Identifying Reusable Language Modules from Existing 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. In such context, a common practice for enabling reuse is the definition of languages modules that can be later put togueter in order to build up new DSLs. However, the identification and reuse of those modules in a set of existing languages is currently relying on manual and costly tasks thus, hindering the reuse exploitation when developing DSLs. In this paper, we propose a solution to i) detect and identify possible reuse in a set of DSLs; and ii) break down those languages into modules that can be later exploited to minimize costs when constructing new languages and when maintaining the existing ones. Finally, we validate our approach by using realistic DSLs coming out from industrial projects and obtained 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 [23], 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 matter 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 [25]. 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]. For instance, 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.

The basic principle underlying the aforementioned reuse mechanisms is that language constructs are grouped into interdependent *language modules* that can be later integrated as part of the specification of future DSLs. Current approaches for modular development of DSLs (e.g., [24,19,15]) are focused on providing foundations and tooling that allow language designers to explicitly specify dependencies among language modules as well as to provide the composition operators needed during the subsequent assembly process.

In practice, however, reuse is rarely achieved as a result of monolithic processes where language designers define language modules while trying to predict that they will be useful in future DSLs. Rather, the exploitation of reuse is often an iterative process where reuse opportunities are discovered during the construction of individual DSLs in the form of replicated functionalities that could be extracted as reusable language modules. For example, many DSLs offer expression languages with simple imperative instructions (e.g., `if`, `for`), variables management, and mathematical operators. Xbase [1] is a successful experiment that demonstrate that, using compatible tooling, such replicated functionality can be encapsulated and used in different DSLs.

The major complexity of this reuse process is that both, the identification of reuse opportunities and the extraction of the corresponding languages modules are manually-performed activities. Due the large number of language constructs within a DSL and the dependencies among them, this process is tedious and error prone. Language designers have to compare DSLs in order to identify commonalities and, then, to perform a refactoring process to extract those commonalities on separated and interdependent language modules.

Inspired in the work of Caldiera and Basili [3], in this paper we propose a computer-aided mechanism that automatically identifies reuse opportunities within a given set of DSLs. Then, reusable language modules are extracted from those commonalities while establishing the corresponding dependencies. Our proposal relies on the static analysis that includes not only the syntax of the DSLs but also their semantics.

We validate our approach in two scenarios. On the first hand we apply this solution and its tooling support in a project involving three industrial partners. Later, for the sake of generality, we applied our solution to realistic DSLs that we obtained from public GitHub repositories fitting our technological space. In both cases, we discovered more than XXX code that can be potentially modularized for the sake of reuse.

The reminder of this paper is organized as follows: Section 2 introduces a set of preliminary definitions/assumptions as well as an illustrating scenario that we use all along the paper. Section 4 describes our approach that is evaluated in Section 5. Section 6 presents the related work and, finally, Section 7 concludes the paper.

2 Background: Domain-specific languages in a nutshell

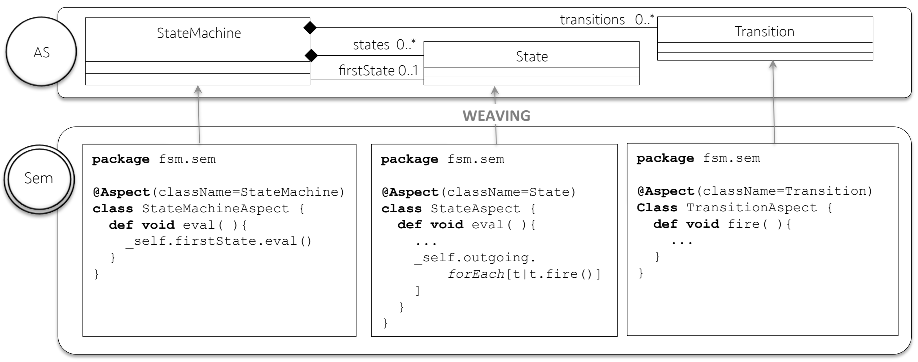
Specification: Like general purpose languages (GPLs), DSLs are defined in terms of syntax and semantics [12]. Hence, the specification of a DSL is a tuple $< syn, sem, M_{syn \leftarrow sem} >$ [7]. The parameter *syn* (the ***syn**tax*) refers to the structure of the DSL and specifies each language 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].

