# A Method for Composing Concerns into a Unified Domain Model in Domain-Driven Design

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**Abstract.** Domain-Driven Design (DDD) advocates iterative software development centered on a semantically rich domain model to bridge the communication gap between domain experts and developers. Although the adoption of a ubiquitous language and Domain-Specific Languages (DSLs) enhances the expressiveness and maintainability of software systems, the increasing complexity and heterogeneity of modern systems necessitate the integration of multiple concern-specific DSLs to capture diverse aspects. However, current DDD approaches lack systematic mechanisms for composing such heterogeneous DSLs, leading to fragmented domain models, weak traceability, and limited automation throughout the development pipeline. To address these challenges, this paper proposes a method for composing concerns into a unified abstract syntax tree (AST) within the context of DDD. The approach specifies the abstract syntax, concrete syntax, and formal semantics of concern-specific DSLs in a consistent manner. Building on this foundation, we introduce an annotation-based composition mechanism that interrelates DSLs and integrates multiple concerns into a unified domain model. This mechanism ensures concern orthogonality, preserves model cohesion, and supports backward traceability across artifacts. We demonstrate the feasibility and practicality of the proposed methodology through a proof-of-concept implementation using the JetBrains MPS language workbench and the JDA framework, evaluated on representative case studies. Our contributions extend the state of the art in modular, extensible, and executable domain modeling for complex software systems.

**Keywords:** Domain-Driven Design · Domain-Specific Language · Domain Model · MPS · Metamodeling

## 1 Introduction

The increasing complexity, scale, and heterogeneity of modern software systems have intensified the need for methodologies that effectively bridge domain knowledge and technical implementation. Domain-Driven Design (DDD) has emerged

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as a prominent approach to this challenge, advocating iterative development around a semantically rich domain model that encapsulates the core logic and rules of the problem domain [10, 17]. Central to DDD is the consistent use of a Ubiquitous Language (UL), which fosters effective communication and shared understanding between domain experts and developers throughout the software lifecycle.

To operationalize the UL and align it with implementation artifacts, Domain-Specific Languages (DSLs) have been widely adopted as expressive means of encoding domain concepts directly in source code [2, 12]. DSLs tightly couple design models with implementation, improving software correctness, maintainability, and extensibility [1, 2, 4, 11, 27, 31].

In the development of complex software systems, defining and integrating multiple concern-specific DSLs—such as those for business logic, security, user interfaces, and performance—is crucial to addressing diverse requirements and abstraction levels [13, 16]. A key challenge in applying DDD to such systems lies in the synchronous representation and integration of these heterogeneous concerns. The absence of systematic composition mechanisms fragments domain models and weakens UL consistency. Moreover, DSL development pipelines are often distributed across isolated tools for editing, verification, and code generation, thereby hindering automation. As domain models evolve, maintaining backward traceability between DSLs and generated code becomes increasingly difficult, further reducing the practical effectiveness of DDD.

Existing DDD approaches support domain modeling but often neglect the systematic formation and management of software modules derived from domain models [6, 15, 16, 28], leading to the absence of robust methodologies for their development and evolution. Furthermore, the lack of precise characterization of software artifacts generated from domain models hampers the effective adoption of DDD in real-world systems.

Current approaches often address concerns in isolation, resulting in tight coupling and limited extensibility. Recent efforts, including our approach to composing concerns into an executable unified domain model (UDML) [22], introduce a novel metamodel based on UML metaconcepts that supports the composition and unification of concern-specific DSLs. Nevertheless, significant limitations remain: integration processes are typically semi-automated and error-prone, rely heavily on high-quality mappings between DSLs, and provide limited support for complex or cross-cutting concerns. Scalability also becomes problematic as the number and complexity of concerns increase, while existing approaches still fall short in capturing sophisticated structural and behavioral aspects [7, 21].

In this paper, we propose a method for composing concerns into a unified domain model. Our approach extends UDML, a comprehensive DSL with well-defined abstract syntax (AS), concrete syntax (CS) and semantics, by unifying multiple concern-specific DSLs into a single abstract syntax tree (AST). This mechanism integrates concern-specific DSLs into the core model while ensuring orthogonality, cohesion, and consistency across concerns. Each concern is specified using its own DSL and systematically composed into the unified

model, thereby facilitating complexity management and improving modularity and extensibility. We implement and validate the approach using the projectional editing capabilities of JetBrains MPS [3, 20] and the DDD framework JDA [9], demonstrating its feasibility and effectiveness in supporting composable, maintainable, and executable domain models through real-world case studies.

