Ontology for Imagistic Domains: Combining Textual and Pictorial Primitives

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Abstract. This paper proposes a knowledge model for representing concepts that requires pictorial as well as conceptual representation to fully capture the ontological meaning. The model was built from the proposition of pictorial primitives to be associated to the original conceptual primitives. The formalized pictorial content is then used to provide an organization to the domain, based on the visual characteristics of the objects as humans are used to do. The combination of both primitives allows the definition of domain ontologies to support visual interpretation activities. The approach was applied to build the Stratigraphy ontology for the definition of Sedimentary Facies and Structures.

Keywords: Visual knowledge, Ontology, Conceptual modeling, Stratigraphy.

1 Introduction

Visual knowledge modeling is an intense area of research. There are many approaches searching for a formal way of representing the visual content of the concepts. Human-interpretation activities are usually strongly based on visual information and images. An efficient formal representation of visual knowledge would allow extracting meaning of pictures, searching for content of images through the Internet, indexing documentation using visual content, and developing expert system to automate the decision process in imagistic domains.

Medicine, stock market analysis, aerial traffic monitoring and Geology are examples of imagistic domains [1], which require from the problem solver the ability of applying visual recognition of objects, and from this initial recognition, to start the search and analytical methods in order to interpret these objects [2].

A formal (computer processable) representation of the visual content is required in order to reach all these goals. Ontologies are being applied to represent visual knowledge because they are formal and allow automatic processing over the represented knowledge. However, ontological representations are mainly

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conceptual, based on the textual definition of a vocabulary associated with the characterisation of each word and their relationship [3]. However, Abel's thesis [4] proved that, in order to support problem solving in imagistic domain, some concepts are necessary, which are not fully represented through a vocabulary.

This paper proposes a set of primitives that combine textual ontological representation with pictorial primitives to formalise concepts in an imagistic domain. These primitives allow the addition of pictorial content to domain ontologies. This is especially significant to those concepts that the experts are not able to externalise the full meaning without the complement of a pictorial representation. Most of the features related to rocks and field that support Geological interpretation are like that and, even more often, those related to Stratigraphy, where we develop our study.

Stratigraphy is an area of Geology that tries to understand the history of formation of some terrain based on the identified sedimentary structures imprinted on sedimentary rocks. The sedimentary structures are the visual aspect of the spatial organisation of the grains of a rock as a result of the process of deposition of these grains during the rock formation [5].

This paper is organised as follows. Section 2 presents previous work in the representation of visual knowledge. The approach of this work is presented in Section 3. Sections 4 and 5 are reserved respectively for discussions and conclusions.

2 Related Work on Visual Knowledge Representation

As much as images are becoming a common content in information sources, more approaches are being studied and developed for visual knowledge representation. Most of them try to deal with the semantic gap that is found between the image representation (commonly digital files that represent maps, graphs or pictures) and the significant content that is recognised in the image and is used by someone to take decisions. The mapping between the low level representation and the semantic content of some image is related to the *symbol grounding problem* by Harnad [6].

Hudelot [7] presents a visual knowledge modelling approach for the symbol grounding problem in an application for the recognition of greenhouse rose leaf diseases. The approach divides the conceptual representation of visual knowledge in three semantic levels, namely *Image level*, *Visual level* and *Semantic level*, each one treating visual knowledge in distinct levels of abstraction. It uses two ontologies (a visual concept ontology and an image processing ontology) and a knowledge base to represent visual knowledge. The image processing ontology is used in the Image level to describe basic forms extracted from images through algorithmic processes. The visual concept ontology is applied in the Visual level where image concepts are linked with domain concepts from the Semantic level through its visual description. The knowledge base encodes in a declarative manner the symbol grounding knowledge employed to map concepts between the Image and Semantic levels.

Santin [8] and Fiorini [9] present similar approaches for visual knowledge modeling in the Geology domain applied for the interpretation of visual features for petroleum exploration. Both divide the conceptual representation in semantic levels, similar to [7] although these approaches apply distinct strategies to deal with image processing algorithms and visual content. Santin extracts visual knowledge from images by combining manual and automatic segmentation and associates the image content to polygons for further interpretation. Fiorini segments the image applying wavelets that recognise significant features in the image according to previously defined experts criteria.

Silva [10] also formalises visual knowledge applied in the evaluation of the quality of rocks as petroleum reservoirs. The approach differs by representing the knowledge in two levels of expertise. The first level uses a domain ontology to formalise the visual knowledge that is easily recognised by a novice. The knowledge formalised in this level is represented by atomic concepts, attributes and values. The expert level represents abstractions and the tacit knowledge applied by the expert in recognising diagnostic features over the images.

