Reasoning over visual knowledge*

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Abstract. *In imagistic domains, such as Medicine, Meteorology and Geology, the tasks are accomplished through intensive use of visual knowledge, offering many challenges to the Computer Science. In this work we focus in an essential task accomplished in many imagistic domains: the visual interpretation task. We call visual interpretation the expert reasoning process that describes a cognitive path that starts with the visual perception of domain objects, involves the recognition of visual patterns in these objects and results in the understanding of the scene. We investigate the role played by foundational ontologies in problem solving methods involving visual information. We propose a cognitive model for visual interpretation that combines domain ontologies, ontologically well founded inferential knowledge structures based on the notion of perceptual chunks and PSM's. The proposed model was effectively applied through a Problem-solving method to solve the task of visual interpretation of depositional processes, within the Sedimentary Stratigraphy domain.*

1. Introduction

Imagistic domains are those in which the problem-solving process starts with a visual pattern-matching process, which captures the information that will further support the abstract inference process of interpretation. In this sense, imagistic domains make intensive use of *Visual Knowledge*, which is the set of mental models that support the process of reasoning over information that comes from the spatial arrangement and other visual aspects of domain entities [Lorenzatti et al. 2011]. Imagistic domains impose many challenges to Computer Science, in terms of acquisition, modeling, representation and reasoning, due to the tacit and unconscious nature [Polanyi 1966] of visual knowledge.

In the computational processing of visual data in imagistic domains, one aims to represent, extract and reason over the raw data, according to the meanings defined by the human mind. In this sense, we consider that the computational processing of visual data is a problem composed by several sub-problems. In general, the recent studies are focusing mainly in two of these sub-problems: the semantic representations of raw visual data [Lorenzatti et al. 2011] and the symbol grounding problem [Hudelot et al. 2005]. The former problem concerns to the development of computational representations that abstracts the raw visual data and captures the meaning of it, in a useful way for human beings. This is an important problem, since the meaning is established in human mind,

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not in the visual data. The latter problem concerns to the issue of embodying the semantic interpretation of symbols into artificial systems, allowing it to establish the relation between the symbols and the raw visual data. We consider that there is a third problem that is addressed in the recent investigations as a less important one: the visual interpretation task, that is, the expert reasoning process that describes a cognitive path that starts with the visual perception of domain objects, involving the recognition of visual patterns in these objects and results in abstract conclusions which are meaningfully connected to these perceptions, that is, the understanding of the scene. According to [De Groot and Gobet 1996] "cognition is perception", in the sense that in the expertise development, the subjects develop dynamic abstractions of visual patterns of domain objects or visual features of domain objects, which guides the problem-solving process. We are interested in visual interpretation processes with these features.

The literature shows many approaches to deal with computational processing of visual data, such as low-level image processing, machine learning and knowledge-based approaches. Approaches that apply Image processing [Rangayyan et al. 2007] and machine learning [Akay 2009] techniques 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 developed in a more abstract level by the experts, as demonstrated in [Abel et al. 2005]. On the other hand, knowledge-based approaches, as semantic image interpretation, aims to model the abstract portion of knowledge that supports visual data understanding and to process this information symbolically, in order to reach conclusions in the domain. Recently, knowledge-based approaches make use of ontologies and Problem-Solving Methods (PSM) [Mastella et al. 2005]. Other works [Hudelot et al. 2005] propose the integration of image processing and knowledge-based approaches with reasoning capabilities, to interpret the raw visual data. However, most of the recent works have not been focused in the investigation of the human-like capabilities of reasoning over the visual knowledge abstracted from the visual data. Thus, the complete characterization of the inferential knowledge structures, needed to carry out visual interpretation tasks in a way that reproduces the human performance, is viewed as a secondary issue. In this work we address this issue, proposing an inferential knowledge structure for visual interpretation tasks.