In brief, the contributions of this paper are as follows:

- A methodology for unifying multiple concern-specific DSLs (e.g., DCSL [21], AGL [7], RBAC [23]) into a single AST of UDML;
- A complete definition of the syntax and semantics of UDML, including AS, CS, and formal semantics;
- A tool-supported proof-of-concept implementation on the MPS platform, advancing the state of the art in modular and extensible domain modeling.

The rest of the paper is organized as follows: Section 2 motivates our work with examples. Section 3 explains the basic idea of our approach. Section 4 provides the syntax and semantics for UDML and the mechanism to compose concerns. Tool support and experiments are explained in Section 5, which discusses the proposed language. Section 6 surveys related work. Finally, Section 7 concludes the paper with a discussion of future work.

## 2 Motivating Example and Background

This section motivates our work through an example and provides the necessary background.

### 2.1 Motivating Example

We use the `CourseMan` domain, adapted from [21], as a motivating example. Fig. 1 presents the `CourseMan` domain model, based on OMG/UML, combin-

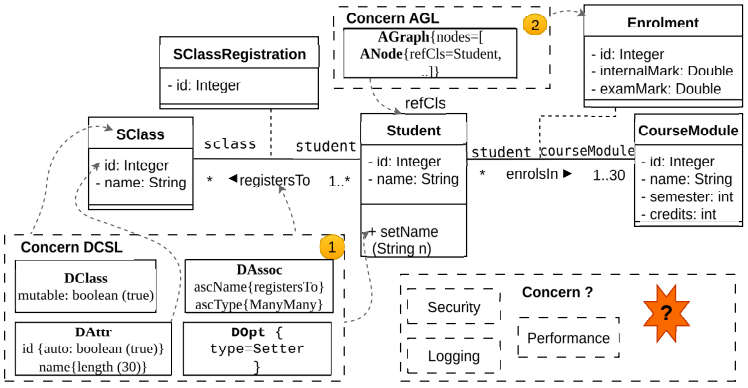


**Fig. 1.** UML class diagram and concern DSLs in CourseMan.

ing a class diagram with concern-specific DSLs. It includes three main classes (`Student`, `CourseModule`, `SClass`) and two association classes (`SClassRegistration`, `Enrolment`). The dashed shapes labeled (1) represent the DCSL concern, which captures the structural aspect through four concepts (`DClass`, `DAttr`, `DOpt`, `DAssoc`) defining entities and associations (e.g., `enrolsIn`, `registersTo`). The dashed shapes labeled (2) denote the AGL concern, which specifies behavioral aspects through `AGraph` defining the reachable state, while the star-like shape '**?**' indicates extensibility for future concerns.

The `CourseMan` system exemplifies a domain with intertwined concerns such as structure, enrollment, access control, and grading. While DCSL [21] supports structural modeling, it lacks modularity, expressiveness, and extensibility for addressing behavior, roles, constraints, and security. This highlights the need for a modeling approach that ensures separation of concerns, systematic integration, and continuous evolution of heterogeneous DSLs within a unified, executable model.

### 2.2 Background

To leverage domain expertise effectively, we revisit foundational concepts that underpin our concern-driven DSL integration approach.

*Executable Domain Models in DDD.* Domain-Driven Design (DDD) [10] advocates iterative development around a semantically rich domain model that encapsulates core logic and business rules. This model establishes a shared foundation between domain experts and developers through a consistent Ubiquitous Language (UL) [17, 34]. Domain-Specific Languages (DSLs) reinforce this alignment by encoding domain knowledge directly into software artifacts [2, 12], enhancing correctness, maintainability, and extensibility.

A key advancement in DDD is the executable domain model, which unifies descriptive and operational semantics [36]. By integrating concerns such as business logic and security into a runnable specification, executable models enable automation, verification, and adaptability [1]. However, achieving this vision requires automated composition of heterogeneous concerns—an ongoing challenge in DDD research.

*Composing Concern DSLs in UDML.* Concerns refer to orthogonal aspects of a system, such as structure, behavior, access control, or performance, that must be independently modeled and composed [19]. UDML [22] supports the composition of such concerns through internal and external DSLs. It extends UML metaconcepts to integrate concern DSLs within a cohesive metamodel.

