Identifying and Measuring Potential Reuse in Legacy Domain-Specific Languages

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Abstract. The use of domain-specific languages (DSLs) has become a successful technique in the implementation of complex systems. However, the construction of this type of languages is time-consuming and requires highly-specialized knowledge and skills. Hence, researchers are currently seeking approaches to leverage reuse during the DSLs development in order to minimize implementation from scratch. An important step towards achieving this objective is to identify commonalities among existing DSLs. These commonalities constitute potential reuse that can be exploited by using reverse-engineering methods. In this paper, we present an approach intended to identify sets of DSLs with potential reuse. We also provide a mechanism that allows language designers to measure such potential reuse in order to objectively evaluate whether it is enough to justify the applicability of a given reverse-engineering process. We validate our approach by evaluating a large amount of DSLs we take from public `GitHub` repositories.

1 Introduction

The use of domain-specific languages (DSLs) has become a successful technique to achieve separation of concerns in the development of complex systems [8]. A DSL is a software language in which expressiveness is scoped into a well-defined domain that offers a set of abstractions (a.k.a., language constructs) needed to describe certain aspect of the system [6]. For example, in the literature we can find DSLs for prototyping graphical user interfaces [22], specifying security policies [17], or performing data analysis [10].

Naturally, the adoption of such language-oriented vision relies on the availability of the DSLs needed for expressing all the aspects of the system under construction [4]. This fact carries the development of many DSLs which is a challenging task due the specialized knowledge it demands. A language designer must own not only quite solid modeling skills but also the technical expertise for conducting the definition of specific artifacts such as grammars, metamodels, compilers, and interpreters. As a mater of fact, the ultimate value of DSLs has been severely limited by the cost of the associated tooling (i.e., editors, parsers, etc...) [13].

To improve cost-benefit when using DSLs, the research community in software languages engineering has proposed mechanisms to increase reuse during the construction of DSLs. The idea is to leverage previous engineering efforts and minimize implementation from scratch [24]. These reuse mechanisms are based on the premise that "software languages are software too" [11] so it is possible to use software engineering techniques to facilitate their construction [14]. In particular, there are approaches that take ideas from Component-Based Software Engineering (CBSE) [5] and Software Product Lines Engineering (SPLE) [27] during the construction of new DSLs.

A classical way for adopting the aforementioned reuse mechanisms is to group language constructs into interdependent language modules that can be later extended and/or imported as part of the specifications of future DSLs. This type of solution has ultimately gained momentum and, nowadays, there are a diversity of approaches that facilitate such modular DSLs design [23,19,15]. However, the definition of language modules that can be actually useful in future DSLs is not easy. In part, this is due to the fact that the reuse of a language module implies the reuse of all the constructs it offers and language designers do not always have the information that allow them to predict the correct combination of constructs that go well together. What is the correct level of granularity? Are there constructs that should be always together? Are there constructs that should be always separated?

A more pragmatical approach to leverage reuse in the construction of DSLs is to focus on legacy DSLs [9]. That is, to exploit reuse in existing DSLs that are were not necessarily built for being reused but that share some commonalities (i.e., they provide similar language constructs). Using this strategy, language designers can obtain valuable reuse information from real DSLs. For example, they can identify groups of constructs that are frequently used together. Then, a catalog of language modules can be extracted from the commonalities of the DSLs by means of reverse-engineering methods. As the reader may guess, the very first step towards the application of such *a posteriori* reuse strategy is to identify commonalities within a set of existing DSLs. Ideally, this process should be automatic because comparing constructs manually can be time consuming and error prone. In addition, language designers should have mechanisms to objectively evaluate whether those commonalities represent potential reuse enough to justify the effort associated to a reverse-engineering process.

In this paper, we present an approach that takes as input a set of DSLs and identifies the commonalities existing among them. To do so, we perform static analysis on the artifacts where the DSLs are specified and compare language constructs at the level of the syntax and semantics. Besides, our approach computes a set of metrics that permit to objectively evaluate those commonalities. This second part of our approach is based on some reuse metrics already proposed in the literature for the general case of software development [1,2] that we adapt them to the specific case of DSLs development.

