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Semantic image interpretation of gamma ray profiles in petroleum exploration

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ABSTRACT

This paper presents the S-Chart framework, an approach for semantic image interpretation of line charts; and the InteliStrata system, an application for semantic interpretation of gamma ray profiles. The S-Chart framework is structured as a set of knowledge models and algorithms that can be instantiated to accomplish chart interpretation in all sorts of domains. The knowledge models are represented in three semantic levels and apply the concept of symbol grounding in order to map the representation primitives between the levels. The interpretation algorithms carry out the interaction between the high-level symbolic reasoning, and the low-level signal processing. In order to demonstrate the applicability of the S-Chart framework, we developed the InteliStrata system, an application in Geology for the semantic interpretation of gamma ray profiles. Using the developed application, we have interpreted the charts of two gamma ray profiles captured in petroleum exploration wells, indicating the position of stratigraphic sequences and maximum flooding surfaces. The results were compared with the interpretation produced by an experienced geologist using the same data input. The system carried out interpretation that were compatible with the geologist interpretation over the data. Our framework has the advantage of allowing the integration of existing domain ontologies with domain independent visual knowledge models and also the ability of grounding domain concepts in low-level data.

1. Introduction

Human image interpretation is a process based on the combination of memorized visual knowledge and interpretation algorithms. The reasoner is able to compare, in a flexible and creative way, patterns captured from the domain with his/her own knowledge base of abstractions created from the previous seen visual patterns. The recognized objects support the semantic interpretation of the whole scene.

We consider that a successful image interpretation system requires the capability of applying visual knowledge to support the recognition and interpretation of objects in the domain. This is even more valid in knowledge intensive domains, where experts employ both visual and conceptual knowledge to infer new information from pictorial data (e.g., from X-ray images in medicine). An image interpretation system can increase significantly the capability of extracting meaningful information from images by combining low-level pixel processing with conceptual models of visual and domain knowledge. Indeed, since the origins of the first systems based on this concept (like VISIONS (Hanson & Riseman, 1978), SIGMA (Matsuyama, 1987)) a great research effort has been made in proposing frameworks that integrate and minimize the semantic gap (Smeulders, Worring, Santini, Gupta, & Jain, 2000) between explicit knowledge models and low-level image processing algorithms. These so called *semantic interpretation systems* are being used with relative success in areas like biology (Hudelot, Maillot, & Thonnat, 2005), traffic control (Fernyhough, Cohn, & Hogg, 2000) and robotics (Chella, Frixione, & Gaglio, 2001).

The main focus of recent research is related to the interpretation of images captured from natural scenes. However, in some specialized domains, the interpretation of images produced artificially (e.g., charts, diagrams, etc.) is a common and critical task (like in Geology (Serra, 1984), Economy (Oberlechner, 2001) and Medicine (Berger et al., 2005)). One typical type of artificial image is the line chart, like the one depicted in the Fig. 1. Line charts are a common visual representation of data sets like space–time series. Since they can be easily plotted from raw data, they are extensively used in many time-critical problems, such as the diagnostic of heart attack, the definition of strategies in petroleum well production, or the identification of faults in monitoring systems. Experts can better visualize trends and patterns hidden in the data when it is projected as line charts. The expert relates them to objects in his/her domain to infer new information. An interpretation system that could automate (or semi-automate) the interpretation process of line charts would incorporate the specific knowledge applied by experts when recognizing trends and patterns on the graph.

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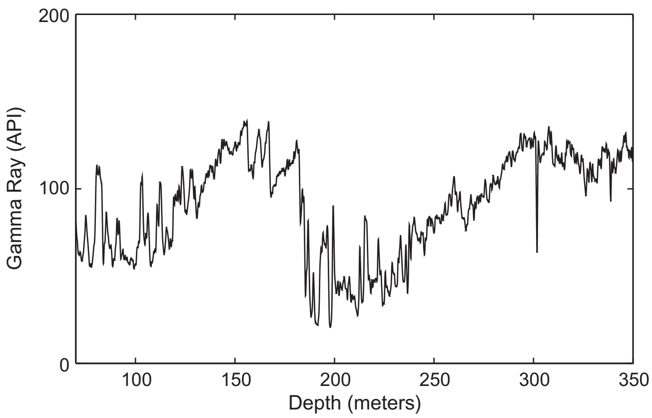

Fig. 1. Line chart example, depicting the variation of the gamma radiation along an exploration well.