We claim here that there are ontological meta-properties of domain concepts that provide the conditions which allow the visual perception of it instances, determining the domain concepts that can participate in the visual interpretation tasks. In this work we attempt to clarify the meta-properties of domain ontology primitives that allows visual interpretation tasks, exploring the role of foundational ontologies in the problem-solving methods used for this kind of task. This ontological clarification should allows the definition of inferential knowledge structures and PSM's that embodies ontological constraints of foundational ontology, increasing the potential reuse of them and allowing a more accurate mapping to the domain ontology. We propose here a knowledge-based computational approach for visual interpretation task that combines domain ontologies with an inferential knowledge structure, called *visual chunk*, which is based on the cognitive notion of perceptual chunk. The properties that the visually observable entities have in the point of view of the human cognition are reproduced in visual chunks through ontological constraints. In this sense, our approach relies on the meta-properties defined in the *Unified Foundational Ontology* [Guizzardi 2005] in order to establish the mapping between the domain ontology and the inferential knowledge structures. Our approach offers some benefits: (a) approximates the class of possible inferential knowledge models to that of intended ones; (b) captures in a narrowest way the organization of the inferential knowledge used by the expert; (c) guides the process of acquisition of the inferential knowledge for visual interpretation tasks, and (d) helps to manage and to maintain the inferential knowledge in the systems.

The Section 2 presents the cognitive and technical foundations of our approach. Section 3 details our inferential knowledge structure for visual interpretation tasks. In this work we deal with a specific type of visual interpretation task, which concerns the visual interpretation of the events responsible by the generation of the visually observed object. Thus, we work with an instance of this task, that is, the visual interpretation of depositional processes responsible by the generation of sedimentary facies, in the domain of Sedimentary Stratigraphy. For these reasons, in section 4 we present an overview of the Sedimentary Stratigraphy domain and describe a PSM that applies the proposed approach in this domain. The section 5 presents the evaluation process of our approach and an analysis of the outcomes. Finally, section 6 presents our main conclusions.

2. Cognitive and technical foundations

We describe here the core theoretical framework of our work, including some studies of the human visual processing, the cognitive characterization of expertise, the unified foundational ontology (UFO) and PSM's.

2.1. Human visual processing

According to [Matthen 2005], the object perception depends on establishing a direct, causal and informational relation with a set of external physical objects, that corresponds to any unique material body that possesses hierarchically organized and cohesive parts, which exists independently of internal states of the perceiver and his/her perceptual systems. Moreover, in [Tversky 1989] it is pointed out that the notion of *parts* and *partonomies* play an important role in the perceptual processes. In this sense, the parts of a complex object play the role of perceptual saliencies, which provide important clues to individuate and recognize the object, through visual perception. The proper configuration of parts determines the shapes that objects can take. In addition, parts, and their perceptual saliencies, seem to be natural units of perception and natural units of function. In this sense, they provide important criteria in order to make more abstract judgments related to the perceived object, such as, functions and behaviors.

2.2. Expertise

The experts organize the knowledge in a qualitatively superior way, influencing the access to the knowledge and the interpretations of the perceptual stimuli coming of the environment. For the experts, the indexes of access to the knowledge are chunks of related perceptual stimuli that, when recognized together, allow the fast access to the knowledge meaningfully associated. These *perceptual chunks* are developed through the repeated recognition of the perceptual stimuli associated to specific situations or events, and play the role of cognitive triggers to the abstractions of those events and situations [Chase and Simon 1973]. Thus, perceptual chunks integrate sets of related perceptual stimuli to more abstract conceptual components and can be seen as abstractions of a solution step in a problem-solving process [Cooke 1992]. In high degrees of expertise, the problem-solving process of visual interpretation tasks is driven by pattern-matching, where the visual stimuli that come from the domain are confronted with the visual patterns stored in perceptual chunks, triggering the abstract interpretations related to them. The gradual elaboration of perceptual chunks leads to the automation of the cognitive processes that integrate perception and the high-level cognition [Sternberg 1997]. These processes can explain the resistance that experts show in verbalizing the fine-grained knowledge that relates the visual aspects of the domain and their high-level interpretations. This intermediary knowledge, composed by domain explicit facts and rules of the domain theories in the early stage of expertise, is chunked and automated during many years of repeatedly application, integrating some specific knowledge developed during the practical activities, which transcends the explicit domain theories offered in the domain literature. Thus, perceptual chunks play the role of cognitive shortcuts, from the visual stimuli to the abstract interpretations related to them.