As a validation for our approach, we conducted an empirical study were we take an important amount of DSLs available on `GitHub` public repositories. The idea is to use our approach for identifying potential reuse in those DSLs. The results were quite promising; they show that there is a large amount of sets of DSLs that share language constructs so reuse opportunities are evident. All the ideas presented in this paper are implemented in an Eclipse-based tool that can be downloaded and installed as well as the validation scenarios.

This paper is organized as follows: Section 2 introduces a set of preliminary definitions/assumptions as well as some motivating examples that we use all along the paper. Section 3 describes our approach. Section **??** presents the empirical study that validates the approach. Section **??** discusses the threads to validity. Section **??** presents the related work and, finally, Section **??** concludes the paper.

2 Preliminary Definitions

2.1 Domain-Specific Languages in a nutshell

Specification: Like general purpose languages (GPLs), DSLs are defined in terms of syntax and semantics [12]. Hence, the specification of a DSL is a tuple $< syn, sem, M_{syn\leftarrow sem} >$ [7]. The parameter syn (the ***syn**tax*) refers to the structure of the DSL and specifies each language construct in terms of its name and the relationships it has with other language constructs. In turn, the parameter sem (the ***sem**antics*) refers to the meaning of the language constructs. This meaning corresponds to the dynamic behavior that establishes the manner in which language constructs are manipulated at runtime. Finally, the parameter $M_{syn\leftarrow sem}$ refers to the mapping between the language constructs and the semantics.

Technological space: Currently, there are diverse techniques available for the implementation of syntax and semantics of DSLs [20]. Language designers can, for example, choose between using context-free grammars or metamodels as specification formalism for syntax. Similarly, there are at least three methods for expressing semantics: operationally, denotationally, and axiomatically [21]. In this paper we are interested on DSLs which syntax is specified by means of metamodels and semantics is specified operationally as a set methods (a.k.a, *domain-specific actions* [7]). Each language construct is specified by means a metaclass and the relationship between language constructs are specified as references between metaclasses. In turn, domain-specific actions are specified as java-like methods that are allocated in each metaclass.

Implementation: In order to implement a DSL, language designers need a tool set that offer capabilities to specify a DSL according to the selected technological space. This kind of tool sets are provided by language workbenches (such as Eclipse Modeling Framework or MetaEdit+) that provide meta-languages for where syntax and semantics can be expressed. The ideas presented in this paper are implemented in an Eclipse-based language workbench. In particular, metamodels are specified in the Ecore language whereas domain-specific actions are specified as methods in Xtend programming language[1]. The mapping between metaclasses and domain-specific actions is specified by using the notion of aspect introduced by the Kermeta 3[2] and Melange[3] as explained in [9].

2.2 On the notions of *commonalities* and *potential reuse* in DSLs

By definition, DSLs are scoped to specific domains so they provide restricted set of language constructs. As a result, there is a proliferation of many DSLs in the literature each of which is useful in certain application contexts [20]. Although many of those existing DSLs are completely different and tackle independent domains; there are related DSLs with overlapping domains [25, p. 60-61]. That is, they share certain language constructs i.e., they have **commonalities** between them. If two DSLs have commonalities and they are specified in the same technological space and using compatible language workbenches, then there is **potential reuse** since the specification of those shared constructs can be specified once and reused in the two DSLs [25, p. 60-61].

Naturally, commonalities can be found not only at the level of the syntax but also at the level of the semantics. For the technological space discussed in this paper, syntactic commonalities appear where DSLs share some metaclasses and semantic commonalities appear where DSLs share some domain-specific actions.

Example: Let us now introduce a toy example to illustrate the concepts introduced so far. Consider the following set of three DSLs:

- **Finite State Machines (FSM):** FSM is a DSL for expressing simple state machines with states and transitions between the states. Each state has an associated action that allow the modification of some data (variables) in a given execution context. In turn, each transition may define a guard (evaluated in the execution context) that expresses the condition(s) under the transition can be fired.
- **Logo:** Logo is a DSL for expressing movements of the classical Logo turtle used in elementary schools for teaching the first foundations of programming. This DSL offers the constructs for moving a turtle forward and backward, as well for rotating the turtle at the left or at the right. In addition, the DSL offers simple arithmetic expressions for indicating the distance/angles the must should move/rotate.
- **Flowchart:** Flowchart is a DSL for expressing simple flow diagrams. Each flow is a sequence of nodes and arcs between them. An arc can be either an action or a decision. An action is a set of instructions that modify some variables in the execution context. A decision is a bifurcation point where depending on a given condition the flow goes from a direction or another.