The reasoning process for visual chart interpretation close resembles the interpretation of real-world images. However, it is not possible to apply the semantic image interpretation methods directly to chart interpretation for two different reasons. First, the visual features that are significant in charts are not modeled in the usual image interpretation methods. Examples of features in line charts are curve patterns, points descriptors and other geometric features. The second reason is the evident difference in the raw data itself. Low-level primitives like pixels, regions and color codes are not representative of the low-level chart data. These differences are enough to encourage the proposal of a new framework for semantic interpretation of line charts.

This paper is divided in two parts. In the first part, we the present the S-Chart, a semantic image interpretation framework specialized in the extraction of meaningful information from chart-like data. The objects we are looking for can be represented in a knowledge model (such as a domain ontology, for instance). The chart-like data is the one-dimensional signal that can be projected as a line chart.

The framework consists of a set of models of visual knowledge conceived for representing the semantic objects that can be visually recognized in charts and the interpretation algorithms. The input of these algorithms is the raw signal, or the measure of some indicator (such as a gamma ray log, as in our application) against some other dimension, such as time, depth, distance, etc., which can be expressed as a chart. The output is the set of the instances of the visual knowledge model that represents the semantic content that can be extracted from the signal. The meaning of the recognized instances is given by the knowledge model itself. Furthermore, the framework is conceived to be domain-independent and it is meant to be applied to problems that require visual knowledge to be solved. It works by associating the recognized pattern on the chart with its high-level representation in the knowledge model. All the process is driven by the knowledge model.

In the second part of the paper, we present the InteliStrata system, an implementation of the S-Chart framework for semantic interpretation of well log charts in the domain of sequence stratigraphy, a sub area of Geology. The task of the InteliStrata system is to infer the presence of particular geological features based on the recognition of significant visual features in the gamma ray logs. The system employs knowledge models (domain and visual) to carry out this interpretation.

Our approach offers new, domain-independent primitives to support chart interpretation compatible with the existent primitives applied in image interpretation. We also show how semantic interpretation can be achieved using standardized representation formalisms, like OWL (McGuinness & Harmelen, 2004) and SWRL (Horrocks et al., 2004).

1.1. Background and related work

Line charts can be considered as projections of continuous, one-dimensional signals. Thus, the interpretation of line charts are strongly related to *signal understanding* area. Signal understanding systems integrate reasoning algorithms with signal processing in order to infer new information from raw data generated by sensors. Some signal understanding systems (Du, 1999; Lesser et al., 1991; Nii, Feigenbaum, Anton, & Rockmore, 1988) employ expert systems as the reasoning component. In these systems, a rule-based knowledge base is used to extract semantic from low-level signal descriptors (themselves extracted by signal processing algorithms). However, it seems that these systems inherited the same problem form the first generation of expert systems (Nikolopoulos, 1997); rule-based knowledge bases are considerably application-specific, which hinders its use across different domains. Beyond that, they are hard to maintain when employed in complex domains, given the explosion in the number of rules. Another rule-based technique, the syntactic pattern recognition (Fu, 1986), seems to suffer of similar problems. On the other hand, some signal understanding systems are based on machine learning (Teller, 1997) techniques. While these methods are useful in narrow domains, they are difficult to apply into complex, knowledge-intensive domains, since the training data are not always available *a priori*.

The S-Chart framework takes a different approach. The person analyzing a line chart – the signal – looks for visual patterns that are related with concepts in his/her domain. The relation between domain knowledge and visual knowledge is then used to refine the interpretation. Our framework captures this separation by representing the visual patterns in a domain-independent visual knowledge model. It also provides a set of constructs for grounding independent domain models in this visual knowledge model. As we will show, separated visual and domain knowledge models avoid the proliferation of rules present in some signal understanding systems and make the framework more reusable across multiple domains. The S-Chart framework also offers constructs for explicitly grounding visual features into low-level features. This eliminates the necessity of training data to infer the generic visual features.

The S-Chart framework is strongly based on the semantic image interpretation. We adapted it for interpretation of line charts. More specifically, we employ the concept of *semantic levels* (Hudelot et al., 2005), where the knowledge about image interpretation is represented in three levels of abstraction.

In natural image interpretation, the lowest abstraction level, which we call *analog level*, represents the information directly related with the image raw data. It provides primitives to describe information commonly related to the image processing area. They can be pixels, regions, color codes and other low-level features extracted directly by image processing. On the other hand, the highest abstraction level is the *semantic level*. It represents the image content as high-level symbolic entities. Those entities are related to the domain. The key component in this approach is the intermediate *visual level*. It captures the image content in a generic visual model, where the information is represented in terms of domain-independent visual primitives. These can be geometric shapes, spatial relations, color shades, textures and so on, described in a conceptual way. Their function is to reduce the semantic gap between the low-level sensorial data and the high-level semantic entities.

The same domain entity has expressions in the three levels. For example, let's consider an image in the fruit domain. One certain