Knowledge formalization for 3D geological modeling

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Abstract
We present an ontological model that formalizes expert's knowledge used to build three-dimensional structural geological models. This formalization is driven by our intention of proposing a knowledge-based system for automatic model construction. The proposed ontological model includes aspects about geological features, their representations, and modeling processes.

Keywords
Knowledge formalization, geological 3D modeling, interpretation, ontologies

1. Overview of the PhD

This contribution is part of an ongoing PhD project that aims to develop a new knowledge-driven paradigm for three-dimensional geological modeling, one that automatically interprets and uses expert knowledge. Traditionally, the process of building 3D models is considered an issue of numerically representing expert understanding using modeling systems [1]. These systems are incapable of retracing the mental processes of experts. Thus, geological knowledge is always held by experts during the process, and systems work principally on data that represents only a portion of existing knowledge. Our approach challenges this notion by emphasizing knowledge formalization and the automation of the interpretation process. In particular, we concentrate on the aspect of knowledge formalization. To represent geological and modeling knowledge, we employ ontological models. In this paper, we delineate the motivation, requirements, applications, and structure of the proposed ontological models, along with presenting initial results.

2. Motivation for using ontologies

In geosciences, ontologies have been used mainly for assisting data annotation and knowledge management applications [2–7], but less for 3D modelling [8]. Overall, this usage is small compared to other domains, such as medical fields or engineering domains [9,10]. Formalizing knowledge for a specific aspect of geosciences (geological modelling) is challenging as this field

Proceedings of the Joint Ontology Workshops (JOWO) - Episode X: The Tukker Zomer of Ontology, and satellite events co-located with the 14th International Conference on Formal Ontology in Information Systems (FOIS 2024), July 15-19, 2024, Enschede, The Netherlands.
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itself is multidisciplinary (interpretation, 3D representation, structural geology). Application of ontologies in such multidisciplinarity raises questions about the use of foundational ontologies, harmonization, and alignment. Finally, because geological modelling has been always a process heavily engaging expert knowledge to overcome a very limited quantity of information, the challenge is to maximize the transfer of expert knowledge into a computable framework.

3. Results

The project has selected case studies centered on modeling folded rocks from observations and existing theories about geological situations. These case studies drive the requirements for the knowledge framework, the interpretation process, and algorithms. Re-use of existing ontologies is a cornerstone of the approach. Preliminary results include:

1. Algorithm: we propose a three-block algorithm to implement the proposed formalism, Figure.1. The first block consists of a knowledge manager that describes geological features, their geological properties and how to implement them. The second block applies the formal interpretation process. The last block oversees exploring interpreted features in a representation space having both physical and temporal extensions.

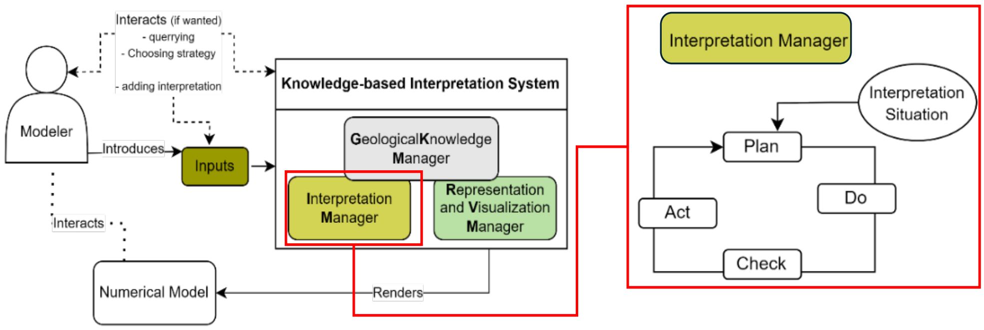

Figure 1: Schematic representation of the modeling system based on the formalism developed in the ongoing PhD project. The red box shows schematic representation of the main stages of the proposed formal interpretation process.

2. Formal Interpretation process: we consider this process to be iterative and incremental as shown in Figure.1. In this process, an unexplained situation is selected, information about it is retrieved, theories about this situation are made, then realized, after that checked. Finally, initial understanding by new information is upgraded. This entire process is implemented in the algorithm using a Deeming wheel for continuous improvement [11] with four subprocesses (Plan, Do, Check, Act). In the proposed formalism, interpreting geological features is basically a process of identifying instances of existing types of features, without discovering new types.
3. Ontologies: current work is focusing on the development of an ontological model that describes the three aspects of the formalism (geological features, interpretation process, and representation aspects) as shown in Figure.2. For describing geological features, we intend to adopt the Geoscience Ontology (GSO) of Brodaric and Richards [12]. The GSO is a modular domain ontology that describes geological aspects and features in three

layers. The GSO is consistent in many aspects with other top-level ontologies (e.g. aspects of DOLCE and BFO). To structure knowledge about Processes, Observations, Knowledge, Information, and Models and their representations, we create the POKIMOn ontology. This ontology draws from existing ontologies such as Information Artefact Ontology [13], the semiotic triangle and adapts a few concepts from the Observation and Measurements standard [14]. Finally, to structure knowledge aspects about cognitive processes we create the GeolReasOn ontology. This ontology is designed mainly to reason with existing information during the modeling process. It describes situations that could be encountered and possible actions that could be taken to deal with them.