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

A simple DSL: Let us illustrate this idea by using a simple example. Consider the metamodel introduced at the top of Figure 1. It is a metamodel for a simple language for finite state machines. It contains thee classes `StateMachine`, `State`, and `Transition`; The class `StateMachine` contains both states and transitions which is represented with containment references. In turn, the code snippets at the bottom of Figure 1 introduce some operational semantics to this metamodel by using K3. Note that the main feature of K3 is the notion of aspect that permits to weave the operational semantics defined in a Xtend class to a metamodel defined in Ecore. In our example, the metaclass `StateMachine` is enriched with the operation `eval()` that contains a loop that sequentially invokes the operation defined for the class `State`. This operation is also defined by using one aspect. The metaclass `Transition` is enriched with the operation `fire()`.



```
package fsm.sem

@Aspect(className=StateMachine)
class StateMachineAspect {
  def void eval( ){
    _self.firstState.eval()
  }
}
```

```
package fsm.sem

@Aspect(className=State)
class StateAspect {
  def void eval( ){
    ...
    _self.outgoing.
        forEach[t|t.fire()]
    ]
  }
}
```

```
package fsm.sem

@Aspect(className=Transition)
Class TransitionAspect {
  def void fire( ){
    ...
  }
}
```

Fig. 1: A simple FSM language

3 Motivation and problem statement

3.1 Illustrating scenario

Consider a team of language designers that conducts the construction of the DSLs for state machines presented in the last section. During that process, language designers implement the language constructs typically required for expressing finite state machines: states, transitions, events, and so on. In addition, the DSL provides a constraints language that permits to express guards on the transitions. The DSL also provides an expressions language that allows to specify actions on the states of the state machine.

After being released their DSL for state machines, the language development team is required again. This time the objective is to build a DSL for manipulating the traditional Logo turtle which is often used in elementary schools for teaching the first foundations of programming [22]. The new DSL is essentially different from the DSL for state machines. Instead of states and transitions, Logo offers some primitives (such as `Forward`, `Backward`, `Left`, and `Right`) to move a character (i.e., the turtle) within a bounded canvas. However, Logo also requires an expressions language. In this case, expressions are needed to express more complex movements. For example, by using arithmetic computations.

As illustrated in Figure 2, the typical solution to this type of situations is to replicate the code in a second DSL. Language designers usually copy/paste the segment of the specification that they can reuse. As a result, we have many clones that are expensive to maintain. Naturally, this situation is repeated each time that there is a new DSL to build. Thi fact is illustrated in the Figure 2 by introducing a third DSL for expressing flowcharts. In this case, the new DSL requires both, expressions and constraints languages.

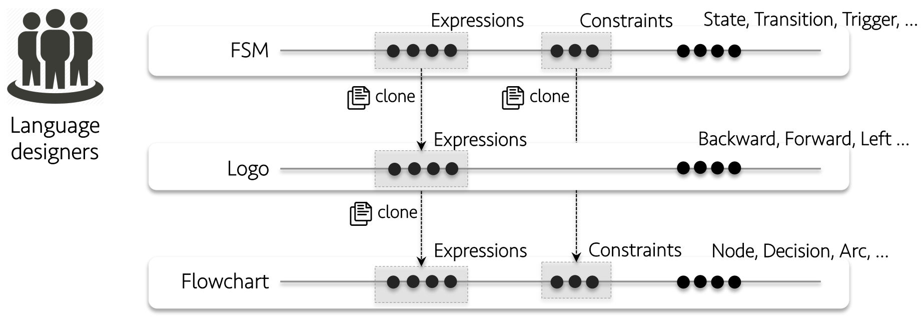


Fig. 2: Cloning in DSLs development process

3.2 Overlapping in DSLs and potential reuse

The aforementioned phenomenon was previously observed by Vöelter et al [26, p. 60-61]. In fact, that study demonstrates that although many of the existing DSLs are completely different and tackle independent domains; there are related DSLs with overlapping domains. 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 [26, 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.

Figure 3 illustrates the phenomenon in our illustrating scenario. 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.

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.