Liu [11] presents a framework to formalise the visual knowledge applied for visual classification of birds. The framework is composed by a domain ontology and a shape ontology. The domain ontology formalises the ornithologists vocabulary when classifying birds. The shape ontology is organised according to the visual features of the birds (body, beak and wing shapes) which captures the visual information that supports the classification. Both ontologies represent different aspects from the domain and the mapping between ontologies establishes the relationship of domain and visual knowledge. The approach proposes the automatic construction of the shape ontology through the clusterization of real images taken from animals.

Bertini [12] presents an approach for visual knowledge modelling applied for video digital libraries annotation in the soccer domain. The approach is composed by a domain ontology and a set of visual concepts. The domain ontology is expressed in linguistic terms and defined by domain experts. The visual concepts are used represent the visual counterpart of abstract linguistic concepts enriching ontologies with pictorial content. These concepts are automatically defined through a visual clustering process of videos and images.

The formalisation of the pictorial content aggregated in ontologies is an important issue in our research. In our work we propose the representation of the pictorial content inspired the idea of *inferential "free-rides"*. Shimojima [13] formally defines inferential free-rides as the capture of semantic information from a visual symbol, i.e. the visual symbol is built in order to express the right semantic information. Fig.1, extracted from [14], depicts this kind of immediate inference. Fig.1-a shows a sentential language, which describes the relationship among the objects A, B and C, which is equivalent to the graphical language presented in Fig.1-b, whose conclusion is reached in a more straightforward way.

Our research also addresses the same general objective of the previous described works: capturing the visual knowledge in formal representations in order to support interpretation tasks in distinct domains. However, our approach differs from the previous presented ones in the following aspects that will be further detailed in this paper:

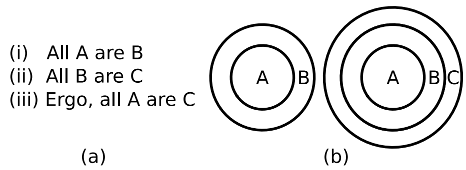

Fig. 1. Example of immediate inference. Extracted from [14].

- The knowledge representation is not going to be fully conceptual as in Silva [10] and Hudelot [7];
- The visual knowledge is not captured through image processing techniques as in Santin [8], Fiorini [9], Liu [11] and [12];
- We use a dual representation – conceptual and pictorial – to capture the knowledge in representational primitives, differently from Hudelot [7], Silva [10], Santin [8] and Fiorini [9];
- The pictorial content does not constitute only a documentation, but is used to define the structure of the domain;
- Pictorial representation is not automatically created (using clusterization) as in Liu [11] and [12].

3 Representing Visual Knowledge through Primitives and Pictorial Content

The cognitive mechanism applied by geologists, when interpreting sedimentary structures to define the stratigraphic history of a rock, is the same than doctors apply when interpreting X-Ray exams in Medicine.

The Stratigraphic concepts represented in our ontology were captured through recorded interviews with the expert, in which he presented the problem and the main principles of the domain in retrospective protocols. The film recordings were later on transcripted to textual files and the concepts were manually identified in the text and incorporated to a list. This list was refined and organised by the expert in a hierarchical structure presented in Figure 2. The initial structure was further populated by new concepts extracted by the indicated literature. Further details of the knowledge elicitation techniques applied can be found in [2].

The main concepts studied in our approach are the *Sedimentary Facies* and the *Sedimentary Structure*. A sedimentary facies is a particular organisation of a rock in a spatial arrangement, that, along with the preserved fossil content, identifies the depositional environment in which the existent sediment has been deposited and consolidated in that rock. The sedimentary structure is the external visual aspect of that internal spatial arrangement. It is the more striking visual object recognised in the domain and the first one to be used in raising interpretation hypotheses. Both concepts comprise two main challenges for ontology engineering. The first is the incapability of the geologists in defining the instances in a pure verbal way, requiring a drawing or a picture to complete the

- Angularity
- Color
- CurrentType
- DepositionalEnvironment
- DepositionalProcess
- DiageneticProcess
- Energy
- Fossil
- Geometry
- Granularity
- Image
- LaminaeShape
- ▼Rock
  - IgneousRock
  - MetamorphicRock
  - ▼SedimentaryRock
    - CarbonaticRock
    - SiliciclasticRock
- Roundness
- SedimentaryFacies
- ▼SedimentaryStructure
  - BiogenicStructure
  - ChemicalDiageneticStructure
  - DeformationStructure
  - ▼DepositionalStructure
    - TractionPlusFalloutStructure
    - TractiveCurrentStructure
    - TractiveWaveStructure
  - ErosionalStructure
- Selection
- Sphericity
- Thickness
- WaterLevel

Fig. 2. Concepts hierarchy

idea. The second is the fact that the terminology associated to the concepts is still informally treated in the domain. Even the specialised literature does not present a formal organisation of the vocabulary and the definition of sedimentary structures [15]. The consequence is the existence of many examples of ambiguous terminology, overloading vocabulary and multiple denominations for the same geological feature.