2.3. Unified Foundational Ontology

Foundational ontologies are meta-ontologies that have been developed based on the theories of a philosophical discipline called Formal Ontology. Foundational ontologies offer guides to make modeling decisions in the conceptual modeling process, clarifying and justifying the meaning of the models, improving the understandability and reusability. In this paper we use domain ontologies to represent the domain shared conceptualizations, and the Unified Foundational Ontology (UFO) to formalize both, the domain ontology and the inferential knowledge model. We will summarize the main UFO features that we will apply in this work. A full description of UFO can be found in [Guizzardi 2005]. UFO defines a set of meta-types and meta-properties that classify concepts in conceptual models. Initially, UFO makes a distinction between *Endurant Universal* and *Perdurant Universal* (or *Event Universal*). Instances of an *Endurant Universal* (such as Dog, Person, Country, etc) are individuals wholly present whenever they are present. On the other hand, instances of a *Perdurant Universal* (such as Game, War, etc), are individuals composed by temporal parts, that is, they happen in time, accumulating temporal parts. Within the *Endurant Universals*, UFO defines *Substantial Universals* whose instances are individuals that posses spatial-temporal properties, are founded on matter and are existentially independent from all other individuals. The relation between a *Substantial Universal* and an *Event Universal* is called *participation*, according to UFO. Some *Substantial Universals* are *Sortal Universals*, which provide principle of identity (PI) and principle of unity (PU). In this context, PI supports the judgment whether two instances of the universal are the same, when PU supports the counting of the instances of the universal. *Kind* is a *Sortal Universal* whose instances are functional complexes. On the other hand, *Moment Universals* are *Endurant Universals* whose instances are existentially dependent individuals that inheres in other individuals. Some *Moment Universals* are *Quality Universals*, which represents the properties in the conceptual models. A *Quality Universal* characterizes other Universals and it is related to *Quality Structures*, that is, a structure that represents the set of all values that a quality can assume. Thus, considering the property color as a *Quality Universal*, a given instance of Car could be characterized by an instance of quality Color, which is associated with a value of ColorStructure, which represents all the possible values that the property color can assume. Finally, UFO proposes four types of parthood relations, clarifying their semantics: *componentOf*, *memberOf*, *subCollectionOf* and *subQuantityOf*. Each parthood relation only can be established between individuals of specific UFO meta-types, respecting some ontological constraints embodied in UFO.

2.4. Problem-solving methods

A PSM consists of an abstract specification that describes the reasoning process at the knowledge level, capturing the expert problem-solving behavior in a domain and implementation independent way, through the specification of the knowledge and control structures required [Perez and Benjamins 1999]. A reasoning pattern is modeled through a PSM, by three components: (i) a *competence specification* that describes what the PSM can do, (ii) an *operational specification* that describes how the process is developed and the knowledge required in each inference step of the process, and (iii) *requirements/assumptions* embodied in the method in terms of domain knowledge.

3. Inferential knowledge structures for visual interpretation tasks

Our approach adopt the notion of perceptual chunk in order to propose a structure of inferential knowledge representation that captures the direct relationship between the visual stimulus and the abstract interpretations meaningfully related to them, in a cognitively well founded way. Moreover, the inferential knowledge representation structure proposed here, called *Visual Chunk*, is organized as patterns of constrained arrangements of domain knowledge. This organization is the result of ontological constraints that allow the participation of only certain domain concepts and relations, arranged in specific way. In visual chunks, only instances of domain concepts classified as *Substantial Universal* according to UFO, can be visually perceived, since substantial universals have instances that satisfy the visual perception conditions: material bodies, which exists independently of internal states of the perceiver and his/her perceptual systems. Thus the core of a visual chunk is a Substantial Universal. The visual stimuli stored in the visual chunk, are values that belong to quality structures associated to quality universals, which characterizes the substantial universal, whose instances are visually inspected by the expert. Furthermore, our model preserves the importance of the parthood relations to the human perceptual and cognitive processes. We claim that an effective modeling of inferential knowledge structures and inference processes in imagistic domains should be focused in revealing and representing the perceptual chunks applied by experts, avoiding the problems related to elicit the tacit fine-grained knowledge that relates perceptual stimuli and their abstract interpretations.

