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Pattern Specification, Instantiation and Reuse

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Abstract: This paper describes an approach for using patterns in domain-specific visual language (DSVL) meta-tools. Our approach facilitates DSVL development via high level design-for-reuse and design-by-reuse pattern modelling tools. It provides a simple visual pattern modelling language that is used in parallel with DSVL meta-model specifications for modelling and reusing DSVL structural and behavioural design patterns. It also provides tool support for instantiating and visualising structural patterns, as well as executing behavioural patterns on DSVL model instances.

Keywords: Meta-tools, domain-specific visual languages, design patterns, code generation, model-driven engineering

1 Introduction

Using DSVLs (a.k.a. DSMLs or DSLs) for software development has recently gained more awareness in industries, open source communities and software tool vendors, thanks to their support for high level visual representations of domain-specific knowledge, making it possible for stakeholders to be more deeply involved in software development. We have previously described our Eclipse-based Marama meta-toolset for generating multi-view DSVL environments in [GHHL08]. Marama features rapid specification of meta-models, visual notations, views, constraints, critics, event handlers, model transformations and code generations for DSVLs. However, its support for reuse is currently very limited. Other meta-tools (e.g. [Mic08, KLR96, LBM⁺01, ZGH⁺07]) have attempted to support design-by-reuse, however, most approaches are limited to code-level (e.g. via white-box framework inheritance or composition) or fine-grained modular model-level reuse (e.g. via copy/paste and import/export). Few (e.g. [Sut02]) have addressed higher-level pattern-based reuse.

In our work with various visual languages and tools, we have identified recurring problems and solutions for DSVL design and implementation. These include patterns for specifying:
- model structures such as hierarchy, composability, cardinality, mutability, multiple linked views and model interoperability; and

- modelling behaviours for common visual analytics tasks such as retrieving model data of interest to create visualisations, detecting and removing conflicts, transforming views and visualisations, and diffing and merging models/views.

In addition, we have discovered a common set of repeatedly used relationships including sub-typing, containment, referencing, dependency, flow, mapping and merging. We are investigating these DSVL design patterns in terms of their generic specification (via a high-level visual language), instantiation/execution and reuse (adoption, adaptation, composition and inheritance).

This paper describes a generic but configurable meta-model level visual language and tool support for DSVL design pattern (both structural and behavioural) specification, application and reuse. It illustrates how loose-coupled structural and behavioural pattern specifications can be integrated coherently with reuse and customisation support. We begin by describing the motivation, related work and the overall tool architecture of our approach. We then separately describe structural pattern specification and instantiation followed by behavioural pattern specification and execution in MaramaDSL. We then discuss early analysis results and future research before we conclude the paper.

2 Our Approach

Our initial motivation for this research came from one of the lessons we learned from our intensive evaluations [Li07] of Marama. Although we used simple metaphoric visual languages (multiple integrated DSVLs for specifying structural and behavioural aspects) that map well to the problem domain for DSVL design specifications, end users are still faced with a steep learning curve and hard mental operations when dealing with complex designs that have both structural and behavioural DSVL aspects. This raises a major barrier to use. However, we have identified that many design specifications are generic (or can be generalised) and are reusable across domains. We believe that facilitating design-for-reuse and design-by-reuse via patterns [Sut02] is an optimal way for removing this barrier.

We aim to capture common aspects of design and implementation support for different DSVLs, and facilitate pattern-based reuse to augment DSVL meta-tools. We want a family of modelling notations and tools for DSVL pattern specification, visualisation, instantiation and execution. We also desire easy reuse of DSVL patterns via language and environment support.

Our earlier work on abstract design pattern specification [MHG07] defined a visual design pattern modelling notation, DPML, and provided tool support for pattern instantiation on a UML object model. DPML provides relatively clean visual representations for various types of pattern participant (e.g. interfaces, methods and operations), their dimensions (collections) and constraints. The instantiation step permits both tailoring and traceability/consistency with pattern specifications. However, DPML was based on the UML meta-model, which constrains its adaptation to a wider range of DSVL application domains (such as performance engineering, business modelling and healthcare planning as in [GHHL08]) and its integration in a generic DSVL meta-tool for design and implementation of non-UML-based visual language notations for those domains. Other existing UML-based pattern languages (e.g.

[FKGS04, MCL04]) are similar. Although they have enough expressive power to specify traditional design patterns, they are not flexible in collaboration with arbitrary DSVLs.

