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Geological storytelling

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ABSTRACT

Developing structural geological models from exploratory subsea imaging is difficult and an ill-posed process. The structural geological processes that take place in the subsurface are both complex and time-dependent. We present *Geological Storytelling*, a novel graphical system for performing rapid and expressive geomodeling. Geologists can convey geological stories that externalize both their model and the reasoning process behind it through our simple, yet expressive sketch-based, flip-over canvases. This rapid modeling interface makes it easy to construct a large variety of geological stories, and our story tree concept facilitates easy management and the exploration of these alternatives. The stories are then animated and the geologists can examine and compare them to identify the most plausible models. Finally, the geological stories can be presented as illustrative animations of automatically synthesized 3D models, which efficiently communicate the complex geological evolution to non-experts and decision makers. *Geological storytelling* provides a complete pipeline from the ideas and knowledge in the mind of the geologist, through externalized artifacts specialized for discussion and knowledge dissemination among peer-experts, to automatically rendered illustrative 3D animations for communication to lay audience. We have developed geological storytelling in collaboration with domain experts that work with the modeling challenges on a daily basis. For evaluation, we have developed a geological storytelling prototype and presented it to experts and academics from the geosciences. In their feedback, they acknowledge that the rapid and expressive sketching of stories can make them explore more alternatives and that the 3D illustrative animations assist in communicating their models.

1. Introduction

The early stage of geological exploration in a new location is typically characterized by having little or no ground-truth data, and perhaps a few, spatially limited 2D seismic sections. Still, an approximate geological model is needed to make the decision whether this location is worth further investigations. These early geological models are therefore just as much influenced by the experience and prior knowledge of the geologist, as by the measured data. This typically leads to subjective models, as shown by the experiment conducted by Bond et al. [1]. They documented that given a geologically sound, but artificial, 2D seismic section, geologists produced highly diverging geological interpretations. This human-biased *conceptual uncertainty* tells us that many geological models, for one location, made by several geologists, should be explored to identify the models with the highest probability.

Building these early-stage models with the computer tools the geologists have today, is very time-consuming, and these tools require more details than is directly supported by the data. General-purpose computer modeling tools are usually not able to represent the model correctly. It is also challenging to evaluate a model, since much of the foundation for the model is based on knowledge and ideas in the mind of the geologist who constructed it. Domain experts state that for these reasons too few models are created and analyzed.

We have made an analysis of these problems in collaboration with two domain experts. These domain experts are geologists, holding the PhD degree, with more than four years of experience with these challenges on a daily basis. The problem that these geologists face is threefold. First, they need computer tools to be able to rapidly construct varieties of alternative geological models, and second, they need a better way to evaluate the geological soundness of these models and to identify the most probable ones. Finally, they need to be able to communicate their models in such a way that they are comprehensible also by non-experts and decision makers.

The approach we present is *geological storytelling*, a novel graphical system for capturing and visualizing the reasoning

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process that leads up to the geological model, for exploring and comparing a set of such models, and for presenting and communicating the most probable ones. We utilize a flip-over metaphor, resembling pen-and-paper drawing, where sketching the individual steps in a story externalizes the mental steps of the modeler when developing a model. The different stories, represented by these discrete story steps, are then visualized in a story tree for easy access and management. This story tree also provides the interface for individual story playback and examination, or comparative visualization of several stories. By treating the story steps as key-frames, we can play back and compare the stories as an animation, thus providing more information to the viewer than through still images. The most promising geological models can be automatically synthesized into 3D geometrical models and the complete story can be rendered as an illustrative animation, improving the communication toward decision makers and non-experts.

Our contribution is a novel system and a non-trivial integration of techniques from sketch-based modeling, computer animation, and geometric modeling. Its individual components are adapted existing and novel, tailor-made techniques. We justify the utility of the system in several target domain scenarios.

To summarize, the geological storytelling system provides a *complete pipeline* from the conceptual models and ideas in the geologist's mind, via externalized artifacts (the sketches) for alternative solutions exploration and discussions, to the synthesis of animation of 3D models for presentation and communication. This paper is an extended version of an Expressive 2012 SBIM paper by Lidal et al. [2].