3.1. Characterization

Let O be a domain ontology, V is the vocabulary that represents this ontology. The vocabulary of interest to the realization of the task of visual interpretation of events is denoted by V_{target}, and corresponds to a subset of V. The V_{target} contains two pairwise disjoint subsets: V_{vk} e V_{int}. The V_{vk} represents the domain primitives (concepts, relations and properties) used by the expert to describe visually the objects of interest in the domain. While V_{int} corresponds to the vocabulary that represents the domain primitives that describe events that can be interpretable through visual inspection of the domain objects described by V_{vk}. Thus:

$$V_{target} \subseteq V$$

$$V_{target} = V_{vk} \cup V_{int}$$

$$V_{vk} \cap V_{int} = \emptyset$$

In a very abstract level, a *Visual Chunk* has the general form of a logical implication, such as

$$antecedent \implies consequent,$$

where the $antecedent$ is a logical formula, constituted by atoms a_{vk}, where $a_{vk} \in V_{vk}$, and the $consequent$ is a logical formula, constituted by atoms a_{int}, where $a_{int} \in V_{int}$. Our aim is to restrict the vocabularies V_{vk} and V_{int}, considering UFO ontological constraints to reflect the cognitive constraints previously discussed. In this sense, these vocabularies can represent only certain meta-concepts and relations offered by UFO.

The vocabulary V_{vk} must contain only and exclusively the following constructs:

ObservableEntity: Represents domain primitives whose instances can be directly visually perceived. We consider that only instances of domain concepts classified as *Substantial Universal*, according to UFO, can be direct visually perceived.

VisualQuality: Represents the abstraction of a possible visual quality of a domain entity visually observable. In this sense, according to UFO, they are *Quality Universals* defined in the domain ontology, which maintains a *characterization* relation with an *ObservableEntity*.

VisualQualia: Represents a constrained set of possible values of a *VisualQuality*. Is a subset of values that belong to the *Quality Structure* associated to a *VisualQuality*.

VisualQuale : Represents a value that belongs to the *Quality Structure* associated to a *VisualQuality*.

PartOfRelation: Represents a parthood relation between two *ObservableEntity* in the domain. This relation is one of that allowed by UFO. The specific type of parthood relation depends on the specific ontological nature of the two *ObservableEntity* related, following the ontological restrictions imposed by UFO.

The vocabulary V_{int} must contain only and exclusively the following constructs:

InterpretableEvent: Represents domain concepts that abstract the events responsible by the generation of the *ObservableEntity*. These concepts are classified as *Event* in the UFO. As an additional requisite, these concepts must be organized in a subsumption hierarchy, since the interpretation task aims to find the more specific subtype of *InterpretableEvent* responsible by the generation of the *ObservableEntity* individual under visual inspection.

ParticipationRelation: Represents a domain *participation* relation between the *ObservableEntity* whose instance is being interpreted, and the *InterpretableEvent* responsible by it generation.

