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Visual interpretation of events in petroleum exploration: An approach supported by well-founded ontologies

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ABSTRACT

In visual domains, such as Medicine, Meteorology and Geology, the tasks are accomplished through intensive use of visual knowledge. In this work, we focus in an essential kind of task that is performed in many visual domains: the visual interpretation task. We call visual interpretation the expert reasoning process that starts with the perception of visual features of domain objects and results in the understanding of the scene. We propose a top-down approach for solving visual interpretation tasks, which is based on symbolic pattern matching supported by well-founded ontologies. Our approach combines well-founded domain ontologies; a meta-model for representing inferential knowledge, which is based on the notion of perceptual chunks; and a reasoning model for visual interpretation. The proposed model was applied for developing an expert system for automating the task of visual interpretation of depositional processes, which a crucial task for petroleum exploration.

1. Introduction

Visual domains are those in which the problem-solving process starts with a visual pattern-matching process that captures the information that support further abstract inference processes of interpretation. In this sense, visual domains make intensive use of *Visual Knowledge*, which is the set of mental models that support the process of reasoning over information of spatial arrangement and other visual aspects of domain entities (Carbonera, Abel, Scherer, & Bernardes, 2011; Lorenzatti, Abel, Fiorini, Bernardes, & dos Santos Scherer, 2011). Visual domains impose many challenges to Computer Science, regarding acquisition, modeling, representation and reasoning.

Visual interpretation is a task that is prevalent in several visual domains. It comprises *the reasoning process that starts with the perception of visual features of domain objects and results in abstract interpretations that are meaningfully related to these perceptions* (Carbonera, 2012; Carbonera et al., 2011, Carbonera, Abel, Scherer, & Bernardes, 2013). An example of visual interpretation process is reported in cognitive studies of expertise in chess (Gobet & Simon, 1998), where chess masters literally "see" the next move, when they observe the state of the chessboard. Other examples are provided by Wood (1999), including the process of *reading a text*, when we interpret abstract meanings from visually perceived patterns of symbols; and the *visual interpretation of radiography*, when the radiologists interpret abnormalities from visual patterns in a radiography.

In this paper, we propose a *knowledge-based approach* for dealing with tasks of *visual interpretation of events*. This approach is based on a *symbolic pattern matching* process that operates over *symbolic representations* of the domain objects and their visual features. In our approach, these symbolic representations are articulated using *domain ontologies* that *specify in a formal and explicit way the shared conceptualization in a given domain* (Studer, Benjamins, & Fensel, 1998). Ontologies have been adopted as the core of knowledge-based systems in recent years, since they allow the *knowledge reusing* and promote the *semantic interoperability* among systems.

Regarding the representation of the domain knowledge, in this paper, we also adopted a foundational ontology called *Unified Foundational Ontology* (UFO) (Guizzardi, 2005) for supporting the development of our domain ontologies. UFO is a theoretically well-founded domain independent system of categories that can be used to construct models of specific domains. Due to this, it can serve as a foundation for analyzing domain specific concepts, providing guides to make modeling decisions in the conceptual modeling process, clarifying and justifying the meaning of the models, improving the understandability and reuse. UFO is an ontology of *particulars* and *universals*. That is, it provides a set of categories of particulars and a set of categories of universals. The

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categories of universals can be viewed as *meta-types*, since they are "types of types". These meta-types are organized in a taxonomy according to some ontological meta-properties, such as *identity*, *rigidity*, *existential dependency*, and so on. They are used for classifying[1] concepts in domain conceptual models according to its ontological meta-properties, fitting the resulting domain model to the meta-conceptualization embedded in UFO. The main benefit of using UFO for ontology development is that it facilitates the expliciting of the meaning underlying the concepts (and detecting cases of *false agreement*, for example).

In our approach, we propose (i) a *meta-model for representing the inferential knowledge* that is applied in visual interpretation tasks, and (ii) reasoning model for visual interpretation. The proposed meta-model, called *visual chunk*, is inspired in a cognitive structure called *perceptual chunk*, which was postulated in a cognitive theory of expertise called *chunking theory* (Chase & Simon, 1973). This meta-model assigns explicit roles to *ontological meta-properties* of domain concepts in computational accounts of visual interpretation tasks. We claim that there are ontological meta-properties of domain concepts that are related to the conditions that allow the visual perception of its instances, determining the domain concepts that can participate in the visual interpretation processes. In this work, we attempt to *clarify the meta-properties of the concepts that participate in visual interpretation tasks*, exploring their roles in the reasoning models that are used for this kind of task. This ontological clarification allows the definition of inferential knowledge meta-models and reasoning models that embody explicit ontological constraints. This increases the potential of reuse of inferential knowledge and reasoning models and allows a more accurate mapping between these models and the domain ontology. The meta-properties that we use for clarifying the concepts that can participate in visual interpretation tasks are formalized in UFO.