Graph grammar based transformation techniques have also been used to specify design patterns [ZKDZ07]. However, the nature of graph transformation (pattern matching plus transformation through left to right-hand side rule mappings) makes it more suitable to define model evolution/refactoring changes instead of up-front pattern specification and instantiation. Configurability also needs to be extended in order to allow reuse of generic rules.

Our current approach facilitates simple and holistic pattern support in DSVL meta-tools. To this end, we have designed a notation that explicitly models generic pattern participant roles and relationships, with the ability to accommodate variance of different DSVL meta-models through visual, meta-level configurations. Our approach allows both domain specific patterns (such as the "Abstract Factory" pattern, specified and instantiated on UML design models) and generic design patterns that can be reused across multiple DSVL domains. Our visual notation has been designed based on a theoretical foundation [Moo09] to make it cognitively manageable by non-programmer DSVL end users.

We have designed MaramaDSL, a tightly integrated meta-tool environment featuring easy to use pattern-oriented modelling tools. It was created using Microsoft DSL Tools [Mic08], deployed to the Visual Studio IDE and applied back to augment the DSL Tools with extended designer views, framework code and code generators. Figure 1 illustrates its usage architecture. A MaramaDSL editor (with multiple designer views) is added into a DSL project (Figure 1 (a) DslExtension.maramadsl) to co-function with the DSL Designer (DslDefinition.dsl – DSL Tools' visual definer for domain classes, relationships, shapes, connectors and diagram element maps). The complementary MaramaDSL model (with user created pattern-related components) generates custom code onto the DSL project that is realised in the generated DSVL environment without the need for any additional configuration. MaramaDSL imports the DSL Designer elements and provides a Domain Model View (Figure 1 (b)), used to display the existing DSVL meta-model elements, but flattened (without trees) and with filtering choices for various components (e.g. relationship role links) to manage diagram clarity. Two pattern specification views linked with the Domain Model View are available, the Structural Pattern Designer (Figure 1 (c)) and Behavioural Pattern Designer (Figure 1 (d)) Views, for structural and behavioural pattern specification respectively. Each exploits orthogonal representations for separate but easy to bind generic pattern specifications and contexts. They make shared use of the DSVL meta-model in a layer as the pattern specification context, with filters to add relevant domain elements for pattern participation.

Patterns are specified in two simple visual languages (structural and behavioural) described in the next sections. Patterns can be saved context-free, i.e. with bindings removed, for design-for-reuse and design-by-reuse, appearing in a Patterns Explorer Tree in the Model Explorer window. They can then be drag-dropped for reuse and binding with other DSVL meta-models. Accessed pattern specifications can also be easily adapted for reuse in a variant manner, e.g. modify or remove any existing participant or relationship at the DSVL client, or add elements to a pattern specification to meet specific needs. MaramaDSL also allows complex patterns to be created by composing existing patterns. We demonstrate pattern composition in Section 4

using a composite behavioural pattern example. We are currently expanding a set of generic DSVL patterns for simple reuse and composition purposes.
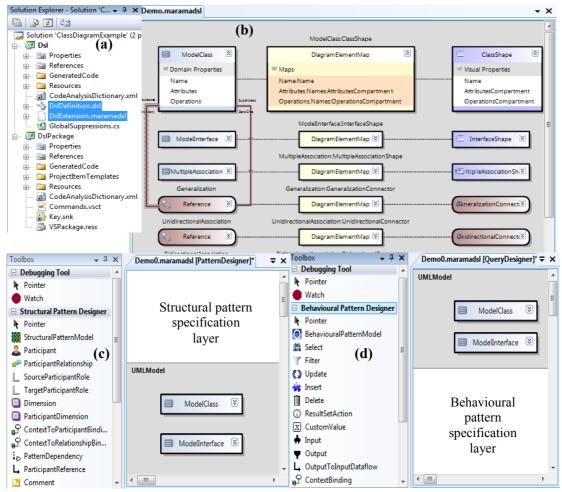

Figure 1. MaramaDSL usage architecture: (a) Integration with DSL Designer, (b) Domain Model View, (c) Structural Pattern Designer View and (d) Behavioural Pattern Designer View

We used a set of consistent modelling and visualisation techniques in the design of MaramaDSL, providing end users with a cognitively manageable user experience. Different visual language metaphors are used for structural and behavioural pattern specifications to accommodate end users' mind maps (elaborated in the following). Drag-drops are largely used for creation and reuse, while links are used for bindings of pattern roles and contexts. An overlay layer of annotations are used to expose constraints and dimensions. Orthogonal layers of pattern modelling elements and the DSVL meta-model are juxtaposed for separated visualisation with cross-cutting concerns and convenient specification. Multiple interacting views (domain model, structural and behavioural pattern perspectives) are also used together to complement one another within a unified underlying model. Complex specifications can be collapsed and filtered, and relationships and links elided to manage diagram clutter.