[1] `http://www.eclipse.org/xtend/`
[2] `https://github.com/diverse-project/k3/wiki/Defining-aspects-in-Kermeta-3`
[3] `http://melange-lang.org/`

These DSLs are essentially different. Each of them is focus on a particular domain and offers different language constructs. However, there are syntactic and semantic commonalities that are illustrated in Figure 1. All the thee DSLs offer some expressions for modifying variables. In the case of FSM these actions are needed the specification of the actions in the states; in the case of Logo expressions are needed to specity the movement and rotation parameters; and in the case of flowchart expressions are needed to specify the body of actions. In addition, both FSM and Flowchart rely on a constraints language. The former for expressing guards in the transitions and the later for expressing guards of the decisions.

Note that each DSL is specified in terms of a set of metaclasses (top of the figure), and a set of aspects (bottom of the figure) that weave some domain-specific actions to the metaclasses. In the case of this example, the semantics of the metaclasses expression and constraints are also shared. That means that the semantics are the same.

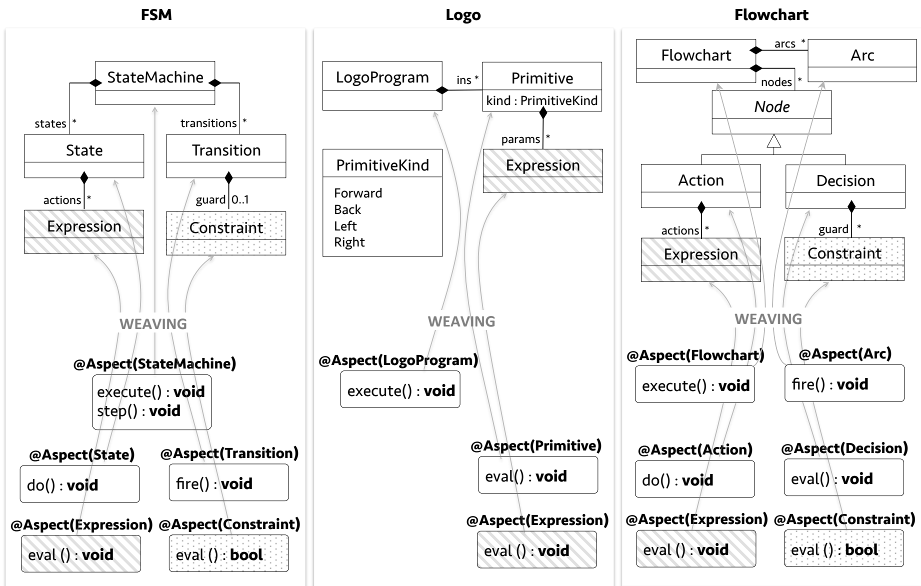

Fig. 1: Commonalities between domains and potential reuse

Semantical variability: It is worth to mention that the fact that two metaclasses are shared does not imply that all their domain specific actions are the same. We refer to that phenomenon as *semantical variability.* There are two constructs that share the syntax but that differ in their semantics. In such case, there is potential reuse at the level of the syntax since the metaclass can be defined once and reused in the DSLs but the semantics should be defined differently for each DSLs.

3 Proposed approach

Given a set of existing DSLs (that we term as the *input set*) our approach is intended to identify commonalities –and so, potential reuse–. Then, we provide some metrics that permit to objectively evaluate those commonalities. The reminder of this section explain how we tackle this problem.

3.1 Identifying commonalities

In the first part of our approach, we perform static analysis in syntax and semantics of a given set of DSLs in order to build a pair of Venn diagrams that allows language designers to easily visually identify commonalities among DSLs under study. The idea is to visualize each DSL as a pair of two sets: The first one is a set of metaclasses representing the syntax, and the second one is a set of domain-specific actions representing the semantics. Syntactic and semantic commonalities are represented as intersections between the corresponding sets. To this end, we designed an algorithm that is able to compute the all intersections among the syntax of the DSLs in the input set.