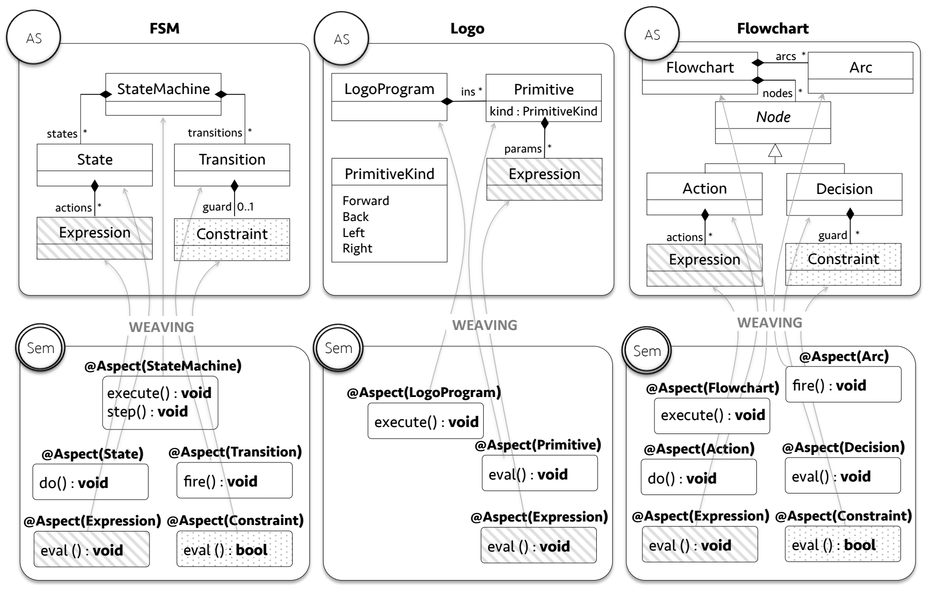


Fig. 3: Commonalities between domains and potential reuse

4 Proposed approach

Aqui hay que poner una imagen que ejemplifique el uso de tu herramienta y presentar los distintos pasos hasta la modulacion

4.1 Identifying overlapping

Given a set of existing DSLs (that we term as the *input set*) our approach is intended to identify a catalog of reusable language modules. To that end, we detect groups of language constructs that usually appear together. Our hypothesis is that if a set of constructs is usually used together is because there can be some strong domain relationships between the concepts they represent.

To detect language modules, we first perform analysis analysis on the input DSLs and we find overlapping among them. Our analysis can be illustrated by means of a Venn Diagram such as the one presented in Figure 4 that uses our illustrating scenario and includes both syntax and semantic overlapping. Syntactic and semantic overlapping is represented as intersections between the corresponding sets. To this end, we designed an algorithm that is able to compute the all overlapping among the syntax of the DSLs in the input set.

Our algorithm for detecting **syntactic overlapping** 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 overlapping among these metamodels. Note that there can be overlapping 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 overlapping** 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 overlapping among these aspects.

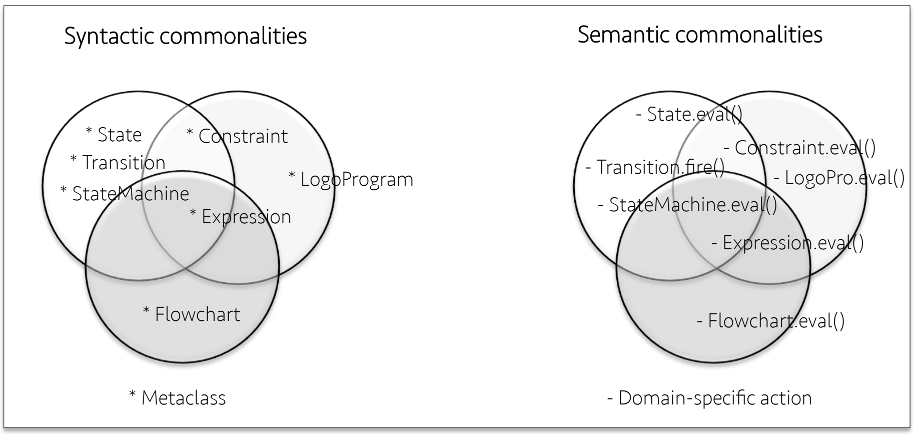


Fig. 4: Visualizing syntactic and semantic commonalities

Comparison operators: A syntactic overlapping is a set of metaclasses that are equal in two or more DSLs. Similarly, a semantic overlapping 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.