3 Structural Pattern Specification and Instantiation

Our structural pattern specification language uses an entity-relationship (ER) based metaphor and a visual notation shown in Figure 2 for depicting (a) patterns, represented by container shapes with a pattern icon and a name decorator; (b) participants, inner shapes with a participant icon and name, type and bound domain context decorators; (c) participant relationships, inner shapes with a connection icon and type and bound domain context decorators; (d) dimensions, inner shapes with a dimension icon and a name decorator, as well as by port shapes on participants; and (e) constraints, port shapes on pattern elements to constrain participants and relationships. The dimension concept is based on DPML [MHG07] and complements participant relationships with participant role cardinality constraints. Constraint specifications use C# expressions (e.g. the constraint expression "participant1 !=participant2" denotes two participants can't be the same runtime instance), but we intend to replace this with OCL features in a Spreadsheet metaphor similar to MaramaTatau in [Li07].

A set of pattern categories, participant and relationship types are defined based on our prior work in the DSVL problem domain. Examples include metrics, multiple view, model integration, query and process pattern categories; domain class, property and relationship, shape and connector participant types; sub-typing, containment, and referencing participant relationship types; and using, refinement, and dependency pattern relationship types. Custom categories and types can be added as end user extensions.
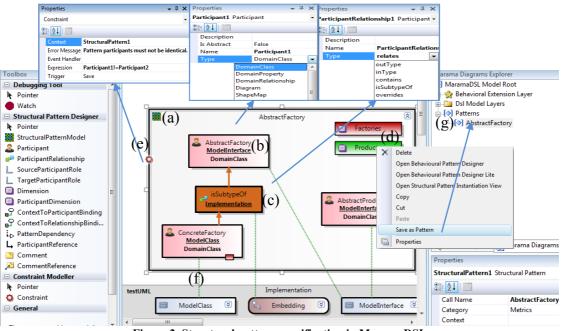

Figure 2. Structural pattern specification in MaramaDSL

The binding of a structural pattern specification to a DSVL meta-model is visually supported via static context bindings, Figure 2 (f), represented by green dotted lines connecting elements in the domain model with their specifications in the pattern specification layer. These are cross-cutting relationships between elements from the two layers, e.g. a domain class

contextualises a participant; and a domain relationship contextualises a participant relationship. Context binding links can be elided at individual pattern element level for diagram clutter management. Context bindings are supplemented by dual text encoding on a pattern element (underlined text in the bound pattern element) to ease context navigation. A specified pattern can be saved context-free (all bindings removed), appearing in the Patterns Explorer Tree, Figure 2 (g), for reuse in other DSVL meta-models.

After static bindings have been defined, the DSVL meta-model on the DSL Designer side is injected with pattern attributes, e.g. patterns and participant names, which are further specified by dynamic bindings on a DSVL model instance. This pattern instantiation process [MHG07], creates a pattern instance associated with a DSVL model. A Structural Pattern Instantiation View, Figure 3 (b), based on and linked to the Structural Pattern Designer View design-level abstraction, is provided for such dynamic bindings. Participant memberships can be added into the pattern instance specification. On pattern instantiation, whether completed or not, the DSVL model instance, Figure 3 (c), is updated with element creation or modification through an extended generic validation procedure (future implementation). These are the generative effects of pattern application, facilitating both up-front design as well as design refactoring. Multiple patterns can be specified for a DSVL meta-model and instantiated into its model instances. Traceability of pattern role bindings on the DSVL model instance is supported via a "Pattern Message Board" (using a "dashboard" metaphor), which allows interactive selection highlights of pattern participants, i.e. selecting a participant in the "Pattern Message Board" will highlight all the participant members in the DSVL model instance.