Each concern is modeled using a dedicated DSL: DCSL [21] for structural aspects, AGL [7] for behavioral logic, and RBAC [23] for access control, with flexibility to incorporate additional DSLs as needed. However, integrating these heterogeneous DSLs into a cohesive domain model poses a significant challenge, as it requires well-defined composition mechanisms that operate at the AST level.

Our goal is to enhance the extensibility and expressiveness of UDML's syntax to enable executable domain modeling in complex software systems. To this

end, we address two research questions: (1) How can concern-specific DSLs be systematically composed into a unified AST? (2) Which language composition mechanisms and tool-supported approaches best support the integration and evolution of heterogeneous concerns in modular, scalable domain models?

## 3 Overview of Our Approach

This section introduces our approach, termed composing concerns into a unified domain model.

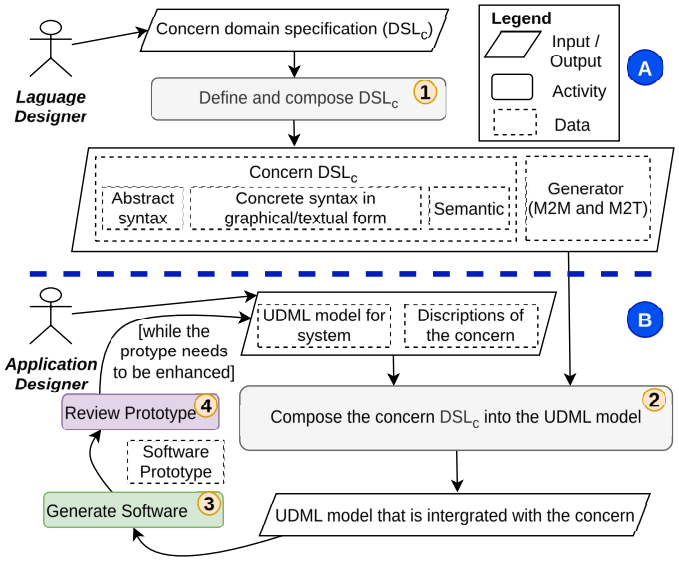


**Fig. 2.** Overview of our approach, structured into (A) language design level and (B) language application level.

Fig. 2 illustrates the method, which follows a four-step iterative process to systematically integrate and refine concern-specific DSLs for the automatic generation of software prototypes. *First*, at the language designer level, the designer specifies the concern domain using a domain-specific language ($DSL_c$) as input. For each $DSL_c$, we formally define its AS, CS, and semantics, resulting in a concern ($DSL_c$) that precisely captures the target concern. *Second*, at the application designer level, the designer leverages both the output from step one and existing UDML models, along with descriptions of new or evolving concern requirements. We compose the concern $DSL_c$ into the UDML model to ensure coherent integration. Designers may use textual or graphical CS to construct a detailed model that represents the specific concern instance. The output of this step is a UDML model fully integrated with the given concern. *Third*, the integrated UDML model serves as the foundation for generating production software. The resulting software artifact is then evaluated by the designer to gather feedback. *Finally*, if feedback is provided, both the UDML model and the

corresponding concern specification are updated accordingly. The process then repeats, supporting a continuous improvement cycle until the software system meets the specified requirements.

## 4 Composing Concern DSLs

This section introduces a method for composing concerns into a unified language, namely UDML, which serves as a modular language ecosystem where independently developed concern-specific DSLs are unified—enabling flexible integration and system-wide consistency.

### 4.1 Defining the Syntax and Semantics of UDML

This work defines UDML with complete AS, CS, and semantics, and integrates concern-driven domain modeling.

**Definition 1.** *The **UDML** language is constructed from a core DSL and a set of concern DSLs* $\{DSL_i\}_{i=1}^{n}$*, where each* $DSL_i$ *describes a distinct aspect of the system.*
*Each DSL is specified by a triplet (*$AS_i$*,*$CS_i$*,*$Sem_i$*), where:*

- $AS_i$*: Abstract Syntax;*
- $CS_i$*: Concrete Syntax;*
- $Sem_i$*: Semantics*

We define the AS of UDML as a collection of domain concepts, attributes, instances, and relations organized into separate concern modules based on UML metaconcepts [26], as shown in Fig. 3. Each concern DSL defines its own AS but conforms to a shared metamodel, enabling inheritance, extension, and composition according to predefined formal rules. We extend the UDML metamodel [22] with the `RefAnnotation` and `Relationship` metaconcepts to support seamless integration of new concerns: the AS can be incrementally extended by adding new concepts, attributes, or relations without disrupting the global structure.

