A Pattern-Based Approach for Explaining Ontology-Driven Conceptual Models

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Abstract. Conceptual models—designed as means for knowledge sharing—are expected to be extensively reused within their respective domains. However, studies reveal that people often struggle to understand already existing models. Assuming that specific conceptual model views can serve as explanations for particular exploratory questions, we demonstrate how these views and questions can be systematically constructed for OntoUML models. This paper presents the results of a preliminary evaluation of the approach conducted through a questionnaire. The findings highlight that our pattern-based approach enables the construction of model views that contain fewer elements than the original model while remaining sufficient to answer the targeted questions.

Keywords: Ontology-Driven Conceptual Models · Conceptual model explanations · OntoUML · User studies

1 Introduction

Conceptual modeling, defined as "the activity of formally describing some aspects of the physical and social world around us for purposes of understanding and communication" [13], is usually employed during the early stages of information system analysis and design. The ultimate output of this process—a *conceptual model* (CM) or an *ontology-driven conceptual model* (ODCM)—is intended to facilitate effective communication during the later stages among users with different backgrounds.

However, a model can only be utilized effectively if it is understood by its users [15]. Given that the number of modeling elements can often be overwhelming, proper comprehension of the model might require suitable explanations. Although the literature presents different types of explanations [2], this paper focuses on a *pragmatic approach*: explaining the original model by constructing a reduced version that still addresses the user's request.

In this paper, we refer to an ontology as what is commonly termed a *foundational ontology* and utilize *Unified Foundational Ontology* (UFO) [8] for our goals. By an ODCM we understand a concrete artifact that represents *conceptualization of a specific domain*, whose development was guided by the ontology. We address the problem of explaining ODCMs by answering the following

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research question: *How can we systematically construct model views in response to user requests for an explanation?*

The remainder of the paper is organized as follows: Sect. 2 provides definitions and represents the semantics of the explanation process; Sect. 3 shows how the views can be generated in request for an explanation for the OntoUML models; Sect. 4 discusses the results of the preliminary experiment; Sect. 5 elaborates on final considerations and future work. The list of patterns and their corresponding exploratory questions, as well as the complete version of the questionnaire with anonymized results are available on the project's GitHub page: https://w3id.org/ExpO/github/CAiSE25.

2 A Pattern-Based Approach to ODCM Explanations

If we agree that an explanation is an answer to a *request-for-explanation* (typically, a *why-question*) as suggested in [9, p.334], and consider a CM as our explanation of the domain, then the model should be able to answer a number of corresponding questions.

The idea of having a list of questions that should be answered is quite popular in ontology engineering, for example. Grüninger & Fox suggested considering user queries that an ontology should answer as informal *competency questions* (CQs) [5]. Although, in theory, CQs should guide the modeling process, in practice ontology engineers face difficulties when writing, using, and managing CQs [18], and, as a result, the final list of questions is rarely shared.

In a domain of (logic-based) eXplainable AI, there is a notion of *prime implicant* or *abductive explanations*—a minimal set of features sufficient for ensuring the prediction of the classifier [12]. If we consider elements of the model (e.g., concepts, relations, generalization sets, etc.) as model features, then the following definitions can be suggested.

Definition 1. *An* explanation of the ODCM with respect for a given question *is an ODCM view sufficient to answer that question.*

Definition 2. *An* ODCM view *is a model obtained from a given reference model by applying one or more explanation transformations that is consistency-preserving.*

These definitions are based on the ideas of the model's *consistency* and its *sufficiency* for answering questions. According to [1], a class is consistent if the model admits an instantiation in which this class has a non-empty set of instances. In the case of ODCMs, the inconsistency may happen due to design errors and violations of the rules of the underlying ontology.

Unlike the definition of a 'view' for ontologies (see [14]), we are not solely focused on a 'portion' of the original ODCM. In general, any transformation that maintains the model's consistency is permitted.

Still, this approach—where CQs are treated as questions of interest and the model is regarded as an explanation for these questions—has at least two drawbacks. First, in contrast to classification systems, the judgment of whether the given model sufficiently answers a question can sometimes be subjective. Second, given that CQs are rarely given, this suggests the hypothesis that the user (who is assumed to be unfamiliar with the model) must first be able to formulate a question and then apply the necessary transformation(s) to find the answer in the model.