Our algorithm for detecting **syntactic intersections** can be described as by the function that receives a set of metamodels (one for each DSL of the input set) and returns a set of tuples containing all the intersections among these metamodels. Note that there can be intersections among any of the combinations of the input set. Hence, in the result there is a tuple for each of the possible combinations of the input metamodels (i.e., the power set). Similarly, our algorithm for detecting **semantic intersections** can be described as a function that receives a set of aspects (one for each DSL of the input set) and returns a set of tuples containing all the intersections among these aspects.

Comparison operators: A syntactic intersection is a set of metaclasses that are equal in two or more DSLs. Similarly, a semantic intersection is a set of domain-specific actions that are equal in two or more DSLs. At this point we need to clearly define the notion of equality between metaclasses and domain-specific actions. That is, we need to establish the criteria under we consider that two metaclasses/domain-specific actions are equal.

- **Comparison of metaclasses:** The name of a metaclass usually corresponds to a word that evokes the domain concept the metaclass represents. Thus, intuitively one can think that a first approach to compare meta-classes is by comparing their names. As we will see later in this paper, this approach results quite useful and it is quite probable that, we can find potential reuse.

$$MC_A \doteq MC_B = true \implies MC_A.name = MC_B.name \tag{1}$$

Unfortunately, comparison of metaclasses by using only their names might have some problems. There are cases in which two meta-classes with the same name are not exactly the same since they do not represent the same domain concept or because there are domains that use similar vocabulary. In such cases, an approach that certainly helps is to compare meta-classes not only by their names but also by their attributes and references. Hence, we define a second comparison operator for metaclasses i.e., $\div$.

$$\begin{aligned} MC_A \div MC_B = true \implies & \\ & MC_A \doteq= MC_B \wedge \\ & \forall a_1 \in MC_A.attr \mid (\exists a_2 \in MC_B.attr \mid a_1 = a_2) \wedge \\ & \forall r_1 \in MC_A.refs \mid (\exists r_2 \in MC_B.refs \mid r_1 = r_2) \end{aligned} \tag{2}$$

Although this second approach might be too restrictive, it implies that the specification of the two meta-classes are exactly the same so potential reuse is guaranteed. At the implementation we provide support for the two comparison approaches explained above. However, additional comparison operators such as the surveyed in [16] can be easily incorporated.

- **Comparing domain-specific actions:** Like methods in Java, domain-specific actions have a signature that specifies its contract (i.e., return type, visibility, parameters, name, and so on), and a body where the behavior is actually implemented. In that sense, the comparison of two domain-specific actions can be performed by checking if their signatures are equal. This approach is practical and also reflects potential reuse; one might think that the probability that two domain-specific actions with the same signatures are the same is elevated.

$$\begin{aligned} DSA_A \mathrel{\overset{\circ}{=}} DSA_B = true \implies & \\ & DSA_A.name = DSA_B.name \wedge \\ & DSA_A.returnType = DSA_B.returnType \wedge \\ & DSA_A.visibility = DSA_B.visibility \wedge \\ & \forall p_1 \in DSA_A.params \mid (\exists p_2 \in DSA_B.params \mid p_1 = p_2) \end{aligned} \tag{3}$$

However, as the reader might imagine, there are cases in which signatures comparison is not enough. Two domain-specific actions defined in different DSLs can perform different computations even if they have the same signatures. As a result, a second approach relies in the comparison of the bodies of the domain-specific actions. Note that such comparison can be arbitrary difficult. Indeed, if we try to compare the behavior of the actions we will have to deal with the semantic equivalence problem that, indeed, is known as be undecidable [18]. In this case, we a conservative approach is to compare only the structure (abstract syntax tree) body of the domain-specific action. To this end, we use the API for java code comparison proposed in [3].

$$DSA_A \triangleq DSA_B = true \implies \\ DSA_A \circeq DSA_B \wedge \\ DSA_A.AST = DSA_B.AST \tag{4}$$

Visualizing the results: Figure 2 shows the Venn Diagram for the case of our motivating scenario. In that figure we can see that the family is an overlapping family in terms of the abstract syntax. In the case of the semantics the results are quite interesting. Note that depending on the type of comparison operator we have different results. When the comparison operator is the naming, we have the same overlapping shape that in the case of the abstract syntax. However, when the operators become more restrictive the overlapping region is reduced.