**Definition 2.** *The **AS** of UDML is defined as the tuple* $AS_{UDML} = (C_{UDML}, A_{UDML}, R_{UDML}, P_{UDML})$*, where:*

- $C_{UDML}$*: Set of concepts (including core and concern DSL concepts)*
- $A_{UDML}$*: Set of attributes*
- $R_{UDML}$*: Set of relations between concepts*
- $P_{UDML}$*: Set of well-formedness rules*

The mapping of metaconcepts from the AS to the CS in a graphical User Interface (UI) is carried out systematically as follows:

- Each metaconcept, representing a core domain construct such as `Class`, `Property`, `RelationShip`, or `Annotation`, is directly mapped to one or more UI elements.

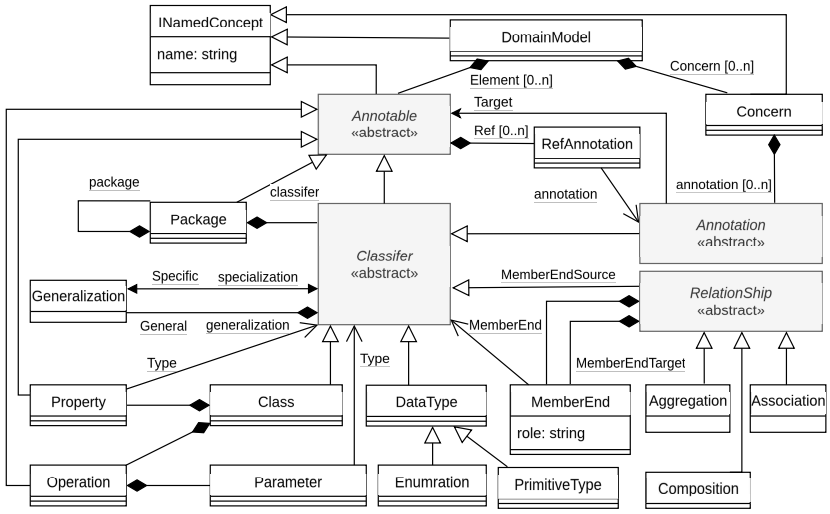


**Fig. 3.** Metamodel of UDML

- Entity-like metaconcepts are represented as distinct graphical blocks with labels and icons on the diagram.
- Relational metaconcepts are visualized as connectors or arrows linking the corresponding blocks.
- Attributes and features of a metaconcept are displayed as fields, columns, or labels within the blocks, or managed through separate configuration dialogs.
- Annotations are visualized using tags, labels, icons, or small graphical overlays attached to the target entities.

**Definition 3.** *The **CS** of UDML is defined as the tuple* $CS_{UDML} = (N, E, L, P, H)$*, where:*

- $N$*: The set of nodes representing instances of concepts in* $C_{UDML}$*. Each node corresponds to a concrete entity on the UI.*
- $E \subseteq N \times N$*: The set of edges between nodes, representing relationships in* $R_{UDML}$ *displayed visually.*
- $L : N \cup E \to$ *Labels: A labeling function that assigns display labels to nodes or edges.*
- $P : N \cup E \to$ *Prop: A function mapping UI elements (nodes or edges) to a set of graphical properties to define their concrete visual representation.*
- $H = \{h_i\}$*: A set of handlers—rules or operations—that support interactive actions such as drag-and-drop, creation, modification, and deletion of nodes and edges on the interface.*

UDML's overall semantics derive from the individual semantics of each concern DSL, enabling independent control and verification of changes at the concern level. Constraint semantics are enforced through two mechanisms: (i) structural constraints embedded in metaconcepts for well-formedness rules [22], and

(ii) checking rules for more complex logic. For instance, a checking rule validates that an `Annotation` applies only to a `Class`, reporting an error if violated.

```
if (!(node.target.isInstanceOf(concept<Class>)))
{    error("Target must be a Class."); }
```

### 4.2 A Mechanism for Composing Concern DSLs in UDML

Concern DSLs are integrated into UDML via a systematic annotation-based approach. Core elements implement a generic `Annotable` interface, while each DSL defines its own `Annotation` types referencing these elements. This allows concern-specific semantics to be attached modularly and non-intrusively, preserving separation and traceability.