Our intention in developing the ontology for Stratigraphy is providing a defined vocabulary to be shared and used by geologists in the description of exploration well cores and outcrops. Achieving a shared accepted vocabulary formally defined will provide the adequate basis for developing knowledge systems for stratigraphic documentation and interpretation. This is the long term aim of our project.

The knowledge acquisition process has allowed us to identify the geometrical attributes that are used by geologists to visually recognise sedimentary structures. These attributes were the basis to organize, by visual criteria the concepts in a hierarchy. The preliminary hierarchy is shown in Fig. 2 under the concept *Sedimentary Structure*. Besides visually providing an organization for the sedimentary structures, this hierarchy also represents the organization of the depositional processes that create the sedimentary structures, since each process imprints int the rock exactly one kind of structure. The identified attributes come from the Depositional Structure class, namely *angularity*, *laminae shape* and *thickness*.

The conceptual content of the visual knowledge is described using a set of textual primitives. The primitives are represented through the CML language (Conceptual Modelling Language) from the CommonKADS methodology [16]. These primitives are responsible for nominating and characterizing the components of the geological features that are possible to be described in textual form.

3.1 Pictorial Content Representation

The pictorial content aggregated to ontologies is meant to capture the knowledge which experts can not fully express through a vocabulary. This content is represented through pictorial icons and described with the visual primitives. The icons created were conceived based on the idea of free-rides.

Fig.3-a depicts an example of sedimentary structure from the Traction plus Fallout Structure class. The angularity attribute of the beddings, which measures the angle between the horizon and the layer, is depicted in Fig.3-b. The laminae shape attribute is depicted in Fig.3-c showing a special geometry of the layer. The thickness attribute is depicted in Fig.3-d. It represents the sum of the layers which constitute the whole structure.

The visual attribute *angularity* can assume the values: *horizontal*, *low angle* and *high angle*. These values are a nominal representation for the possible numerical values assumed by angle A in Fig.3-b. Horizontal means an angle between $0°$(zero) and $2°$ degrees, low angle means an angle between $2°$ and $10°$ degrees and high angle means angles over than $10°$ degrees. The respective pictorial representation of the angularity attribute values is depicted in Figure 4-{(a), (b) and (c)}.

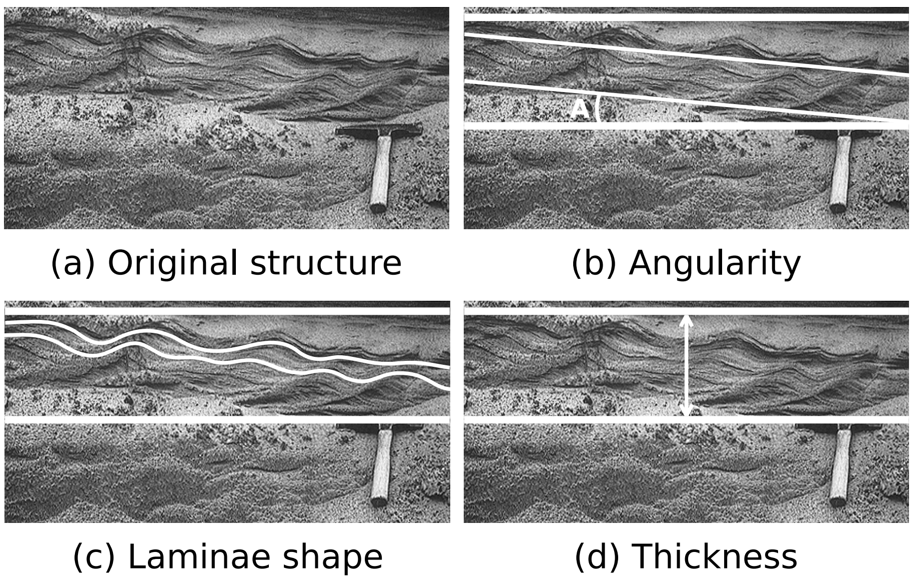

Fig. 3. Example of sedimentary structure with visual attributes emphasized

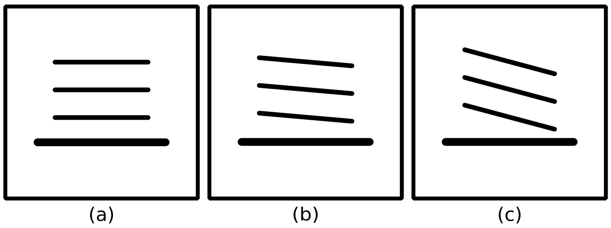

Fig. 4. Icons representing the values for the angularity visual attribute: (a) horizontal; (b) low angle; (c) high angle