The *Visual Chunk* is structured according to some internal structures, which represent recurrent patterns of relationship among the constructs previously presented. This structure can be described as following, in a semi-formal way. Firstly, a *VisualChunk* is the structure that relates *VisualFeatures* and an *Interpretation*.

$$VisualChunk =_{def} (VisualFeatures, Interpretation)$$

VisualFeatures can be simple (*SimpleVisualFeatures*) or complex (*ComplexVisualFeatures*).

$$VisualFeatures =_{def} SimpleVisualFeatures \vee ComplexVisualFeatures$$

SimpleVisualFeatures is a structure that relates an *ObservableEntity* and a set of *PossibleVisualFeatures*.

$$SimpleVisualFeatures =_{def}$$
$$(ObservableEntity, \{PossibleVisualFeatures_1, ..., PossibleVisualFeatures_n\})$$

where

$$VisualFeatures \Longrightarrow Interpretation$$

PossibleVisualFeatures is a structure that relates a *VisualQualia* and a *VisualQuality*, which maintains a *characterization* relation with the *ObservableEntity*. Here, *VisualQualia* corresponds to a constrained sub-set of values of the *Quality Structure* associated to the *VisualQuality* in the domain ontology. This sub-set of values represents the values that the *VisualQuality* can assume to support the *Interpretation* according to the expert.

$$PossibleVisualFeatures =_{def} (VisualQuality, VisualQualia)$$

ComplexVisualFeatures, on the other hand, is a structure that relates a *SimpleVisualFeatures* to a set of *VisualPart*.

$$ComplexVisualFeatures =_{def}$$
$$(SimpleVisualFeatures, \{VisualPart_1, ..., VisualPart_1\})$$

VisualPart is a structure that relates a *PartOfRelation* to a set of *VisualFeatures* derived from ($ObservableEntity_{part}$), which are parts of the *ObservableEntity* (representing the whole visually observed). The *PartOfRelation* relates the *ObservableEntity* that are wholes to the $ObservableEntity_{part}$, which are their parts.

$$VisualPart =_{def} (PartOfRelation, \{VisualFeatures_1, ..., VisualFeatures_n\})$$

Interpretation is a structure that relates a *ParticipationRelation* to an *InterpretableEvent*.

$$Interpretation =_{def} (ParticipationRelation, InterpretableEvent)$$

In this sense, considering a specific *VisualChunk*, when *VisualFeatures* is *found*, then *Interpretation* is also *found*. In the case of *VisualFeatures* to be a *SimpleVisualFeatures*, we say that it is *found* when all the *PossibleVisualFeatures* related to the *ObservableEntity* are *found*. A *PossibleVisualFeatures* is *found* when there is a *Quality individual* that is instance of the *VisualQuality*, which *inheres in* the particular *ObservableEntity* under visual inspection and that assumes a value which is a *VisualQuale* that belongs to the correspondig *VisualQualia*. On the other hand, a *ComplexVisualFeatures* is said *found* when the *SimpleVisualFeatures* is *found* and all the *VisualPart* are *found*. A *VisualPart* is *found* when there is a *PartOfRelation* between the *ObservableEntity* and an $ObservableEntity_{part}$ that is its part, and when at least one of the *SimpleVisualFeatures* (derived from the $ObservableEntity_{part}$) is *found*. When the *Interpretation* is *found*, the *ParticipationRelation* that relates the *ObservableEntity* and the *InterpretableEvent* is instantiated.

4. Case study: Sedimentary Stratigraphy

Sedimentary Stratigraphy is the study of sedimentary terrains in surface or subsurface of the Earth, in order to define the geological history of their formation based on the visual description of well cores and outcrops. The main objects of study and description is: Sedimentary Facies (SF), Sedimentary Structures (SS) and Depositional Processes (DP). A SF is a region in a well core or outcrop, visually distinguishable of adjacent regions. Each SF is assumed as a direct result of the occurrence of a DP. A SS is the external visual aspect of some internal spatial arrangement of the rock grains. Finally, DP are events that involve the complex interaction of natural forces and sediments. DP are responsible for the formation of sedimentary rocks, through transport and deposition of sediments in a sedimentation place. Our domain ontology of Sedimentary Stratigraphy is ontologically well founded, using UFO. In this work, we present the ontological characterization of these three main concepts, but the properties will not be fully detailed.

Sedimentary Facies (SF): Instances of SF can be visually recognized, individuated and counted. SF offers a principle of identity and it instances cannot cease to be SF without ceasing to exist. According to UFO it is a *Kind*. The set of *Quality Universals* that characterizes SF include: lithology, sorting, roundness and others. There is a relation between SF and SS, called *hasSedimentaryStructure*, which is a *componentOf* relation, according to UFO.