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

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., $\doteqdot$.

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

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.

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

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 [2].

$$\begin{aligned} DSA_A \triangleq DSA_B = true \implies & \\ & DSA_A \doteq DSA_B \wedge \\ & DSA_A.AST = DSA_B.AST \end{aligned} \tag{4}$$

4.2 Extracting reusable language modules

Breaking down the input set: After being identifying commonalities among the input set, we extract a set of reusable language modules. To do so, we focus the attention on analyzing overlapping among the sets. Each overlapping contains a set of metaclasses/domain specific actions that are used together in a given set of DSLs. In the illustrating scenario we can see that the overlapping among Logo, FSM, and Flowchart is a set of language constructs that permit to express expressions. They go well together and it makes sense to group them. Similarly, the overlapping between Flowchart and FSM is a set of constructs about constraints. Note that this example show us that it is not appropriated to put constraints and expressions in one language module. In that case, Logo would include constraints that is not necessary.

From that observation, we propose to create one module for each overlapping as presented in Figure 5. For each different overlapping, we create a language module. Of course, there are certain dependencies among modules that we need to express. Besides, breaking down DSLs in language modules only makes sense if we can later compose those modules to obtain complete DSLs. Then, a composition strategy is needed.

Encapsulating language modules: Let us now, to explain how we support the capability of encapsulating subsets of language constructs in separated and interdependent language modules. Different modules specify different constructs; a complete DSL is obtained by composing a set of modules. Accordingly, the main requirement for supporting separation of features in DSLs relies on the capability of expressing dependencies between language modules. In the following, we explain each of them and we present the corresponding tool support.

There is a *requiring module* that uses some constructs provided by a *providing module*. The requiring module has a dependency relationship towards the providing one that, in the small, is materialized by the fact that some of the classes of the requiring module have references (simple references or containment references) to some constructs of the providing one. In order to avoid direct references

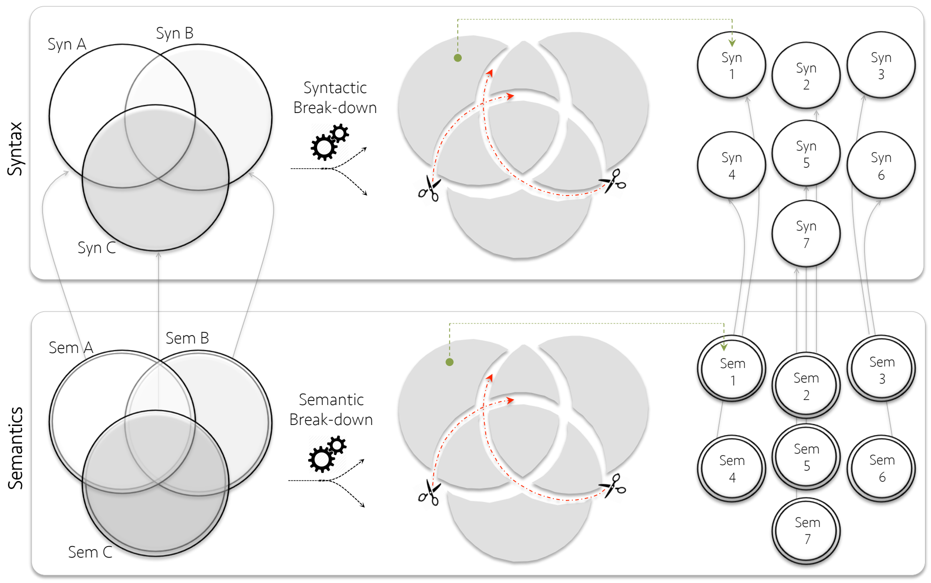


Fig. 5: Breaking down the input set by separating overlapping

between modules, we introduce the notion of interfaces for dealing with modules' dependencies. In the case of aggregation, the requiring language has a *required interface* whereas the providing one has the *provided interface*. A required interface contains the set of constructs required by the requiring module which are supposed to be replaced by actual construct provided by other module(s).