In summary, our approach innovates (i) by adopting *foundational ontologies* to model the domain ontology in an ontologically well-founded way; (ii) by using ontological meta-properties and cognitive foundations to propose a meta-model (called *visual chunk*) for representing the inferential knowledge that is applied in the solving of visual interpretation tasks; (iii) by using ontological foundations for constraining the mappings between the knowledge represented in the domain ontology and the inferential knowledge; and (iv) by applying instances of Visual Chunks as inferential knowledge in the reasoning model.

It is important to notice that our approach deals only with symbolic representations of visual knowledge. In this sense, it does not deal directly with raw visual data. The objects that are visually perceived in a given scene are described as instances of the domain ontology that is being considered in the problem at hand, and the reasoning model performs the interpretation taking these ontology instances as input.

This work is part of the *Obaitá Project* (Carbonera et al., 2011, 2013; Garcia, Carbonera, & Abel, 2014; Lorenzatti et al., 2011; Lozano, Carbonera, Abel, & Pimenta, 2014), which investigates integrated approaches for dealing with visual knowledge, regarding the acquisition, modeling, representations and reasoning. Our investigations consider Petroleum Geology as the target domain of study. The petroleum exploration activities usually requires the performing of several knowledge intensive and resource-consuming tasks and, due to this, there is an increasing interest in the development of intelligent software that automate them. Some of these tasks also rely on an intensive application of visual knowledge. Therefore, in order to build intelligent systems in this context, it is necessary to deal with this kind of knowledge. In the current stage of the project, we are interested in a visual domain called Sedimentary Stratigraphy, focusing on the task of *visual interpretation of depositional processes*. In this task, the geologists visually inspect geologic records in rocks and interpret which was the correspondent geologic process that was responsible by the formation of this record. This task is a resource-consuming job, which relies intensively on the visual knowledge of geologists, and that is considered a crucial step in *petroleum exploration*. We understand this task as a special case of *visual interpretation of events*, which is a special case of visual interpretation task (as we defined previously).

In this paper, we also apply our approach for developing and *expert system for visual interpretation of depositional processes* within the domain of Sedimentary Stratigraphy. Our system takes as input symbolic descriptions of bodies of rock (with a set of sedimentary facies) and interprets, for each facies, the depositional process that was responsible by its formation. The description of bodies of rock is performed though a commercial descriptive software called Strataledge,[2] which was developed based on the concepts described in this paper and uses the same domain ontology that is embedded in our expert system. Our system was developed using the Java programming language, adopting a relational database for storing the user data, as well as the domain ontology and the instances of visual chunks. We have performed an evaluation of the system, by comparing its outcomes against the interpretations associated to cases that were collected from the literature.

This paper explicitly extends our previous works (Carbonera, 2012; Carbonera et al., 2011, 2013), providing a more comprehensive view of our proposal, improving the formal aspects of our approach. We provide here details of our framework that have not been presented before and show some results of the application of the expert system developed using our approach for interpreting depositional processes from descriptions of *real* sedimentary facies.

In Section 2, we present the context of our approach, discussing some computational approaches that deal with the visual data processing. In Section 3, we present our main contribution; a symbolic pattern matching approach supported by ontologies for visual interpretation of events. Since we apply our approach in the problem of visual interpretation of depositional processes, which carried out by experts in the Sedimentary Stratigraphy domain, in Section 4 we provide an overview of this domain and our target task. Section 5 presents an expert system for visual interpretation of depositional processes, which rely on our approach for visual interpretation of events. In this session, we also present some results of an evaluation test that was performed with real domain cases. Finally, Session 6 presents our final remarks and discusses future works.

2. Related works

The literature presents many approaches for dealing with computational processing of visual data, such as low-level *image processing*, *machine learning* and *knowledge-based* approaches. The approaches that apply image processing (Rangayyan, Ayres, & Desautels, 2007) and machine learning techniques (Akay, 2009) are based on detectable geometric features of the image (such as texture and shape) extracted from the raw data. These features cannot support the inferences that are performed in a more abstract level by the experts, as discussed by Abel, Silva, Campbell, and De Ros (2005). Besides that, it is not obvious how is the visual appearance (and how are its admissible variations) of a given feature in complex natural domains such as Geology.

[1] Concepts in domain conceptual models are instances of the meta-types provided by UFO.

[2] <http://www.endeeper.com/products/software/strataledge>.