We revisit the Abstract Factory pattern example specified in DPML in [MHG07] and illustrate its new "skinning" in MaramaDSL. By repeating this example, we emphasise the generality and configurability of our new language. Figure 3 (a) shows the pattern specification juxtaposed with the UML meta-model (bottom). The pattern contains six participants (Abstract Factory, Concrete Factory, Abstract Creator, Concrete Creator, Abstract Product and Concrete Product) and their relationships ("isSubtypeOf", "contains", "overrides", and "outType"). Context bindings include: a UML Model Interface participates as an Abstract Factory; a UML Model Class participates as a Concrete Factory; and a UML Implementation relationship links the Abstract Factory and the Concrete Factory. Two dimensions are defined in the pattern: Products and Factories. They are selected by various participants as indicated by coloured overlay annotations. These are used to specify that the number of participant instance members (as shown later in Figure 3 (b)) should be equated to the number of dynamic items added to a dimension, with the cross product of the numbers if more than one dimension is set on a participant [MHG07]).

Figure 3 (b) is the Structural Pattern Instantiation View associated with a specific UML model instance, here showing the actual UML elements that are participants in the various roles in the Abstract Factory pattern. Pattern creation effects, including creation of participants and relationships of the right types on the DSVL model instance, are based on the pattern instantiation. For instance, on adding a MetalFactory member for the Concrete Factory participant in the Structural Pattern Instantiation View, a UML Model Class is created with that name on the DSVL model instance and an Implementation relationship is created linking it to the Abstract Factory member, GUIFactory, as shown in Figure 3 (c).
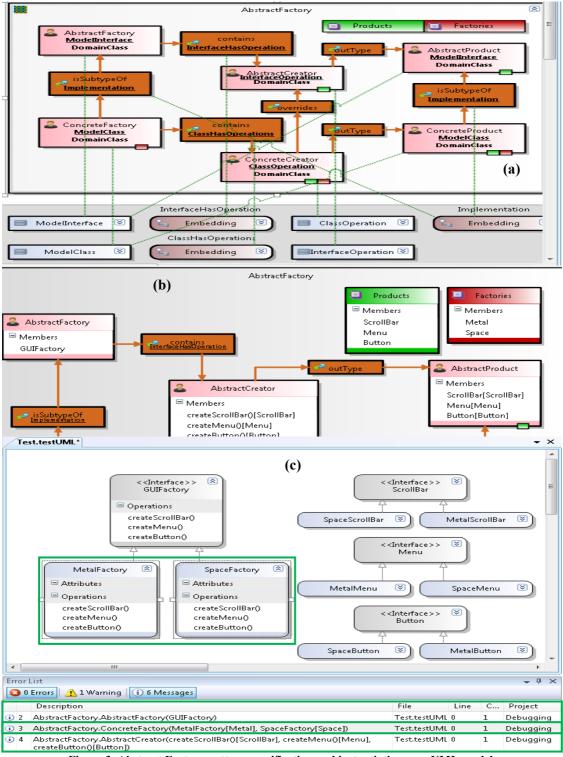
Figure 3. Abstract Factory pattern specification and instantiation on a UML model

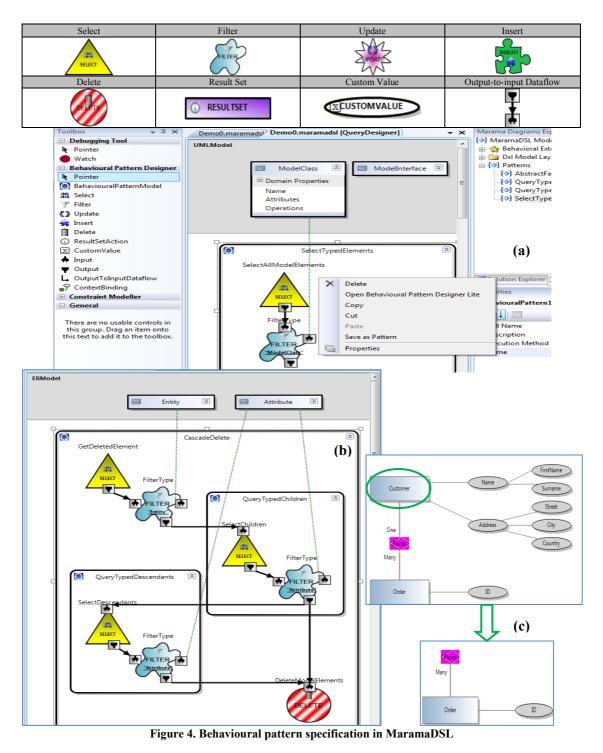## 4 Behavioural Pattern Specification and Execution

We initially used a uniform ER-based visual language representation for both structural and behavioural pattern specifications, with behaviours represented as Event, Query, Filter, or Action participants. However, the ER metaphor proved a failure for behaviours. We thus used a more traditional dataflow-based metaphor for behavioural pattern specifications, representing behaviours as executable queries and actions, composed from a set of generalised query and action elements. This approach is significantly different to UML using visual composition of strongly typed reusable activity building blocks for selection, insertion, deletion, update and visualisation of DSVL elements.