3.2 Measuring potential reuse

As a second part of our analysis, we propose a quantitative evaluation of the potential reuse represented as commonalities in a set of DSLs. Such evaluation is based on the metrics introduced in [1] which are originally defined for software products in general and that we adapted for the case where the software products are domain-specific languages. We choose these metrics because they perfectly fit in the idea of conceiving potential reuse as intersections of Venn diagrams and because they were already evaluated in an industrial case study [2].

Figure 3 shows the reuse metrics graphically. They are intended to normalize the size of the commonalities existing among the DSLs of the input set. To do so, the idea is to see the intersections in terms of percentages. Hence, they answer questions such as: what is the percentage of language constructs of a given DSL that are also defined in another DSL in the input set? In this section we present these metrics in terms of the formulas we used to compute them. It is important to remember that the results provided by those metrics also depend on the comparison operator.

- **Size of Commonality (SoC):** The size of commonality metric is intended to measure the amount of metaclasses and domain-specific actions that are shared by all the DSLs in the input set. It is defined as the size of the intersection of all the DSLs in the input set.

  The usefulness of this metric relies on the identification of a common *core* among all the DSLs. This is quite relevant because there are certain reuse approaches for DSLs (such as the one presented in [26]) where the existence of a core is a prerequisite.

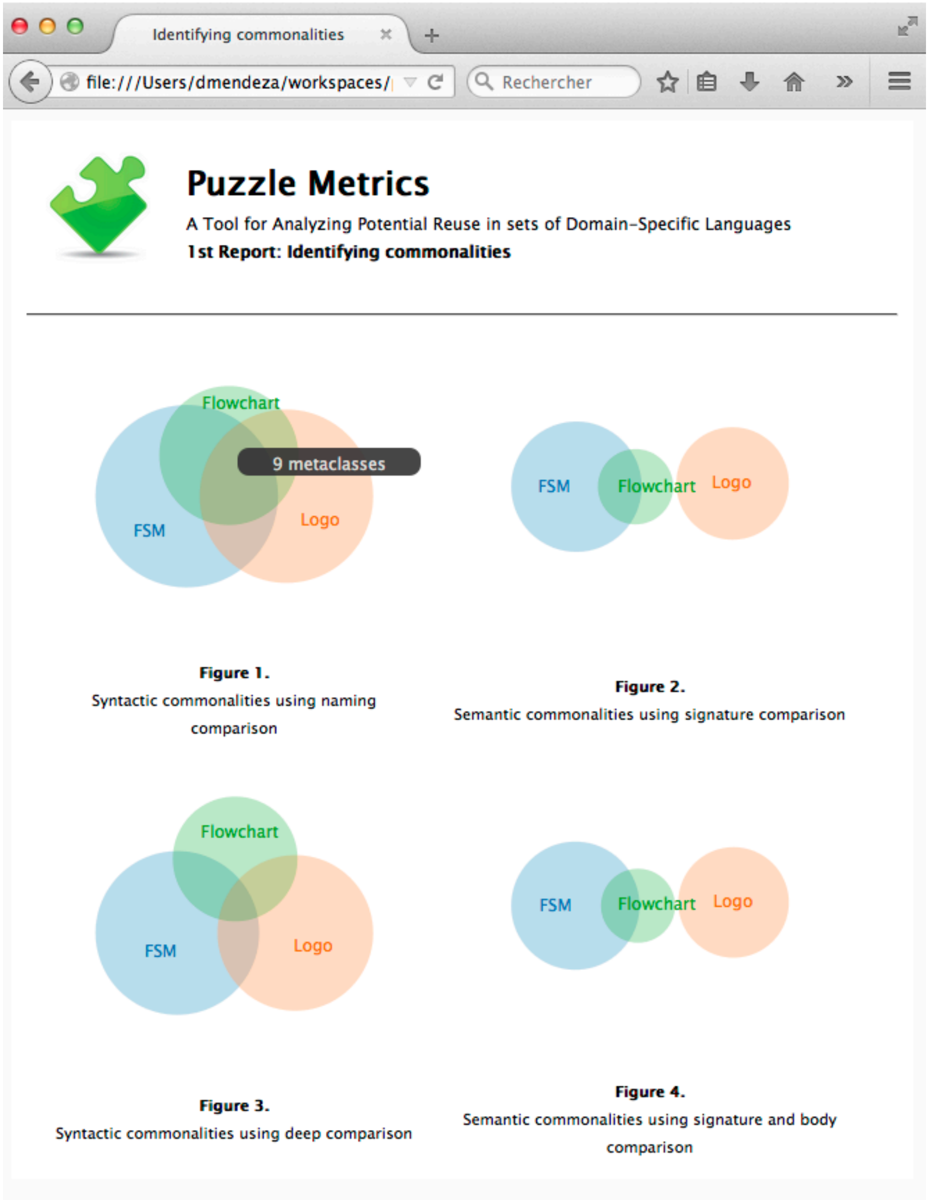

Fig. 2: Visualizing syntactic and semantic commonalities

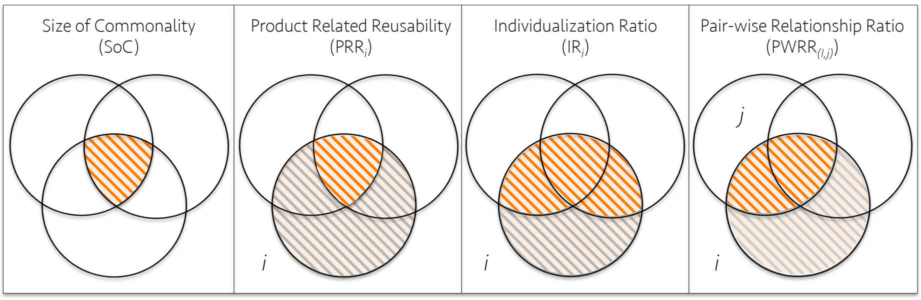

Fig. 3: Metrics for evaluation of potential reuse

$$SoC_{syn}(dsls) = |\bigcap_{i=0}^{|dsls|} dsls_i.syn| \tag{5}$$

$$SoC_{sem}(dsls) = |\bigcap_{i=0}^{|dsls|} dsls_i.sem| \tag{6}$$