Reoccurring ontology modeling situations can be addressed using *ontology design patterns* [4]. Thus, in the case of ODCMs, we may use the incorporated semantics and suggest that *each modeling pattern corresponds to a set of exploratory question templates*. Therefore, we may help our users by generating questions that the model can answer where the sufficiency of the resulting ODCM view is guaranteed by the pattern.

The idea of having a particular model view that is sufficient to answer a question correlates with the concept of pragmatic explanation for domain ontologies [16] and complexity management of CMs (see [3,11]).

3 OntoUML Models and Their Explanation

In principle, ODCMs are not bound to any specific ontology, but we chose UFO [8] because of the existence of an associated ontology-driven conceptual modeling language, named OntoUML. *OntoUML* is a language that extends UML class diagrams by defining a set of stereotypes. These stereotypes expand the UML's meta-model so that classes and associations decorated with them bring precise (real-world) semantics grounded in the underlying UFO [7]. For a detailed discussion and formal characterization of UFO and OntoUML, we refer the reader to works by Guizzardi *et al.* [7,8], while in this paper we focus on explaining the approach through an illustrative example.

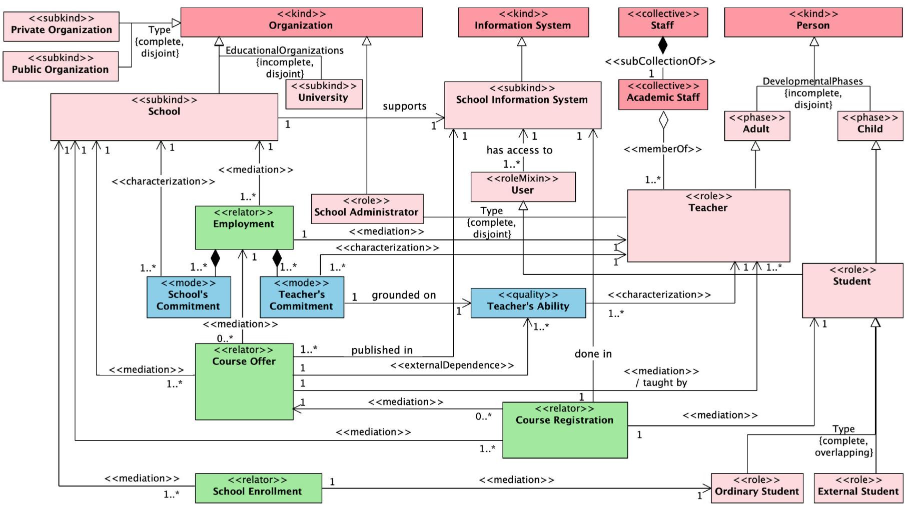


Fig. 1. Student enrollment and course management in OntoUML model.

The OntoUML model shown in Fig. 1 was developed based on the following description of the domain of student enrollment and course management within a school:

Children are enrolled in the school and can register for various courses offered by the school through an information system. Each course has an assigned teacher, and part of their responsibility under their employment contract is to conduct these courses. In addition, students from other schools, referred to as external students, are also allowed to participate in these courses. The school information system records enrollment details and the controlling organization has the ability to monitor this information, including which students are enrolled in which courses.

In the model: *(1)* the coloring schema follows the color convention of the OntoUML plugin for Visual Paradigm[1]; and *(2)* material relations derived from relator types are omitted[2]. Here we are not considering *events* and *situations*. All concepts in the example are *endurants* (object-like entities) [7].

As mentioned, OntoUML is an ontology pattern language [19], where the patterns are formulated in terms of possible stereotypes (for details, see [6,17]). Table 1 shows *Subkind* and *Relator* patterns and how they are exemplified in our model. Table 2 presents templates for exploratory questions aligned with these two patterns. It also includes how these questions are realized for our example and text answers. A complete list of all templates is available on the project's GitHub page.