To develop this approach, we initially hand implemented 40+ behavioural specification examples on different domain models, for visual analytics tasks such as content retrieval, conflict management and information aggregation. We examined similar codings, identifying common abstractions from which we obtained a vocabulary for behavioural specifications. The vocabulary comprises a set of (50+) query building blocks specialising the following query and action types: SELECT, FILTER, UPDATE, INSERT and DELETE, plus a RESULTSET for rendering elements selected by queries. They are used to retrieve data, set filtering criteria, or alter model/view elements for various query-based visual analytics tasks. The elements are all parameterized with query context (e.g. model/view or element/relationship/shape/connector parts) and criteria (e.g. typed value). Each has a returning result state as the output.

Our developers have found behavioural composition using these elements to be much easier than the original ER metaphor, requiring then to just place necessary building blocks and pipe the output from one to input of another. We wanted to allow non-programmer DSVL end users to take advantage of the generalised query and action elements to create behaviours via a visual language that represents the elements visually, and defines how they interact with each other to facilitate behaviour composition. We also wanted to minimise behavioural specification effort by providing high-level behavioural pattern reuse.

The behavioural pattern language is realised via a Behavioural Pattern Specification View. Graphical symbols with in- and out-ports and links between express what should happen (i.e. state retrieval, state modification and output generation) after a given data push or pull. The symbols include Behavioural Pattern Model, Select, Filter, Update, Insert, Delete, Result Set, Custom Value, and Port Dataflow in the visual forms shown in the table in Figure 4 (top). We used different shapes to represent queries, actions, result sets and values, and different icons, colours and textures for different query and action types to enhance understandability. For each visual symbol, text also plays an important role in determining the specific building block within the more general category of Select, Filter, etc. As with the structural patterns, we juxtapose a DSVL meta-model to allow convenient context bindings, except that the DSVL meta-model layer is shifted to the top in this view to better fit the top-down data piping style of behaviour composition. Every Behavioural Pattern model has two execution methods the user can specify: automatic or controlled. The former enables automatic execution based on user-diagram interaction; the latter provides context menus for users to run the behaviours.

Select	Filter	Update	Insert
Delete	Result Set	Custom Value	Output-to-input Dataflow
	RESULTSET	CUSTOMVALUE	

Figure 4. Behavioural pattern specification in MaramaDSL

A simple example is shown in Figure 4 (a). It defines a Behavioural Pattern Model specifying a generic "select all elements and filter on type" operation. The filter is bound in this case to

the ModelClass domain element, so selects all ModelClass elements in diagrams it is applied to. Figure 4 (b) shows a more complex example: a composed behavioural pattern is specified over an ER tool to perform a cascade-delete behaviour. On deleting an Entity from an ER model, its associated attributes and their descendant member attributes (for compound attributes) are also deleted, as shown in Figure 4 (c). Specification of this behavioural pattern composes two earlier defined generic behavioural patterns: QueryTypedChildren and QueryTypedDecendants, which express the selections of children or descendants of generic model types. It also contains additional query and action elements between the composing and composed behavioural pattern model to describe the cascade deleting effect and bindings to the domain model for application of the composed behavioural pattern to ER diagrams.

5 Analysis

Our approach explicitly models pattern participant roles and relationships for easy configuration across DSVLs. Compared to UML-based approaches (e.g. [FKGS04, MCL04, MHG07]) it has fewer constructs (e.g. no inheritance, aggregation, interface or operation) and is thus simpler. It has a clearer role collaboration model (participants, relationships, dimensions, constraints and behaviours) specific to the pattern description domain so is more visually expressive for pattern specific concepts. It allows easier domain context binding of generic pattern models through decoupled but interacting parts; and it allows sharing of common pattern structure for better reuse of specification (e.g. the State and Strategy patterns have a common structure, and by using our approach one specification can be easily adapted based on the whole other without the need to re-specify common individual parts).