2. Background and requirements

The application focus of our work is the early stage of exploring a new location for discovery of natural resources, such as oil and gas. Collecting high quality, dense 3D seismic data and drilling test wells for collecting ground-truth data is very expensive, especially offshore. Before these large investments are made, a pre-screening is conducted. During this process, the data available for the location is limited, often consisting of only spatially sparse 2D seismic data. It is up to the geologists, typically under heavy time constraints, to create rough, early geological models to evaluate the possibilities of oil and gas. A 2D seismic section is shown in Fig. 1. This seismic section is called "WESTLINE shotpoints 4500–8500" and it is publicly available through the Virtual Seismic Atlas [3]. We use this seismic slice as a guiding example throughout the paper. Fig. 2 shows close-up views of two possible seismic interpretations of this seismic section. Such interpretations often form the basis for geological models.

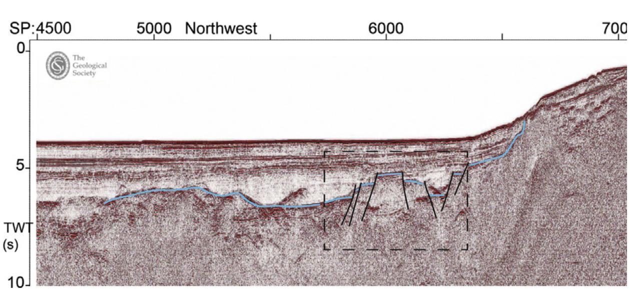

Fig. 1. An example of a 2D seismic section showing a seismic profile. This section has been augmented with an interpretative sketch. Such an interpretation is the starting point for an early-stage geological model. One of our collaborating geologists made this example in Microsoft PowerPoint.

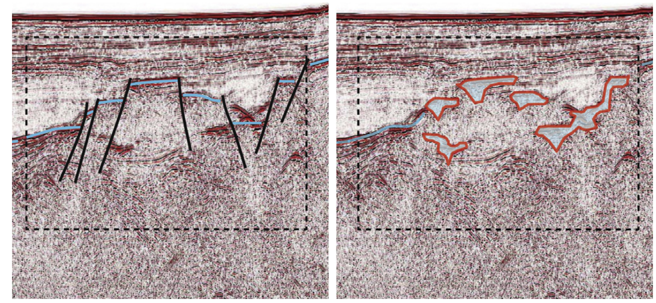

Fig. 2. Close-up images of two very different interpretations from the exactly same position on the seismic section. These interpretations will result in two very different geological models. These close-ups were also made in Microsoft PowerPoint by one of our collaborating geologists.

If the geological models indicate possibilities of oil and gas, and the company is willing to spend the resources needed for mapping out the subsurface in details, then other geoscience experts, such as additional geologists, geophysicists, reservoir engineers, and drilling engineers, will become involved. The geologists who created the early models will typically not participate, as they have moved on to pre-screen other unexplored locations.

Domain specific modeling software packages, such as Petrel [4], focus on producing detailed models based on data only existing in the later stages of the exploration pipeline. Applying such tools when creating the early models is time demanding and they are more complicated than is required. Some geologists use pen and paper for sketching their models. Pen and paper is very expressive and quick. It is however often a challenge to discuss the paper sketches, especially in remote collaboration meetings. In addition, paper sketches are often large and complicated to scan and archive. The knowledge captured is therefore not accessible. Others geologists are using presentation software, such as Microsoft PowerPoint. Although these tools are suited for presentations, they have very limited drawing capabilities. Expressing a geological sketch in PowerPoint is difficult. General purpose drawing programs, such as CorelDRAW [5] are positioned somewhere in between, being more expressive than PowerPoint, but requiring more time than pen and paper, and it is difficult to edit the models in work meetings.

During our discussions with the geologists, we uncovered that the model sketches they produce do not capture the mental reasoning behind the interpretation, only the interpretation itself. Without oral explanations from the modeler, it is often difficult for another geologist to validate a model. Thus, a key requirement is to capture more information in the produced artifacts. We have derived a set of requirements that needs to be fulfilled to solve their problem. The requirements are shown in Table 1 and they are based on our interviews with the two specialists who we collaborate with.

3. Related work

Geology is a visual science requiring substantial spatial reasoning skills from the geologists. Studies have shown that modern visual aids, such as interactive visualization, conveying terrain topography, and 3D geologic block visualizations, increase geospatial comprehension [6]. The first appearance of dedicated software for assisting spatial perception of geological structures for high-school students was Geo3D [7] that claimed credits for drastic improvement of students' performances in structural understanding.