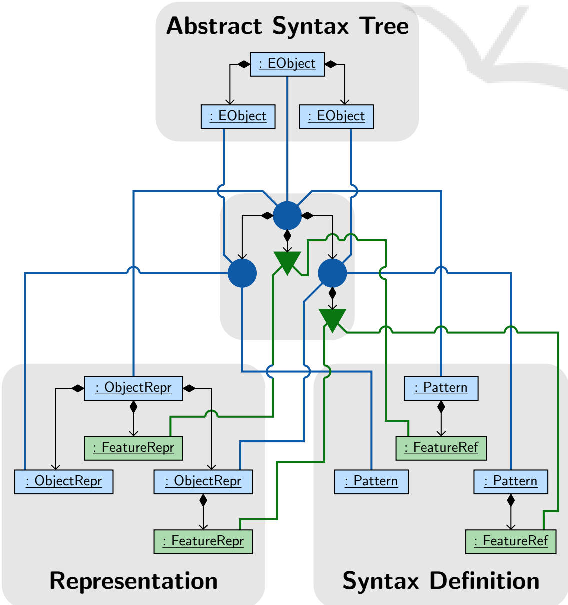


Figure 7: The structure of a mapping model containing mappings for objects (denoted by circles) as well as mappings for features (denoted by triangles). Diamond arrows visualize (direct or transitive) containment relations.

The simplified representation metamodel is shown in Figure 8. A block always contains a body and may have an optional head line and an optional tail line. A body has an indentation number and contains a collection of body elements. A body element is either a block or a line. A line instance constitutes the connection between block and line structure and describes a logical line that may comprise several physical lines. To this end, besides the cells storing the text visible to the user, a logical line contains line breaks; line breaks can be generated in order to ensure width bounds of the surrounding pane. Syntactically linked line elements can be grouped to fragments.

The representation models contain logical elements for object representations and feature representations. An object representation – which is connected to an AST object and a syntax definition element via a proper element within the mapping model – is either a block (block structure) or a fragment (line structure); a feature representation – that is connected to a corresponding syntax definition element via a mapping element – is either a body or a fragment. The design principle of logical lines instead of modeling a container object for each physical line facilitates modifications of the representation model with only a small effort when physical line breaks are added, removed, or moved, e.g., after cells and fragments have been changed.

4.3 From Representation to Presentation

The editor user interface visualizes the representation model using proper JavaFX elements. The Java-based

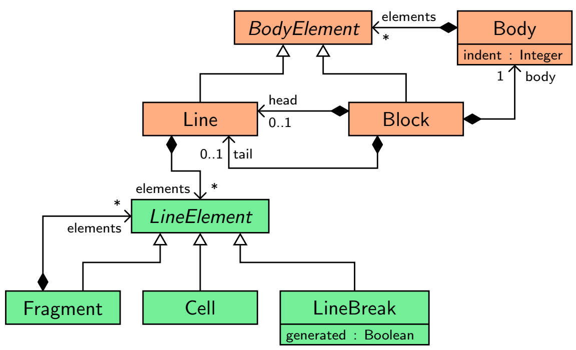


Figure 8: Kernel of the representation metamodel.

framework *JavaFX*[9] comes along with a GUI library for creating desktop and rich web applications. It includes special components to support an integration with *SWT* (*Standard Widget Toolkit*)[10], the graphical toolkit used for the Eclipse IDE. When the editor is saved, all model files involved in the model system – representation model, mapping model, and the abstract syntax tree – are saved.

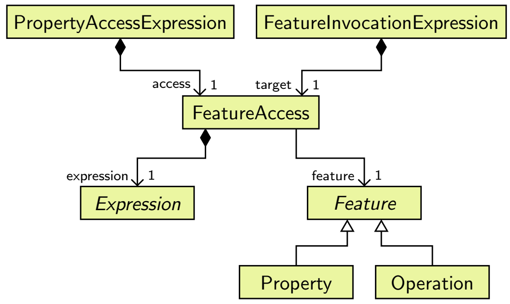
The major editor part is the main pane. For performance reasons, only a subset of all representation elements are mapped to corresponding GUI elements. Fragments are not mapped to presentation elements at all. Cells contained in the representation model are mapped to JavaFX labels. Blocks and their bodies are mapped to rectangles.