Sedimentary Structures (SS): It is an analogous case to SF. Therefore it is also a *Kind*. The SS concept has many subkinds organized in a taxonomy. The set of *Quality Universals* that characterizes SS include: laminae shape, angularity, thickness, laminae shape and so on.

Depositional Process (DP): Entities of DP happen in time. We consider DP as an *Event*. Since the SF's are the final results of a DP occurrence, they are participants of DP, that is, there is a *participation* relation, called *generatedBy*, between SF and DP. There are many specific types of DP, which are organized in a taxonomic structure.

During the inspection of a well core or an outcrop, the expert visually segments the body of rock in many distinct SF, observing several discontinuities of the visual properties. After this segmentation process, each SF is visually examined to interpret a specific type of DP, since that each SF was generated by a DP occurred in a remote past. The expert points out the DP by visually observing an aggregation of visual stimuli of the rock, which preserves many visual features which record the action of plastic forces of the DP occurrence. This interpretation process is based on the expert extensive previous knowledge, indexed by perceptual chunks. Thus, the elicitation of these perceptual chunks was a core question of the interaction with the domain expert, during the knowledge acquisition process. The Figure 1 presents an instance of *Visual Chunk* built on the domain ontology of Sedimentary Stratigraphy.

The reasoning pattern that the expert uses to interpret visually Depositional Processes was abstractly captured in a PSM (represented in Figure 2). The PSM uses the *Visual Chunks* presented in the section 3, as inferential knowledge structures. The *competence* of our PSM takes a visual description of an *Observable Entity* and a taxonomy of *Interpretable Events* and infers the specific *Interpretable Event* indicated by the *Observable Entity*. The *assumption* of our PSM is that the visual features imprinted in the *Observable Entities* of the domain indicate an *Interpretable Entity*. The *requirements* are the visual chunks that the expert applies to relate the visual stimuli of the *Observable Entities* to *Interpretable Event*. The *operational specification* describes the inferences in the PSM, which can be detailed as follow:

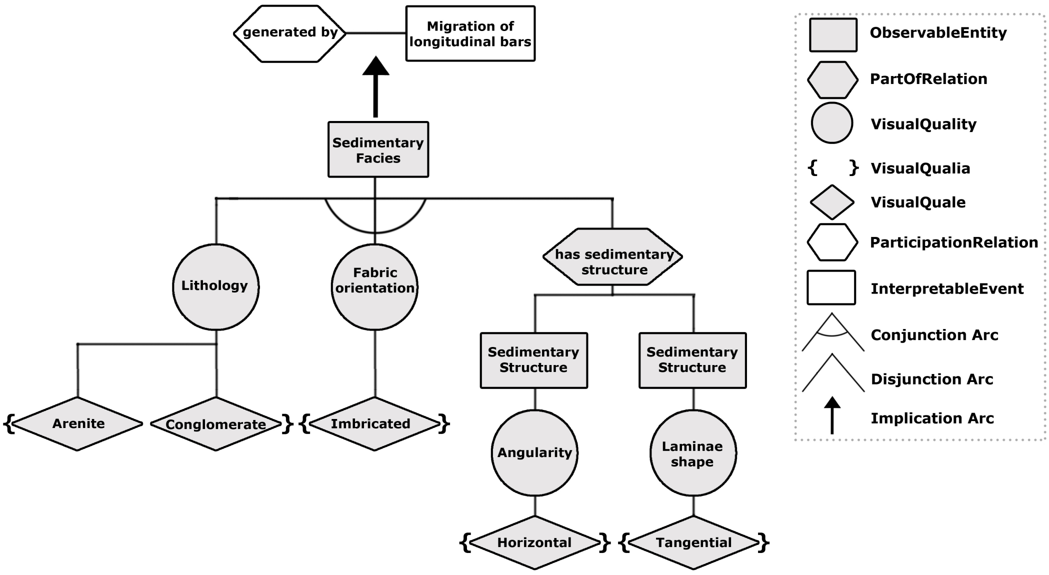

Figure 1. Representation of a Visual Chunk for interpretation of Depositional Processes

Generate: Generate *candidate* interpretations according to the constraints of the taxonomy of *Interpretable Entities* in domain ontology.