It is important to highlight that we use *model types* [?] to express both required and provided interfaces. As illustrated on top of Figure 6, the relationship between a module and its required interface is *referencing*. A module can have some references to the constructs declared in its required interface. In turn, the relationship between a module and its provided interface is *implements* (deeply explained in [?]). A module implements the functionality exposed in its model type. If the required interface is a subtype of the provided interface, then the provided interface fulfills the requirements declared in a required interface.

The tool support we provide for specifying interfaces on language modules is based on annotations at the level of the abstract syntax (i.e., the metamodel). That means that the required constructs of a requiring module are declared as meta-classes in the metamodel as the same as the actual constructs of the module. However, the required constructs are annotated with `@Required` to distinguish them from the actual constructs.

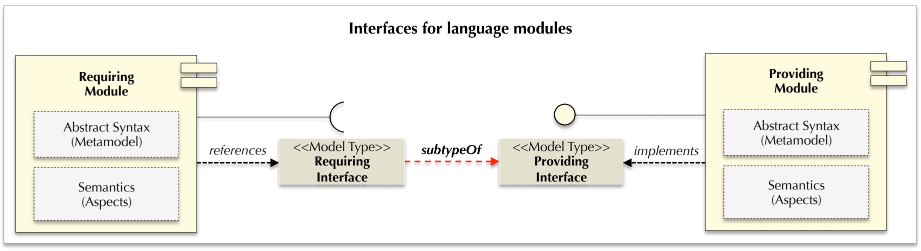

Interfaces for language modules
Requiring Module
Abstract Syntax (Metamodel)
Semantics (Aspects)
references
<<Model Type>> Requiring Interface
subtypeOf
<<Model Type>> Providing Interface
implements
Providing Module
Abstract Syntax (Metamodel)
Semantics (Aspects)

Fig. 6: Interfaces for language modules

5 Evaluation

In this section we evaluate our approach by using two different evaluation scenarios. The former corresponds to a case study of a set of DSLs for expressing state machines. The idea is to test our approach in a set of language where we know that there are commonalities that we know in advance. The second case study aims to test our approach in a more realistic scenario. We take some DSLs from GitHub public repositories.

Table 1 shows the hypothesis of the experiments executed to validate our approach. To make the experiments reproducible, a number of fixed assumptions are made, such as homogeneous feature costs. ChocoSolver [4], with it's default heuristic, is used as the CSP solver for extracting software products from the feature model presented in Figure ??

poner la tabla para con los datos de los experimentos que vamos a ejecutar/hemos ejecutado. Intenta pensar cuales pueden ser las conclusiones que quieres extraer. Yo propongo 3 abajo.

Technological space and experimental platform: 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. The experiments were conducted using a version of Puzzle implemented in Java. Further, Puzzle was installed in the Grid5000 Cloud, which is a cluster with more than 5000 cores from were we took XX dual-CPU Dell Blades with Intel Xeon X3470 CPUs running at 2.93GHz, with 16 threads per CPU, and CentOS v6. Each dual-CPU Dell Blade has 36GB of RAM.

[4] `http://www.emn.fr/z-info/choco-solver/`

Hypotheses of Experiment 1	
Null Hypothesis (H_0)	Puzzle is capable of detecting commonalities in the case study that motivated this research.
Alt. Hypothesis (H_1)	Puzzle is not capable of detecting commonalities in the case study that motivated this research.
Dependent variable	The set of ecores representing our languages.
Blocking variables	The most sold phones and the market share indexes.
Model used as input	*models in* `urlhacialosmodelos`

Hypotheses of Experiment 2	
Null Hypothesis (H_0)	The use of Puzzle will not result in a higher market-share impact metric than selecting the most commonly sold phones, for a given maximum budget.
Alt. Hypothesis (H_1)	The use of Puzzle will result in a higher market-share impact metric than selecting the most commonly sold phones, for a given maximum budget.
Model used as input	*Android feature model presented in Figure* **??**
Blocking variables	The most sold phones, market share indexes and the maximum cost allowed set to 600$.
Model used as input	*Android feature model presented in Figure* **??**

Constants	
CSP solver	*ChocoSolver v2*
Heuristic for variable selection in the CSP solver	*Default*

Table 1: Hypotheses and design of experiments.

5.1 Experiment 1: ATOS industrial project

5.2 Experiment 2: Identifying potential reuse in the wild

5.3 Experiment 3: Scalability of our solution

6 Related work

7 Conclusions and Perspectives

Acknowledgments

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