**Algorithm 1** Tree-merging algorithm for integrating concern DSLs into UDML

**Input:** $D = \{DSL_1, DSL_2, \ldots, DSL_n\}$: A set of concern DSLs, each specified as a triplet $(AS_i, CS_i, Sem_i)$.
**Output:** $UDML_{unified}$: The unified UDML comprising a global $AS$, $CS$, and $Sem$

1: Initialize: $AS_{UDML} \leftarrow AS_{core}$, $CS_{UDML} \leftarrow CS_{core}$, $Sem_{UDML} \leftarrow Sem_{core}$
2: **for** each $DSL_i = (AS_i, CS_i, Sem_i) \in D$ **do**
3:  **for** each concept $c \in AS_i$ where $c \notin AS_{UDML}$ **do** //*Merge Abstract Syntax*
4:  **if** $c$ extends core concept **then**
5:  Integrate inheritance per metamodel
6:  **end if**
7:  Add attributes, relations, constraints to $AS_{UDML}$
8:  **end for**
9:  **for** each new or extended concept **do** //*Merge Concrete Syntax*
10:  Add graphical elements (nodes, edges, labels)
11:  Extend UI handlers (drag-drop, annotations)
12:  **end for**
13:  Integrate $Sem_i$ into $Sem_{UDML}$ modularly //*Merge Semantics*
14:  Compose new constraints into $P_{UDML}$ and update validation rules.
15: **end for**
16: **return** $UDML_{unified} = (AS_{UDML}, CS_{UDML}, Sem_{UDML})$

Algorithm 1 presents a tree-merging process that incrementally unifies concern-specific DSLs into the UDML framework. The algorithm merges AS by incorporating new concepts and extending core types. CS is augmented with graphical elements and interactive behaviors associated with the extended concepts. Formal semantics are composed modularly, integrating validation rules and behavioral constraints defined by each concern. This yields a unified, executable model that consolidates diverse concerns while preserving their modularity and traceability.

## 5 Tool Support and Experiments

We developed a support tool for UDML that enables the modular separation of concern-specific DSLs, allowing designers to directly model all relevant aspects of the domain.

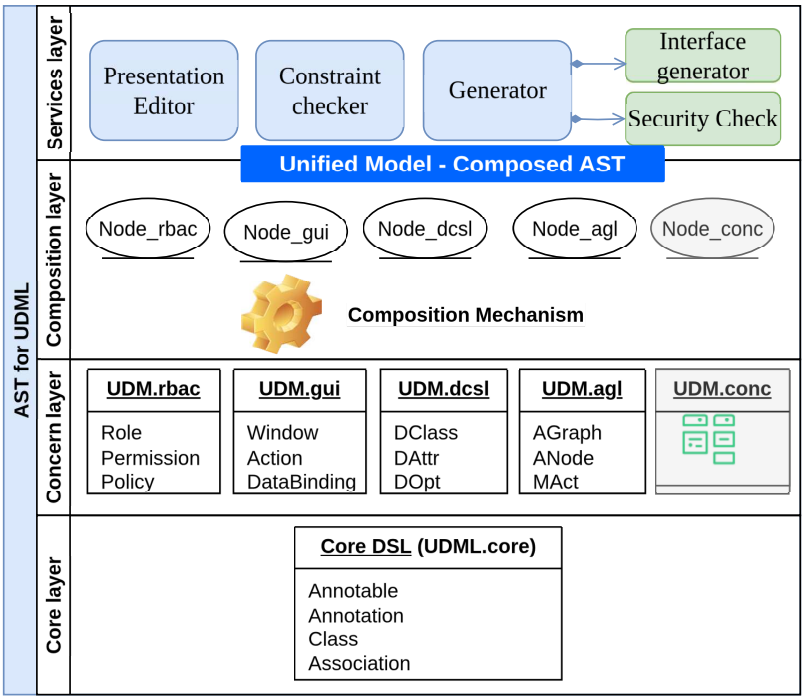


**Fig. 4.** Tool architecture of UDML with the proposed method.

The tool is organized into four main layers, as illustrated in Figure 4:

1. The core layer: Defines the syntax of the core DSL (`UDML.core`), providing the foundation for integrating other concerns into UDML. This includes fundamental concepts such as `Annotable`, `Annotation`, `Class`, and `Association`.
2. The concern layer: Defines the AS for each specific concern tailored for development goals. For instance—`UDM.rbac`, `UDM.gui`, `UDM.dcsl`, and the other concerns `UDM.conc`—for general concepts.
3. The composition layer: Facilitates the composition of the defined concerns into the UDML model, utilizing an enhanced composition mechanism to create a unified and consolidated AST.
4. The services layer: Provides graphical interface services that enable designers to perform tasks such as presentation editing, constraint checking, and software/prototype generation, alongside auxiliary services like Security Check.