Our solution provides appropriate abstractions, simple-to-use visual notations and high-level instantiation, execution and reuse support for both structural and behavioural pattern functionalities to be realised in DSVL tools. We have applied the Physics of Notations theory [Moo09] for a principled visual language design:

- Our language supports *Cognitive Integration* by using multiple linked views with separated layer representations of sharable and filterable domain context elements; it also provides consistent design-for-reuse and design-by-reuse mechanisms for structural and behavioural pattern specifications and context bindings.
- *Graphic Economy* is the dominant principle in our language, for which some tradeoffs were made. We chose to use "symbol overload" (e.g. one participant symbol representing various types of pattern participants; one query symbol representing multiple behavioural building blocks) in both types of pattern specification. This resulted in reduced *Semiotic Clarity*, but this is desirable to provide a cognitively manageable number of symbols. As a result, our language heavily relies on text *Dual Coding* to distinguish pattern elements.
- We applied the *Principle of Perceptual Discriminability*: colours and iconic annotations provide visual distance to distinguish pattern elements from each other. We didn't use the full range of visual variables from the *Principle of Visual Expressiveness*, but the channels used in the current form have sufficient visual expressiveness. The *Principle of Semantic Transparency* is addressed by using depictive icons to suggest symbol semantics.
- Some visual patterns can become complex, with many symbols. Applying the *Principle of Complexity Management*, we introduced a mechanism to elide pattern elements into a sub pattern using the same container symbol but in elided form. Form-based filtering features

(to turn selected elements/links on/off) are also supported. The mechanism to reuse patterns also assists in managing complexity. For behavioural pattern specifications, we provide a Behavioural Pattern Designer Lite View (not illustrated in the paper due to limit space) with elided technical details such as ports and context bindings, using mainly descriptions and flows. This applies the *Principle of Cognitive Fit* by exhibiting multiple dialects. The Lite View essentially represents the same concept of the Behavioural Pattern Designer View, can perform the same tasks, and translate to the same underlying query and action elements. It benefits users wanting high level specifications while the Behavioural Pattern Designer View is for users needing behavioural composition detail. The ability to convert between the forms provides users alternative perspectives.

We have also conducted a Cognitive Dimensions [GP96] analysis to evaluate tradeoffs, strengths and weaknesses of our solution. The visual language has expressiveness equivalent to domain-specific code written with APIs, but with a lower *abstraction gradient*, augmented understanding, reduced effort, and a much shallower learning curve via better *closeness of mapping* to users' mental models of pattern use. Instantiating a pattern specification requires some *hard mental operations* and *premature commitment* when choosing appropriate pattern elements to compose. However adding *abstractions* in the form of pre-defined patterns reduces complexity and *diffuseness*. The use of the visual language reduces *error proneness* compared to coding, but requires proactive checking of model semantics for correctness. *Progressive evaluation* is allowed but requires a compile-and-run cycle. The language uses a *terse* set of graphical symbols but with a rather *verbose* set of textual labels for expressing pattern elements. *Diffuseness* caused by that is mitigated by using them within typed symbol groups. The visual symbols have clear *role expressiveness*. We use layout in behavioural pattern specification as a *secondary notation* because it does not affect any semantics but is good for promoting readability of the flow sequences with visual cues. The usual diagram insert *viscosity* problems occur, and require automatic layout to mitigate. We have mitigated areas of *hidden dependency* and v*isibility* in the language by *juxtaposition* of orthogonal layered views, and dual coding of custom values though context links and dynamic properties.

The preliminary analyses also helped identify missing functionality requiring further work. DSVL design patterns a level of quality to domain-specific modelling, as validated design patterns are quality design models themselves, so correctly applying them onto DSVLs supports quality model design. However, we are yet to address how we can validate the DSVL design patterns and their instantiations/executions for completeness, consistency and soundness. Another important issue is that conflicts do exist in design patterns and when a pattern language is supported, balancing the conflicts and providing users with decision support for pattern adoption is essential. To address this, we plan to use Mussbacher et al's goal-oriented approach [MWA06] for forces analysis in the pattern language. Runtime animated visualisation of the execution of behavioural pattern elements was a suggested feature but is only partially supported to date. We are also planning extensive usability studies.

6 Conclusion

Our aim is to augment DSVL meta-tools with pattern-oriented design for easier end user experience. MaramaDSL, extending the DSL Tools, is a unified meta-modelling environment with both structural and behavioural pattern specification and usage. MaramaDSL provides a

general language for specifying DSVL design patterns with also tool support for pattern instantiation, execution and cross-domain reuse. Our ultimate goal is to facilitate a knowledge base (with formalised pattern representations) for sharing DSVL design knowledge to benefit the wider communities, and the work we demonstrated here leads towards that direction.

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