Retrieve: Retrieves a set of *Visual Chunks*, whose *Interpretable Event* corresponds to the current *Candidate* interpretation.

Select: Selects a *Visual Chunk* of the previously retrieved set of *Visual Chunks*.

Decompose: Decomposes the *Observable Entity* in other *Observable Entity* that compose it.

Specify: Specifies relevant *Visual Attributes* of the *Observable Entity* and its components.

Obtain: Obtains relevant *Visual Features* (visual attributes and values assigned to then).

Match: Tries to match a specific *Perceptual Chunk* to the relevant features of the *Observable Entity*.

Assign: Assigns the *Candidate* as the current interpretation, in case of positive match of *Visual Features* and *Perceptual Chunk*.

The PSM receives as input an *Observable Entity* (5) and *Interpretable Entities* (1) organized in a taxonomy. The *Observable Entity* is decomposed in other *Observable Entities* that compose it (8). Relevant visual attributes (6 and 9) of the *Observable Entities* are specified, and visual features are obtained (7 and 10) from these attributes. Candidate interpretations (2) are generated from the taxonomy of *Interpretable Entities* (according to the subsumption hierarchy in the domain ontology). A set of *Visual Chunks* (3) whose *Interpretable Event* corresponds to the current candidate interpretation is retrieved. From this set, it is selected a *Perceptual Chunk* (4). Finally, the PSM tries to match the *Perceptual Chunk* with the *Visual Features* of the *Observable Entity*. In the case of positive match (11), the candidate is assigned as the current interpretation (12). This process traverses the taxonomy of *Interpretable Entities* in a top-down way, trying to reach a more specific interpretation in each step. The final interpretation is the last *Interpretable Entity* with at least one *Perceptual Chunk* matched. The process occurs until a leaf of the

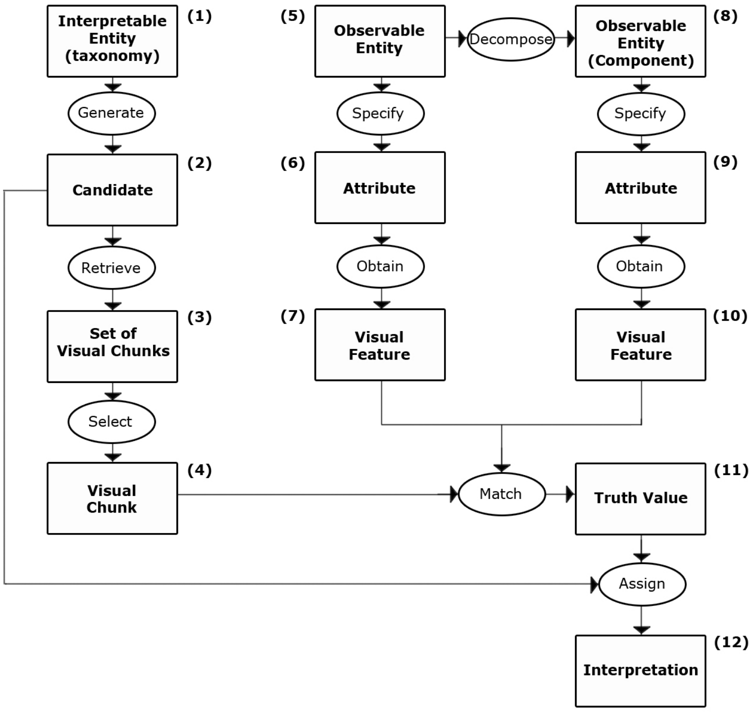

Figure 2. Representation of the PSM to visual interpretation of Depositional Processes