We recognize that users may would like to have the flexibility to pose arbitrary questions of interest: Can the 'Teacher' of one 'Course' be a 'Student' in another 'Course'?[3] For such questions, we hypothesize that a *combination of patterns* could serve as an explanation. To evaluate whether this approach improves user perception of the generated views, we used a questionnaire.

4 Experiment with Exploratory Questions

The primary goal of the study was to evaluate whether pattern-based ODCM views are perceived as effective explanations for arbitrary exploratory questions.

The questionnaire consisted of three sections. The first section focused on gathering information about the interviewees' experience with conceptual modeling. The second section presented a complete ODCM with the narrative and then several views derived from this ODCM, along with the corresponding questions. The final section assessed participants' satisfaction with the views, specifically

[1] https://github.com/OntoUML/ontouml-vp-plugin.

[2] According to the relator pattern [17], there can be a material relation between the mediated concepts to which the relator refers. In the case of 'Employment', this could be the 'works for' relation from 'Teacher' to 'School'. These relations are ommitted here due to space limitations.

[3] In the example any course is always conducted by an adult and followed by children, so the answer is 'No'.

Table 1. Patterns in OntoUML and their exemplifications.

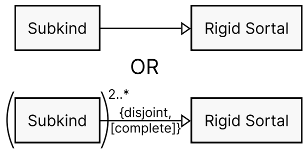
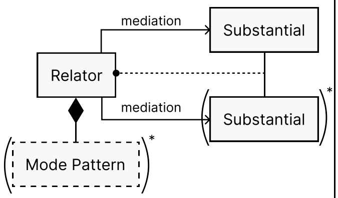
Name and idea	**Template**	**Example in Fig. 1**
Subkind pattern is used when there is a need to distinguish rigid (static) specializations of a kind. This can be applied to kinds whose instances are objects, quantities, collectives, qualities, modes and relators.		'Organization' with 'Private Organization' and 'Public Organization', 'School' and 'University' subkinds (these two sets are orthogonal, see [6]); 'School Information System' as subkind for 'Information System'.
Relator pattern is a pattern which objectifies a material relation and aggregates all these externally dependent modes that the involved relata acquire in the scope of that relation.		'Employment' with 'School's Commitment' and 'Teacher's Commitment'; 'Course Offer'; 'School Enrollment'; 'Course Registration'.

Table 2. Some templates for generating exploratory questions.

Pattern	**Question template**	**Generated question**	**Text answer**
Subkind	Can a $<\mathit{Subkind}_1>$ become a $<\mathit{Subkind}_2>$?	Can a 'Private Organization' become a 'Public Organization'?	No, that would be a new 'Organization'.
	Can a $<\mathit{Subkind}_1>$ be a $<\mathit{Subkind}_2>$ at the same time?	Can a 'Private Organization' be a 'Public Organization' at the same time?	No, because the corresponding generalization set is disjoint.
Relator	What is in the nature of a <RelatorType>? What are the aspects that the relata acquire when mediated by a <RelatorType>?	What is in the nature of an 'Employment'? What are the aspects that 'Teacher' and 'School' acquire when mediated by an 'Employment'?	Both 'Teacher' and 'School' acquire a number of commitments in the scope of an 'Employment'.
	When is a particular $<\mathit{Relatum}_1>$ related to a particular $<\mathit{Relatum}_2>$?	When is a particular 'Student' related to a particular 'School'?	A 'Student' is related to a particular 'School' iff there is a 'Course Registration' that connects them.

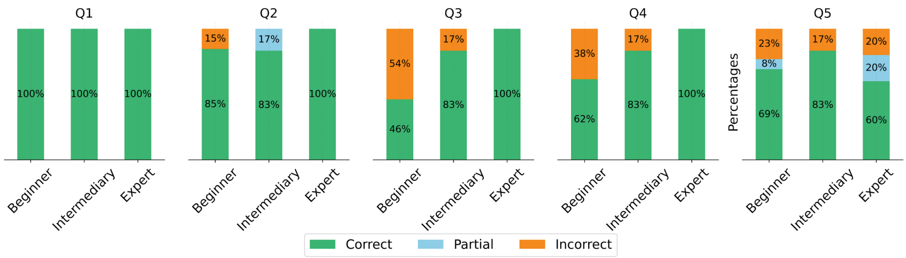


Fig. 2. Correctness of answering questions.

considering their *sufficiency as explanations for the questions*. The questions in the final section were adapted from the System Causability Scale (see Fig. 3) [10].