When a GUI element is created for a representation element, the trace that connects the runtime element and the persisted representation object is stored within a mapping structure. Using this data structure, the presentation can be modified incrementally when the representation model is changed.

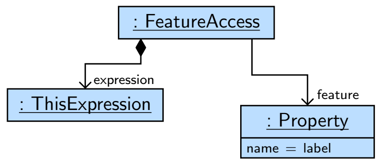
4.4 Sample Model System

In this section, the architecture concepts depicted above are applied to an exemplary cutout of an ALF model. Figure 9 shows the relevant part of the ALF metamodel as well as an example abstract syntax tree and its representation model. The cutout of the metamodel (cf. Figure 9a) refers to feature access expressions, i.e., references to ALF properties or calls of ALF operations. In this case, a reference of an ALF property is considered (cf. Figure 9b); the FeatureAccess object contains a ThisExpression and has an outgoing cross link to a Property instance. The representation model (cf. Figure 9c) consists of line elements only; it contains three cells which are grouped by means of fragments. For both references expression and feature, corresponding FeatureFragment objects are present. For the FeatureAccess and the ThisExpression objects within the abstract syntax tree, the representation model contains corresponding ObjectFragment objects.

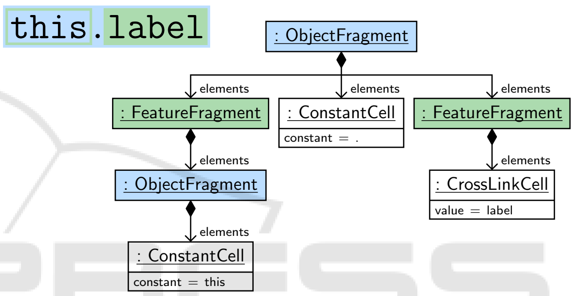
The abstract syntax tree, the representation elements, and the elements within the syntax definition are connected by mappings. An object mapping connects an object in the abstract syntax tree with the corresponding pattern in the syntax definition as well as the representation element (in this case an ObjectFragment object) in the representation model. Feature references within the syntax definition are connected with appropriate representation elements (in this case



(a) Cutout of the ALF metamodel.



(b) The abstract syntax tree as an instance.



(c) The corresponding representation model in concrete and in abstract syntax.

Figure 9: The model system for an exemplary ALF model.

FeatureFragment objects) by feature mappings. The object hierarchy of the abstract syntax tree is retained; the object mapping for the ThisExpression is contained in the one for the FeatureAccess instance. The feature mappings for the references are child elements of the object mapping for the FeatureAccess object.

The user interface of the projectional editor shows labels for the cells contained in the representation model. When the modeler, for instance, changes the referenced property, i.e., the value label is altered, first the cross link within the abstract syntax tree is modified, afterwards the cross link cell in the representation model is adapted, and finally the corresponding label of the user interface is changed.

5 CONTEXT-FREE SYNTAX DEFINITIONS

The context-free mapping from the abstract syntax to the concrete syntax is performed by means of projection rules. This section describes the structure and

[9]https://www.eclipse.org/efxclipse/index.html
[10]https://www.eclipse.org/swt/

feasibilities of the textual metalanguage for the projection rules as well as the editor for defining them. The language is exemplarily depicted by syntax definitions of some ALF elements that are visible in Section 3.2, Figure 5 which employ the most important language features.