– **Product-Related Reusability (PRR_i):** The product-related reusability is a metric that, for each DSL of the input set, measures the percentage of the metaclasses and domain-specific actions that are defined in the core detected by the SoC metric. It permits to see how related is each DSL with the core of the input set.

$$PRR_{syn}(dsls, i) = \frac{|dsls_i.syn|}{SoC_{syn}(dsls)} \times 100\% \tag{7}$$

$$PRR_{sem}(dsls, i) = \frac{|dsls_i.sem|}{SoC_{sem}(dsls)} \times 100\% \tag{8}$$

– **Individualization Ratio (IR_i):** The individualization ratio is a metric that, for each DSL in the input set, measures the percentage of the metaclasses and domain-specific actions that are common with at least another DSL. This metric shows how particular is each language. That is, how many metaclasses and domain-specific actions are tailor-made for the DSL.

$$IRsyn(dsls, i) = \frac{|dsls_i.syn|}{|\{x \mid (\exists d \in dsls \mid d \neq dsl_i \wedge x \in d.syn)\}|} \times 100\% \tag{9}$$

$$IRsem(dsls, i) = \frac{|dsls_i.sem|}{|\{x \mid (\exists d \in dsls \mid d \neq dsl_i \wedge x \in d.sem)\}|} \times 100\% \tag{10}$$

– **Pairwise Relationship Ratio ($PWRR_{(i,j)}$):** The pair-wise relationship ration is a metric that measures the reusability between each possible pair of DSLs in the input set. This metric can be seen as a pair-wise similarity that indicates how different is a DSL for each of the other DSLs in the input set.

$$PWRR_{syn}(i,j) = \frac{|dsls_i.syn|}{|dsls_i.syn| - |dsls_i.syn \cap dsls_j.syn|} \times 100\% \tag{11}$$

$$PWRR_{sem}(i,j) = \frac{|dsls_i.sem|}{|dsls_i.sem| - |dsls_i.sem \cap dsls_j.sem|} \times 100\% \tag{12}$$

Acknowledgments

The research presented in this paper is supported by the European Union within the FP7 Marie Curie Initial Training Network "RELATE" under grant agreement number 264840 and VaryMDE, a collaboration between Thales and INRIA.

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