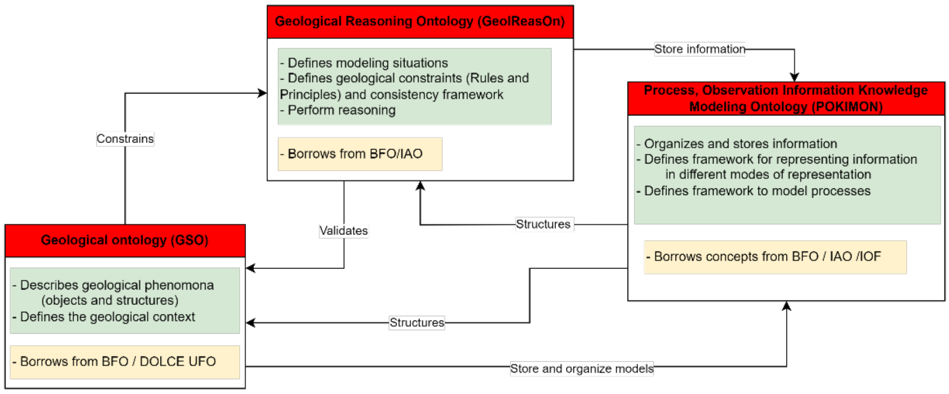

Figure 2: Schematic architecture of the proposed ontological model with the three blocks (GSO, POKIMOn and GeolReasOn)

4. Conclusion

We summarize the goals, approaches, and preliminary results for a PhD project aimed at developing an ontology-driven approach to 3D geological modeling. The overall aim is to better leverage existing knowledge for improved models, with the work currently in progress.

Acknowledgements

This work was carried out in the framework on the ANR-JCJC project MaLISSiA (Machine Learning and Interpretation of Sub-Surface Architectures) directed by Gautier Laurent and funded by the French national research agency (ANR) under the number ANR-22-CE56-0001-01. This work was also supported by the BRGM in the framework of I. Laouici's PhD and TelluS Program of CNRS/INSU in the framework of the project named Cornerstone.

References

[1] Wellmann F, Caumon G. 3-D Structural geological models: Concepts, methods, and uncertainties. Advances in Geophysics. 2018;59:1–121.

[2] Raskin RG, Pan MJ. Knowledge representation in the semantic web for Earth and environmental terminology (SWEET). Computers and Geosciences. 2005;31(9):1119–25.

[3] Babaie HA, Davarpanah A, Banda JM. Ontology of Optical Microscopic Imaging and Analysis. 2020 Dec 1;2020:IN030-03.
[4] Fauziati S, Watanabe K. Ontology of Volcano System and Volcanic Hazards Assessment. International Journal of Geoinformatics. 2010;6.
[5] Garcia LF, Abel M, Perrin M, Alvarenga R dos S. The GeoCore ontology: A core ontology for general use in Geology. Computers and Geosciences [Internet]. 2020;135. Available from: https://doi.org/10.1016/j.cageo.2019.104387
[6] Zhong J, Aydina A, McGuinness DL. Ontology of fractures. Journal of Structural Geology. 2009 Mar;31(3):251–9.
[7] Abel M, Gastal ESL, Michelin CRL, Maggi LG, Firnkes BE, Pachas FEH, et al. A Knowledge Organization System for Image Classification and Retrieval in Petroleum Exploration Domain. In: ONTOBRAS. 2019.
[8] Perrin M, Rainaud JF. Shared earth modeling : knowledge driven solutions for building and managing subsurface 3D geological models. Paris, 400pp: Technip Editions; 2013. 400 p.
[9] Dermeval D, Vilela J, Bittencourt II, Castro J, Isotani S, Brito P, et al. Applications of ontologies in requirements engineering: a systematic review of the literature. Requirements Eng. 2016 Nov 1;21(4):405–37.
[10] Ivanović M, Budimac Z. An overview of ontologies and data resources in medical domains. Expert Systems with Applications. 2014 Sep 1;41(11):5158–66.
[11] Moen R. Foundation and History of the PDSA Cycle. In: Asian network for quality conference Tokyo https://www deming org/sites/default/files/pdf/2015/PDSA_History_Ron_Moen Pdf. 2009.
[12] Brodaric B, Richard SM. The GeoScience Ontology. 2020 Dec 1;2020:IN030-07.
[13] Ceusters W, Smith B. Aboutness: Towards Foundations for the Information Artifact Ontology. In: Proceedings of the Sixth International Conference on Biomedical Ontology (ICBO). CEUR vol. 1515; 2015. p. 1–5.
[14] Cox S. Geographic Information: Observations and Measurements. 2010 Nov 10 [cited 2023 Feb 13]; Available from: https://publications.csiro.au/rpr/pub?list=BRO&pid=csiro:EP115859&sb=RECENT&n=8&rpp=10&page=59&tr=5496&dr=all&dc4.browseYear=2010