5.1 The Syntax Definition Language

Analogously to the representation concepts (cf. Section 4.2), the structure comprises blocks and lines. The layout of the projection rules does not have any semantical background. Rather, keywords are used to describe blocks, bodies, lines, and line elements. For each non-abstract metaclass, several patterns can be defined. Each pattern is surrounded by the keywords def and enddef and is either a block pattern – containing an optional head directive, a body with a collection of body elements, and an optional tail directive – or a line pattern – containing a collection of line elements. Listing 1 depicts a projection rule that defines the syntax of ALF classes (Class objects) by means of a block pattern. It contains a head directive (cf. lines 2 ff.) as well as a body (cf. lines 7 ff.).

```
1  def Class
2    head [ftr visibility Visibility endftr]
3        ['abstract' ? isAbstract]
4        'class' ftr name String endftr
5        [ftr specialization seq cross Class
6        delim ',' endseq endftr]
7    body ind 4 ftr ownedMember delim '{' '}'
8      seq
9        Member
10     endseq
11 enddef
```

Listing 1: A projection rule for defining ALF classes.

Patterns contain feature references, i.e., elements referring to structural features. A feature reference is either a line element containing further line elements or a body containing body elements. All structural features of the class or of a supertype can be addressed by feature references contained in the patterns with the restriction that in each pattern, each structural feature is referenced at most once. The head directive of the pattern shown in Listing 1 contains aside from the keyword class feature references for the attributes visibility (cf. line 2) and name (cf. line 4) as well as the cross reference specialization (cf. lines 5 f.). All feature references in the head directive are line elements, starting with the keyword ftr followed by the name of the feature and ending with the keyword endftr with the containing line elements in between.

The feature references for the attributes visibility and name contain access elements for their values. While for the string value of the attribute name, the keyword String is provided (cf. line 4), the feature reference for the attribute visibility contains a link to the enumeration definition Visibility (cf. line 2, contains a link to Listing 3). Cross links (e.g., the links for the reference specialization) are denoted by the keyword cross followed by the expected type (in this case the metaclass Class, cf. line 5). Sequences of elements (e.g., sequences of referenced superclasses, cf. lines 5 f.) are represented by the surrounding keywords seq and endseq with an optional separator element between the elements (keyword delim). For optional fragments, square brackets are used – inspired by EBNF. Since neither a visibility value nor superclasses are mandatory elements within in the concrete syntax, the fragments are optional. Additionally, the keyword abstract is optional; it is bound to the boolean attribute isAbstract, i.e., the keyword is set if and only if the boolean value is set to true, denoted by the quotation mark followed by the respective boolean attribute (cf. line 3).

The body (cf. lines 7 ff.) constitutes another feature reference that refers to the containment reference ownedMember (keyword ftr) and possesses a specified indentation (keyword ind) as well as delimiters (keyword delim); while for sequences the keyword delim is followed by the separator (e.g., a comma for separating ALF parameters), for bodies it introduces the surrounding characters (e.g., curly brackets surrounding class bodies). The body of an ALF Class contains a collection of members. For containment references, the feature reference contains access to a pattern or an alias (cf. line 9, contains a link to the alias definition shown in Listing 2).

```
1 alias Member
2   (
3     line Property endline |
4     Operation
5   )
6 endalias
```

Listing 2: An alias for ALF properties and operations.

Members of ALF classes can be Property and Operation objects. In order to bundle the metaclasses, an alias Member can be defined that is shown in Listing 2. In contrast to patterns, aliases are named definitions for parts of patterns – as a kind of variables used several times – which do not refer to metaclasses. Disjunctions are denoted by surrounding parentheses and a delimiting pipe symbol – also inspired by EBNF. While operations have a block structure, a property has a line structure. Therefore, properties constitute line elements and not block elements; by means of surrounding line and endline keywords (cf. line 3), line elements can be converted into a block element in order to be compatible to the structure of the respective context.

While for primitive attributes, the keywords String, Integer, etc. are provided, for enumerations, special definitions are specified by using the keywords enum and endenum. Listing 3 depicts the enumeration rule for visibilities (referenced by Visibility in Listing 1). Enumeration literals are identified by their literal strings. After all the visible literals are defined (cf. line 2), an optional blank value can be added (cf. line 3); blank values are default values for which no literal is set within the concrete syntax (in this case, for package visibility, no keyword is provided by ALF).

```
1 enum Visibility
2   'public' 'private' 'protected'
3 blank 'package' endenum
```

Listing 3: An enumeration for ALF visibilities.