To reduce the internal validity threat of our evaluation, we grounded the main section of the questionnaire on two different models and randomized our interviewees among them. Both models did not require special knowledge. The first one was our example from Fig. 1 (but without OntoUML stereotypes), while the second one described the relations between Customers and Fitness Studio.

The number of elements in each model was not very high but still demanding some time for an exploration. First, we asked three simple preliminary True / False questions to make sure the respondent can understand the model. For example, one of the questions for the model on Fig. 1 was "According to the model every Child has to be a Student" (False). After the preliminary questions, the interviewee received five multiple-choice questions (Q1–Q5). Our goal was to check whether the questions could be correctly answered based on the views. Finally, the respondent received five exploratory questions with the already given text answers and views (SQ1–SQ5), where our question to the interviewees was "Does the model contain sufficient information to answer this question?".

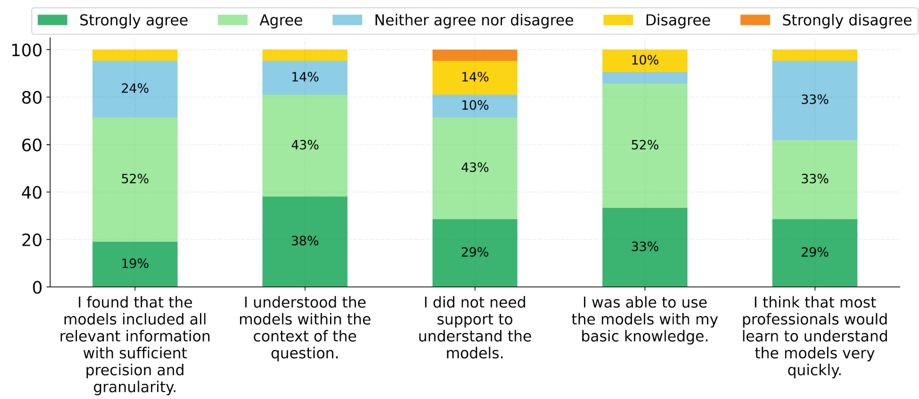


Fig. 3. Results for the adapted System Causability Scale.

In total we received 30 responses. However, the answers of 6 interviewees were disqualified as they made mistakes while answering our preliminary questions. In general, about half of our interviewees were beginners in conceptual modeling and—from the second part of the questionnaire—we can see that the correctness of the responses correlates with the expertise (see Fig. 2). On average, the respondents have spent about 20 min answering the questionnaire.

Most of the time our questions were answered correctly (Fig. 2). Moreover, the confidence in answers was also quite high. Furthermore, respondents reported that the given ODCM view is complete enough with respect to the question to which it is supposed to answer: 78% in average for one model and 83% for another one. The results of the adapted System Causability Scale are presented in Fig. 3 and are also positive (details are available on the project's GitHub page).

5 Conclusions

The paper presents a pattern-based approach for constructing pragmatic explanations of ontology-driven conceptual models. We suggested that specific model views—consistent and sufficient to answer the question of interest—are perceived as explanations of the original model.

In order to guarantee sufficiency, we used model patterns as building blocks for constructing the final views. Since each pattern corresponds to a set of questions, we can also generate by template some exploratory questions to help our users familiarize themselves with the model.

In the conducted questionnaire, we extracted only 'portions' of the models as explanations. In general, the approach we suggest does not limit us in model transformations as soon as consistency with the original model is kept. Thus, we can also apply abstraction in order to reduce the number of modeling elements.