taxonomy is reached or the matching process return false to all the *Perceptual Chunks* associated to the candidate interpretation (meaning that only an interpretation of intermediary level of specificity can be reached from the visual description at hand). Thus, this reasoning model can be viewed as a process of hypothesis generation, retrieval of its associated *Visual Chunks* and symbolic pattern matching between the *Visual Chunks* and the symbolic visual description of the domain objects. The hypotheses are generated according to the constraints embodied in the taxonomy of *Interpretable Entities*. In this sense, when a hypothesis is proved, the next step assumes the concepts of the next level of the taxonomy as the new set of hypothesis to be tested.

5. Evaluation of the approach

Our approach was applied to interpret a set of three real stratigraphic descriptions available in the literature, and interpretations carried out by our approach were compared with the interpretations offered by the literature. Since that this work was focused only in a sub-type of depositional processes called *depositional processes of tractive currents*, it is expected that the PSM interprets only sedimentary facies that had been generated by processes of this sub-type. In other cases, it is expected that the PSM interprets the process as a *Depositional Process*, the more general process in the taxonomy. We consider that an outcome of this type is an *inconclusive interpretation* (a non-answer). Since the PSM can reach interpretations in several levels of generality/specificity, is also expected that for some cases, the conclusion generated by the PSM will be more general than the interpretation of the literature. Thus, to evaluate our approach in detail, we defined some distinct categories of outcomes. Firstly, the outcomes can be satisfactory, when the outcome of the PSM is compatible with the expected interpretation; or unsatisfactory, when the outcome is incompatible with the expected interpretation. Among the *unsatisfactory outcomes*, we distinguish the *false negatives*, when the outcome is an *inconclusive interpretation* and an interpretation was expected; and *false positives*, when the PSM had offered an interpretation and was expected an *inconclusive interpretation*, or when the outcome is a specific interpretation that do not corresponds to the expected interpretation. Within the *satisfactory outcomes*, we distinguish the *true negatives*, when the outcome is an *inconclusive interpretation* for the cases in that the depositional process is not a *depositional process of tractive currents*; and the *true positives*, when the outcome is compatible with the expected interpretation. Finally, within the *true positives* we distinguish the *Specific* correspondences, when the approach provides the more specialized interpretation according to the input; and *General* correspondences, when the outcome is a generalization of the expected interpretation. The Table 1 shows an analysis of the evaluation process.

Table 1. Analysis of the outcomes of the evaluation process

Evaluated cases	Number of facies	Unsatisfactory Outcomes		Satisfactory Outcomes		
		False positives	False negatives	True negatives	True positives	
					Specific	General
Case 1	14	0%	0%	50%	36%	14%
Case 2	8	0%	0%	50%	38%	12%
Case 3	7	0%	0%	29%	57%	14%

The evaluation analysis showed that, for the considered datasets, all the results accomplished had been satisfactory. However the analysis also revealed that, for a significant percentage of facies descriptions, our approach offered interpretations more general than those offered by the literature. One hypothesis that explain this observation is the possibility of the visual descriptions of datasets to be excessively general to support the specificity of the interpretations offered in the literature. This hypothesis will be investigated in future works.

6. Conclusion

We described a modeling approach to explicitly deal with the semantic embedded in visual objects that are used by experts to support problem solving. We built our approach based on the comprehension about how people individuate significant objects when scanning them through the visual system. We recognized that the notion of perceptual chunk, previously identified in several studies, plays a fundamental role in the connection of perceptual capture and further interpretation inference over the domain knowledge. Therefore, we showed that the inherent properties of visually recognized objects can be identified and expressed using constructs that are ontologically founded. The ontological constructs provide the necessary independence between the application and the model that allows reusing both, the reasoning algorithms and the domain ontology. Thus, this work shows the role played by foundational ontologies in problem solving methods involving visual information. We have applied the proposed model to build a robust representation of visual knowledge in a complex real application in Petroleum Geology, and explore it to extract useful stratigraphic interpretations of events and their register in the Earth.

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