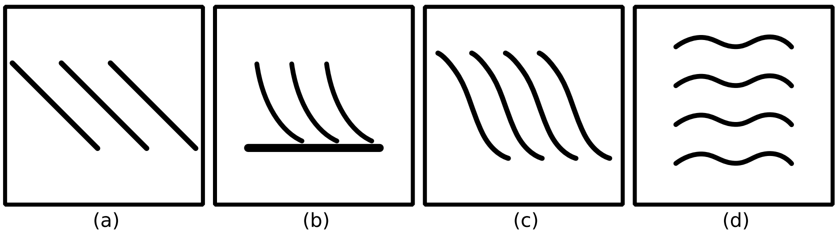

Fig. 5. Icons representing some of the values for the laminae shape visual attribute: (a) planar; (b) tangential; (c) sigmoidal cross-strata; (d) wavy lamination

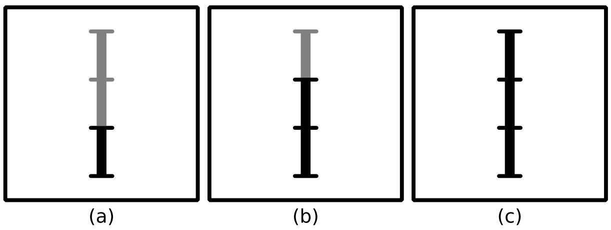

Fig. 6. Icons representing the values for the thickness visual attribute: (a) small; (b) midsize; (c) large

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CONCEPT StructureX
  SUB-TYPE-OF: Traction plus Fallout Structure;
  ATTRIBUTES:
    angularity: low_angle;
    laminaeShape: wavy lamination;
    thickness: large;
END CONCEPT StructureX;
```

Fig. 7. Description of a visual entity corresponding to a sedimentary structure

The nominal values of the visual attribute *laminae shape* are *planar*, *tangential*, *sigmoidal cross-strata*, *wavy lamination*, *truncated wavy lamination*, *trough cross-strata*, and *horizontal lamination*. These values represent the shape of the bedding in relation to the base line of the sedimentary structure. The pictorial representation for some of the values of the laminae shape are depicted in figure 5-{(a), (b), (c) and (d)}.

The nominal values of the visual attribute *thickness* are *small*, *midsize*, and *large*. They are nominal values for the height of the all structure. Structures from 1 centimetre to 5 centimetres are classified as small thickness, from 5 to 10 centimeters are midsize and over than 10 centimetres structures are classified as large thickness. The pictorial representation of the thickness attribute values is depicted inf Figure 6-{(a), (b) and (c)}.

The visual description of the sedimentary structure, presented in Fig.3-a, and its attributes using the primitives is depicted in Fig.7. The pictorial content, which represents the visual features of the sedimentary structure that is aggregated to the domain ontology are the icons presented in the Fig.4-b, Fig.5-d and Fig.6-c.

4 Discussion

The Stratigraphy domain ontology is not complete so far. There are many details in the domain which require a refinement of the constructed model.

The elicitation of the visual attributes of the sedimentary structures is a complex task, since these attributes are mostly part of the tacit knowledge of the expert that is hardly externalised. Moreover, sedimentary structures are the result of some natural process, which can show a wide range of variations in transportation media, intensity and duration, resulting in a large amount of different structures with slight distinctions from one to another. Capturing all the nuances of the visual differences can happen to be a challenge in terms of knowledge acquisition that we are still dealing with. We believe that the complete population of our models will be reach only through a cooperative work inside the Geological community.

However, the approach presented in this paper has some advantages when compared with those presented in section 2:

- The icons formalize the visual knowledge used by experts in their activities in a more straightforward way;
- We can organize the concepts by their visual aspects as the Geologists are used to do, which would not be possible without a formal representation of these visual aspects;
- The formalisation of the pictorial content allows someone to query a knowledge base for domain concepts, using the visual features of some image to drive the search.

5 Conclusion

This paper proposes a set of primitives to formalise concepts in imagistic domain that require pictorial content to complement the conceptual content in order to be correctly defined.

We have proposed a visual language whose elements can be combined to build the definition of the visual content of the concepts in a restricted domain. The elements were conceived based on the idea of free-rides and associated to a textual translation of the main representative aspects.

The visual attributes of the concepts were also applied to organise the domain in a hierarchy of objects. The chosen organisation reflects as well the organisation of the genetic processes that produced the represented objects in the Nature, thus being useful to be further applied in the interpretation of these processes from the visual characteristics of the objects.

Although the language is strongly connected with the domain, the general approach applied in its construction can be replicated to build visual representations in other image-based applications.

Future work is to develop experiments to collect and evaluate the feedback from the geologists about the proposed model.

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