Our approach is implemented using JetBrains MPS [3, 35], which provides a flexible platform for AST-based language composition and seamless integration into existing development workflows. Each DSL defines a set of concepts (AST node types). The unified AST aggregates all these concepts with cross-references among them. Projectional editors enable each concern-specific DSL to have its

own dedicated interface, while all operate on a shared AST. The tool facilitates the design, extension, and integration of concern DSLs, validating the approach's expressiveness, feasibility, and satisfiability. The practical applicability of our method is illustrated in Figure 5, and the implementation is publicly available at the Git repository[3].

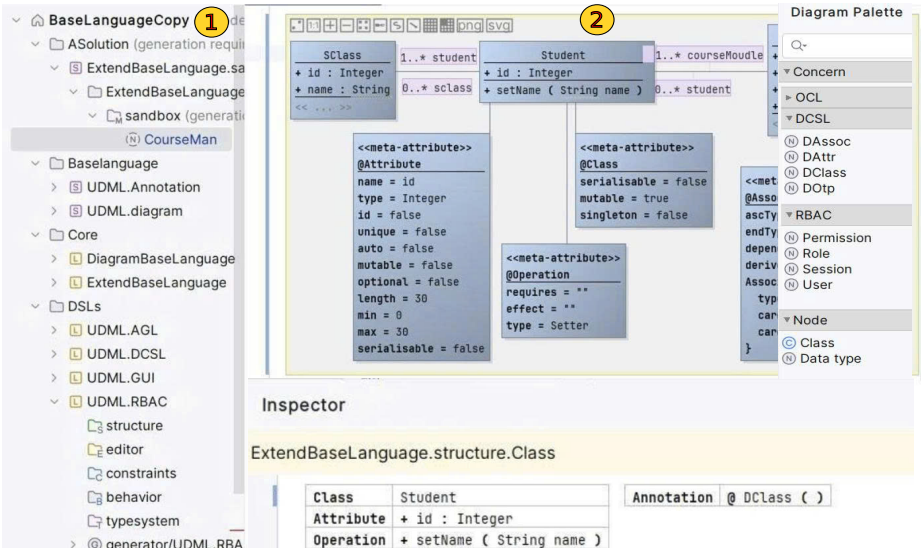


**Fig. 5.** MPS-based realization and practical integration of concern DSLs in UDML

Figure 5 illustrates our implementation. On the left, three core components are defined: (i) Instructor, specifying metaconcepts for UDML and concern DSLs; (ii) Editor, providing a graphical concrete syntax with drag-and-drop capabilities; and (iii) Generator, transforming the AST into executable code via the JDA framework [9]. We designed the UDML language as modular packages: `UDML.core` provides the integration foundation, while `UDML.dcsl`, `UDML.agl`, and `UDML.rbac` capture structural, behavioral, and security concerns, respectively. The central area offers a graphical interface for domain modeling, supported by a palette that enables intuitive construction through rapid insertion of concern-specific elements.

We applied the support tool to the CourseMan case study. Figure 5, label (2), illustrates the UML class diagram together with the integrated concern DSLs: DCSL, AGL, and RBAC. The tool then generates the corresponding source code. Finally, a software prototype is produced using the JDA framework, with further technical details provided in Figure 6.

[3] https://github.com/vinhskv/udml-syntax-soict2025.git

In Figure 6, the left side (label (1)) shows the definition of a template file in the language workbench editor, while the right side (label (2)) presents the resulting `Student` domain model, which is part of the course management system. This domain model is subsequently embedded into the JDA framework to generate the final software artifacts.