The editor commands for mapping the abstract syntax tree elements to elements of the representation models interpret the resulting syntax definition model. Block and line structures of the projection rules are mapped to block and line structures of the representation model. Line elements within the syntax definition (e.g., keywords and value access elements) are inserted in representation lines with separating whitespaces, by default. In order to prevent a whitespace at the specified position (e.g., for ALF multiplicities, the square brackets surround the bounds without any whitespaces), the keyword nospace is provided. In the representation model, bodies are contained in blocks with an indentation that is specified by the corresponding body in the syntax definition. In order to add additional empty lines within a body, the keyword extraline can be used.

5.2 The Syntax Definition Editor

For specifying the context-free syntax, a textual editor is provided. So far, for our framework we assume that the projection rules are fixed and do not change after they have been defined by the DSL developer. Currently, the editor is realized with Xtext. When the rules are specified completely, a persistent model is built from the text file that is used for references within the architecture of the framework.

Besides comfortable tool support as highlighting, hovering, and code completion, the editor comes along with a validator that checks for compliance with several constraints. One significant constraint is that referenced patterns for child objects are compatible to the context. The type of a referenced pattern within a feature reference must conform to the type of the feature reference. Apart from type compatibility, also structural compatibility must be ensured; an object with block structure cannot be contained in a line, for instance. Furthermore, for each metaclass, all patterns must be unique with respect to the names.

For the future, we plan a bootstrapping process that provides for using our editor for the syntax definition language in order to avoid dependencies to third-party frameworks.

6 IMPLEMENTING STATIC SEMANTICS

This section describes the extension points to our framework for defining static semantics of the languages that are implemented by the DSL developers. When a plug-in is generated for a language, empty high-level code stubs are generated which can be implemented by the DSL developer. We strive for a very user-friendly environment which makes customizing the providers as intuitive as possible. Future work comprises support for custom validation, code highlighting, hovering, etc.

Listing 4 shows a cutout of the scope provider for ALF as the example language (cf. Section 3.2, Figure 5). Currently, Xtend stubs, i.e., the head lines of Xtend classes, are generated; within the class body, custom scoping rules can be defined by overriding the related method. For the future, we plan to change from Xtend to Java stubs to avoid dependencies to third-party frameworks. The language-specific class AlfScopeProvider inherits from the default implementation DefaultScopeProvider (cf. line 2) that provides the method getScope(...); it is called when a link from a context element to a target element – that is identified by a specified value, e.g., its name – is resolved. The method provides a parameter for the context element and another one for the reference (cf. lines 4 f.).

The scope provider refers to the cutout of the ALF metamodel shown in Figure 9a. In this scenario, the cross reference FeatureAccess::feature is considered (cf. lines 7 f.). A FeatureAccess object links to a Feature instance, i.e., a Property – then the feature access object is contained in a PropertyAccessExpression object – or an Operation object – then it is contained in a FeatureInvocationExpression object. The listing depicts the case where the context element (a FeatureAccess instance) is directly contained in a PropertyAccessExpression (cf. lines 11 f.) – i.e., it links to a Property instance – and a ThisExpression is specified (cf. lines 13 f.) – i.e., the properties within the surrounding classifier or a supertype are taken into account. For simplification reasons, no association ends are considered by this listing (they are not contained in the member classes). Visibilities are not considered since respective constraints are usually captured by an additional validation provider in order to provide adequate error information. The method hierarchy(...) (cf. line 19) returns the inheritance hierarchy built by the given classifier and its supertypes. The scope is built hierarchically, in the opposite order of the classifier hierarchy (by using the method reverseView(...), cf. line 20).

```
1  class AlfScopeProvider
2      extends DefaultScopeProvider {
3
4    override getScope(
5        EObject contextElem, EReference ref) {
6
7      if (ref == AlfPackage.Literals
8          ::FEATURE_ACCESS__FEATURE) {
9        val fr = contextElem as FeatureAccess
10
11       if (fr.eContainer instanceof
12               PropertyAccessExpression &&
13           fr.expression instanceof
14               ThisExpression) {
15         var scope = Scope::BOTTOM_SCOPE
16         val contClz = contextElement
17             .getContainerOfType(Classifier)
18
19         for (clz : contClz.hierarchy
20             .reverseView) {
21           val EList<EObject> properties =
22               clz.ownedMember
23               .filter[it instanceof Property]
24               .newBasicEList
25           scope = Scope::createScope(
26               properties, scope)
27         }
28         return scope
29       }
30     }
31     ...
32   }
33 }
```