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References

1. Berardi, D., Calvanese, D., De Giacomo, G.: Reasoning on UML class diagrams. Artif. Intell. **168**(1–2), 70–118 (2005). https://doi.org/10.1016/j.artint.2005.05.003
2. Chari, S., et al.: Explanation ontology: a general-purpose, semantic representation for supporting user-centered explanations. Semant. Web **15**(4), 959–989 (2024). https://doi.org/10.3233/sw-233282
3. Figueiredo, G., et al.: Breaking into pieces: an ontological approach to conceptual model complexity management. In: Proceedings of RCIS 2018, pp. 1–10 (2018). https://doi.org/10.1109/RCIS.2018.8406642

4. Gangemi, A., Presutti, V.: Ontology design patterns. In: Handbook on Ontologies, pp. 221–243 (2009). https://doi.org/10.1007/978-3-540-92673-3_10
5. Grüninger, M., Fox, M.S.: Methodology for the design and evaluation of ontologies. In: Proceedings of the IJCAI 1995 Workshop on Basic Ontological Issues in Knowledge Sharing (1995). http://www.eil.utoronto.ca/wp-content/uploads/enterprise-modelling/papers/gruninger-ijcai95.pdf
6. Guizzardi, G., Almeida, J.P.A.: Stability patterns in ontology-driven conceptual modeling. In: Proceedings of ONTOBRAS 2020. CEUR, vol. 2728, pp. 148–160 (2020). https://ceur-ws.org/Vol-2728/paper11.pdf
7. Guizzardi, G., et al.: Types and taxonomic structures in conceptual modeling: a novel ontological theory and engineering support. Data Knowl. Eng. **134**, 101891 (2021). https://doi.org/10.1016/j.datak.2021.101891
8. Guizzardi, G., et al.: UFO: unified foundational ontology. Appl. Ontol. **17**(1), 167–210 (2022). https://doi.org/10.3233/AO-210256
9. Hempel, C.G.: Aspects of scientific explanation. In: Aspects of Scientific Explanation and Other Essays in the Philosophy of Science, pp. 331–496 (1966)
10. Holzinger, A., Carrington, A., Müller, H.: Measuring the quality of explanations: the system causability scale (SCS). KI - Künstliche Intelligenz **34**(2), 193–198 (2020). https://doi.org/10.1007/s13218-020-00636-z
11. Lozano, J., et al.: Ontology view extraction: an approach based on ontological meta-properties. In: Proceedings of ICTAI 2014, pp. 122–129 (2014). https://doi.org/10.1109/ICTAI.2014.28
12. Marques-Silva, J., Ignatiev, A.: No silver bullet: interpretable ML models must be explained. Front. Artif. Intell. **6** (2023). https://doi.org/10.3389/frai.2023.1128212
13. Mylopoulos, J.: Conceptual modeling and Telos. In: Conceptual Modelling, Databases and CASE: An Integrated View of Information Systems Development, pp. 49–68 (1992)
14. Noy, N.F., Musen, M.A.: Traversing ontologies to extract views. In: Modular Ontologies: Concepts, Theories and Techniques for Knowledge Modularization, vol. 5445, pp. 245–260 (2009). https://doi.org/10.1007/978-3-642-01907-4_11
15. Parush, A.: Conceptual Design for Interactive Systems: Designing for Performance and User Experience (2015). https://doi.org/10.1016/c2013-0-06903-4
16. Romanenko, E., Calvanese, D., Guizzardi, G.: Towards pragmatic explanations for domain ontologies. In: Proceedings of EKAW 2022, vol. 13514, pp. 201–208 (2022). https://doi.org/10.1007/978-3-031-17105-5_15
17. Ruy, F.B., et al.: From reference ontologies to ontology patterns and back. Data Knowl. Eng. **109**, 41–69 (2017). https://doi.org/10.1016/j.datak.2017.03.004
18. da Silva Quirino, G.K., Salamon, J.S., Barcellos, M.P.: Use of competency questions in ontology engineering: a survey. In: Conceptual Modeling, vol. 14320, pp. 45–64 (2023). https://doi.org/10.1007/978-3-031-47262-6_3
19. Zambon, E., Guizzardi, G.: Formal definition of a general ontology pattern language using a graph grammar. In: Proceedings of FedCSIS 2017, vol. 11, pp. 1–10 (2017). https://annals-csis.org/Volume_11/drp/pdf/001.pdf