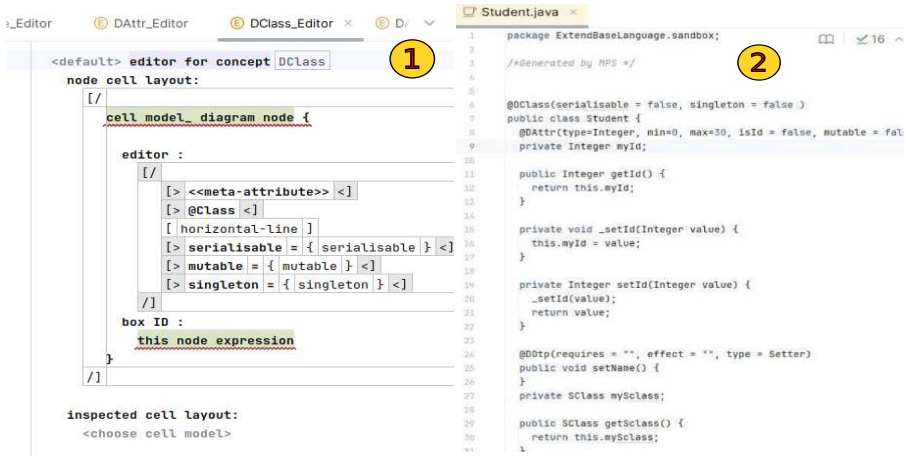


**Fig. 6.** MPS-based Realization and Code Generation via the JDA Framework

Figure 7 illustrates the interface of the software artifact generated for the course management system. This artifact is produced after the executable unified domain model has been created and deployed within the JDA framework, which transforms the model specifications into a functional application interface.

**Discussion.** We have successfully applied UDML in developing software for real-world problem domains. However, several validity concerns arise. First, correctness depends on the expressive adequacy of individual concern DSLs and their coherent integration via UDML, in line with DDD principles. Second, integrating heterogeneous external DSLs requires sufficient syntactic support, which is currently ensured through systematic metaconcept validation, interface design, transformation testing, and verification of generator rules. Third, the generated Java code may misalign with requirements if generation errors occur within the JDA framework. To mitigate this, we conduct careful review and verification of the generated output.

## 6 Related Work

We position our work at the intersection between the following areas: DSL Engineering, DDD concern DSLs, Integrating concern DSLs.

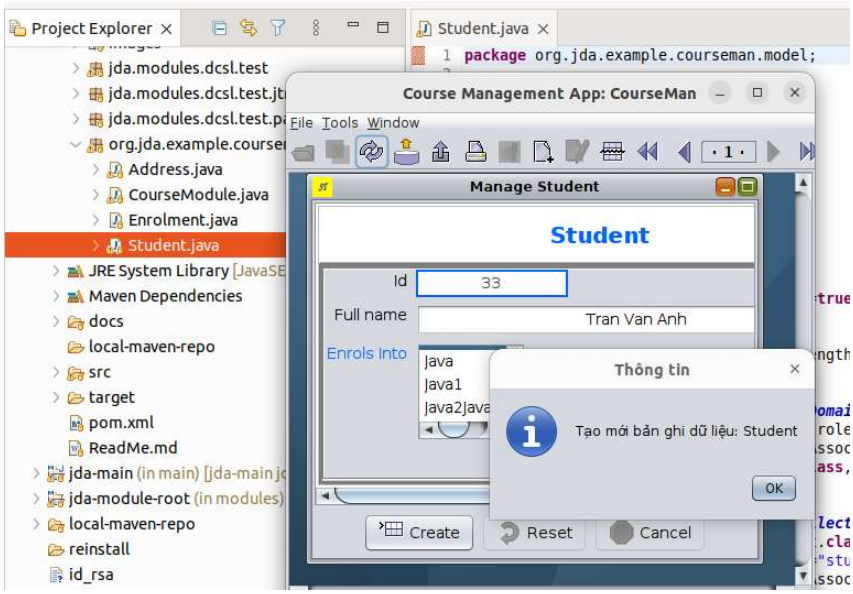


**Fig. 7.** Software artifacts generated by the JDA framework

***DSL Engineering and Language Workbenches.*** DSL engineering has matured significantly [36], with language workbenches such as JetBrains MPS [3] playing a pivotal role in enabling the design, implementation, and maintenance of DSLs for both academic and industrial use. The ability to define, extend, and compose DSLs in MPS has been demonstrated in various domains, including finance, healthcare, safety-critical systems, and industrial automation, where tailored DSLs have led to increased productivity, improved quality, and more effective leveraging of domain expertise.

***DDD and Concern-Specific DSLs.*** DDD [10] advocates an iterative software development approach centered on a semantically rich domain model that encapsulates the core logic and rules of the problem space. Vernon [34] provides practical guidance for applying DDD principles in the construction of complex systems, while Jaiswal [17] addresses the gap between business requirements and object-oriented modeling in software development.