Listing 4: A cutout of the scope provider for ALF.

For each classifier in the hierarchy, its contained properties are added to the scope (cf. lines 21 ff.). A scope comprises a collection of objects as well as a reference to another scope (the next scope). This forms a chain of scopes which provides shadowing strategies; when a link is resolved, the chain is traversed successively. The end of the chain constitutes the bottom scope that does not contain any objects (cf. line 15). Additionally, each scope has an identifying strategy that describes the mapping between string values and link target objects. By default, objects within a scope are identified by their names. The method createScope(...) (cf. lines 25 f.) returns a scope for a specified collection of objects as well as the given next scope. In order to provide a customized identifying strategy – e.g., for primitive types –, an extended method is available that comes along – besides parameters for the elements and the next scope – with a parameter for the identifying strategy (not shown in the listing).

7 CONCLUSION

In this paper we presented our framework for generic projectional editors for arbitrary EMF models. In contrast to syntax-based editors which are derived from the grammar of a modeling language and which persist the representation, e.g., text, instead of model files, our approach allows for persisting models including the preservation of inter-model references. The main benefit of persisting models instead of their representations, e.g., plain text, is a much easier integration in the existing EMF modeling ecosystem as existing tools and technologies for processing the obtained models can be used out of the box.

In its current state, the framework allows developing customized textual editors for textual languages with minimal effort. While the context-free syntax of the language is specified by means of an intuitive declarative language, static semantics can be customized by implementing high-level code stubs. The feasibility of our approach has been demonstrated by a projectional editor for the textual modeling language ALF.

Future work comprises the integration of other model representations including diagrams and tables and support for user-specific validation, code highlighting, hovering, etc. Concepts for language imports and compositions will be taken into consideration, as well. Furthermore, we plan to remove dependencies to the Xtext and Xtend implementations.

REFERENCES

Bahlke, R. and Snelting, G. (1986). The PSG system: From formal language definitions to interactive programming environments. *ACM Trans. Program. Lang. Syst.*, 8(4):547–576.

Ballance, R. A., Graham, S. L., and de Vanter, M. L. V. (1992). The pan language-based editing system. *ACM Trans. Softw. Eng. Methodol.*, 1(1):95–127.

Behringer, B., Palz, J., and Berger, T. (2017). Peopl: projectional editing of product lines. In Uchitel, S., Orso, A., and Robillard, M. P., editors, *Proceedings of the 39th International Conference on Software Engineering, ICSE 2017, Buenos Aires, Argentina, May 20-28, 2017*, pages 563–574. IEEE / ACM.

Bettini, L. (2014). Developing user interfaces with EMF parsley. In Holzinger, A., Cardoso, J. S., Cordeiro, J., van Sinderen, M., and Mellor, S. J., editors, *ICSOFT-PT 2014 - Proceedings of the 9th International Conference on Software Paradigm Trends, Vienna, Austria, 29-31 August, 2014*, pages 58–66. SciTePress.

Bettini, L. (2016). *Implementing Domain-Specific Languages with Xtext and Xtend*. Packt Publishing Ltd., Birmingham B3 2PB, UK, second edition.

Campagne, F. (2015). *The MPS Language Workbench*, volume I. Fabien Campagne, second edition.

Habermann, A. N. and Notkin, D. (1986). Gandalf: Software development environments. *IEEE Trans. Software Eng.*, 12(12):1117–1127.

Heidenreich, F., Johannes, J., Karol, S., Seifert, M., and Wende, C. (2011). Model-based language engineering with emftext. In (Lämmel et al., 2013), pages 322–345.

Klint, P. (1993). A meta-environment for generating programming environments. *ACM Trans. Softw. Eng. Methodol.*, 2(2):176–201.

Lämmel, R., Saraiva, J., and Visser, J., editors (2013). *Generative and Transformational Techniques in Software Engineering IV, International Summer School, GTTSE 2011, Braga, Portugal, July 3-9, 2011. Revised Papers*, volume 7680 of *Lecture Notes in Computer Science*. Springer.

Madiot, F. and Paganelli, M. (2015). Eclipse sirius demonstration. In Kulkarni, V. and Badreddin, O., editors, *Proceedings of the MoDELS 2015 Demo and Poster Session co-located with ACM/IEEE 18th International Conference on Model Driven Engineering Languages and Systems (MoDELS 2015), Ottawa, Canada, September 27, 2015.*, volume 1554 of *CEUR Workshop Proceedings*, pages 9–11. CEUR-WS.org.

Medina-Mora, R. and Feiler, P. H. (1981). An incremental programming environment. *IEEE Trans. Software Eng.*, 7(5):472–482.

OMG (2017a). *Action Language for Foundational UML (ALF)*. Object Management Group, Needham, MA, formal/2017-07-04 edition.

OMG (2017b). *Unified Modeling Language (UML)*. Object Management Group, Needham, MA, formal/2017-12-05 edition.

OMG (2018). *Semantics of a Foundational Subset for Executable UML Models (fUML)*. Object Management Group, Needham, MA, formal/2018-12-01 edition.

Ratiu, D., Pech, V., and Dummann, K. (2017). Experiences with teaching MPS in industry: Towards bringing domain specific languages closer to practitioners. In *20th ACM/IEEE International Conference on Model Driven Engineering Languages and Systems, MODELS 2017, Austin, TX, USA, September 17-22, 2017*, pages 83–92. IEEE Computer Society.

Steinberg, D., Budinsky, F., Paternostro, M., and Merks, E. (2009). *EMF Eclipse Modeling Framework*. The Eclipse Series. Addison-Wesley, Boston, MA, 2nd edition.

Voelter, M. (2011). Language and IDE modularization and composition with MPS. In (Lämmel et al., 2013), pages 383–430.

Voelter, M., Birken, K., Lisson, S., and Rimer, A. (2019). Shadow models: incremental transformations for MPS. In Nierstrasz, O., Gray, J., and d. S. Oliveira, B. C., editors, *Proceedings of the 12th ACM SIGPLAN International Conference on Software Language Engineering, SLE 2019, Athens, Greece, October 20-22, 2019*, pages 61–65. ACM.

Völter, M., Siegmund, J., Berger, T., and Kolb, B. (2014). Towards user-friendly projectional editors. In Combemale, B., Pearce, D. J., Barais, O., and Vinju, J. J., editors, *Software Language Engineering - 7th International Conference, SLE 2014, Västerås, Sweden, September 15-16, 2014. Proceedings*, volume 8706 of *Lecture Notes in Computer Science*, pages 41–61. Springer.

Yue, J. (2014). Transition from EBNF to xtext. In Sauer, S., Wimmer, M., Genero, M., and Qadeer, S., editors, *Joint Proceedings of MODELS 2014 Poster Session and the ACM Student Research Competition (SRC) co-located with the 17th International Conference on Model Driven Engineering Languages and Systems (MODELS 2014), Valencia, Spain, September 28 - October 3, 2014.*, volume 1258 of *CEUR Workshop Proceedings*, pages 75–80. CEUR-WS.org.