Several studies [2,4,11,31] emphasize maintaining strong consistency between design models and implementation source code, thereby enhancing correctness, maintainability, and extensibility. These works focus less on fully automating the development process or exhaustively modeling all system aspects, and more on ensuring reliable model–code alignment.

Valle [33] offers insights into the practical challenges software teams face in understanding and modeling complex business domains. Karagiannis [8] highlights domain-specific conceptual modeling as a crucial technique for produc-

ing high-quality information systems aligned with business needs. Similarly, Kapferer [18] leverages domain-specific languages (DSLs) and toolchains to standardize and automate aspects of Strategic DDD, improving both efficiency and design accuracy in complex software systems.

Wasowski [1] presents methods for designing, constructing, and applying DSLs to achieve effective modeling, automation, and reuse in software development. Voelter [35] shows how DSL engineering enables domain experts to directly express their concepts in source code, narrowing the gap between business requirements and technical implementation. Chiprianov [5] proposes the strategic integration of DSLs into the software engineering process to improve productivity, quality, and stakeholder communication.

Other works [6, 7, 21, 28] focus on applying DDD principles using internal DSLs—specifically annotation-based DSLs—embedded directly in object-oriented programming languages. This approach enables orthogonal integration, ensures model consistency across concerns, and facilitates formal reasoning and automated code generation. By leveraging projectional editing in JetBrains MPS and the DDD-oriented JDA framework, our approach bridges the gap between flexibility of internal DSLs and the rigor of external, metamodel-driven DSL engineering.

***Integrating Concern DSLs.*** The work of Haber et al. [16] presents an effective solution for integrating heterogeneous modeling languages, enabling seamless interaction between distinct modeling paradigms. Nosal et al. [25] propose an innovative technique for combining heterogeneous programming languages and DSLs through the use of source code annotations. This approach enhances code expressiveness, simplifies the development and maintenance of complex systems, and allows developers to select the most suitable language for each task within the same source file. Loiret et al. [24] introduce a flexible method for incorporating domain-specific requirements into component-based systems using aspect-oriented programming (AOP) and annotations, effectively separating functional and non-functional concerns.

Pfeiffer [30] provides insights into effective strategies for constructing complex models through systematic composition. Similarly, Ugaz et al. [32] focus on methods and tools for weaving and integrating multiple aspects of Domain-Specific Modeling Languages, particularly cross-cutting concerns, in order to improve reusability, maintainability, and consistency in software systems.

Furthermore, several works [3, 14, 20, 29, 35] highlight JetBrains MPS as a powerful and flexible platform for DSL engineering. MPS facilitates the design, implementation, reuse, and composition of language components, enabling their seamless integration into existing software development workflows. This capability significantly improves the efficiency and quality of software engineering by promoting modularity and composability in language design.

In our previous work [22], we proposed an approach to composing concerns into an executable unified domain model. This approach leverages a metamodel based on UML metaconcepts to support the composition and unification of concern-specific DSLs. Each concern is specified using an external DSL, which

is then mapped to an internal DSL to produce an executable domain model embedded in an object-oriented programming language (OOPL) for source code generation.

In contrast, the present work defines the full syntax of concern-specific DSLs and introduces an integration method based on tree merging at the AST level (Unified AST). Moreover, we define a unified syntax for composing concern-specific DSLs.

However, existing approaches often fall short in supporting the full DSL development pipelinespanning editing, verification, code generation, and automated testing. Backward traceability between models and generated code remains a critical challenge, especially as systems evolve.

## 7 Conclusion and Future Work

This paper introduces a methodology for integrating multiple concern-specific DSLs into a unified domain model. Building upon this foundation, we define the complete syntax and semantics of UDML, an external DSL designed to support domain-driven development. UDML is structured as an AST, where each node corresponds to a concept from a specific concern DSL. This structure enables modular development and seamless integration of heterogeneous concerns, while preserving consistency across structural, behavioral, and security dimensions of the domain model. The proposed approach is realized through a prototype tool developed using JetBrains MPS and the JDA framework. The tool demonstrates the feasibility, expressiveness, modularity, and executability of UDML in modeling complex software systems aligned with DDD principles.

In the future, we plan to develop an MPS plug-in for our method for many domain concerns. We also intend to develop a technique for automatically transforming a specification requirement into complex software systems.

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