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Quality control of geological voxel models using experts' gaze

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A B S T R A C T

Due to an expected increase in geological voxel model data-flow and user demands, the development of improved quality control for such models is crucial. This study explores the potential of a new type of quality control that improves the detection of errors by just using gaze behavior of 12 geological experts. Gaze is used as input for an attention model that results in 'attended areas' on sliced representations of part of a geological voxel model. We compared attended areas to errors as manually marked by the experts. We found a clear match between manually marked errors and attended areas as determined using gaze. We also found that a large proportion of this match is reached within a small amount of total viewing time.

1. Introduction

Geological voxel models are predictions of the architecture and properties of the subsurface in 3D. Especially when undertaken at national scale, geological voxel modeling uses and produces vastly more data and information than traditional 2D geological mapping (van der Meulen et al., 2013). This in its turn presents new challenges, since it surpasses the capabilities of current model quality control.

It is generally accepted that errors will draw experts' attention and visual attention is closely intertwined with gaze location (Rizzolatti et al., 1987; Corbetta et al., 1998; Carpenter, 1988; Land and Furneaux, 1997) and gaze duration (e.g., Brouwer et al., 2013). We devised an experiment that captures eye gaze behavior of 12 geological experts who were asked to visually check a geological voxel model for errors, and then also manually mark the errors they identified. In this way, we explored the effectiveness and reliability of a novel, potentially faster method to check the model relying on gaze alone.

Other than speed, a potential advantage of using gaze data analysis over conventional error reporting is that it circumvents conscious deliberations of the experts. These can be related to (unconscious) reluctance to manually report errors due to own involvement with the geological model. More importantly, an expert may be reluctant to mark a feature as erroneous if he or she cannot explain why, i.e., if it is only a 'feeling' that something is wrong. However, even if observers do not consciously recognize anomalies when gazing at anomalous objects, gaze duration tends to be longer (Droll et al., 2005; Hayhoe et al., 1998). If this holds true, then quality control based on gaze would unlock expert intuition and experience in a new way. To explore the potential of this new type of quality control, we define the following research questions:

RQ1 To what extent do attended areas as determined from experts' gaze data match with geological model errors as subsequently indicated by the same experts using a mouse?
RQ2 How does this match change over time during geological model quality control?

2. Geological model

The geological voxel model used in this study is GeoTOP (Stafleu et al., 2011). GeoTOP is a schematization of the subsurface using voxels ('3D pixels') of 100 by 100 m in horizontal directions and 0.5 m in the vertical direction (see Fig. 1). Each voxel has estimates of stratigraphy and lithology: clay, sand (in three grain-size classes), gravel, peat or 'other' (see for example Fig. 2).

The GeoTOP modeling procedure consists of automated database queries, 2D modeling of stratigraphic surfaces and 3D

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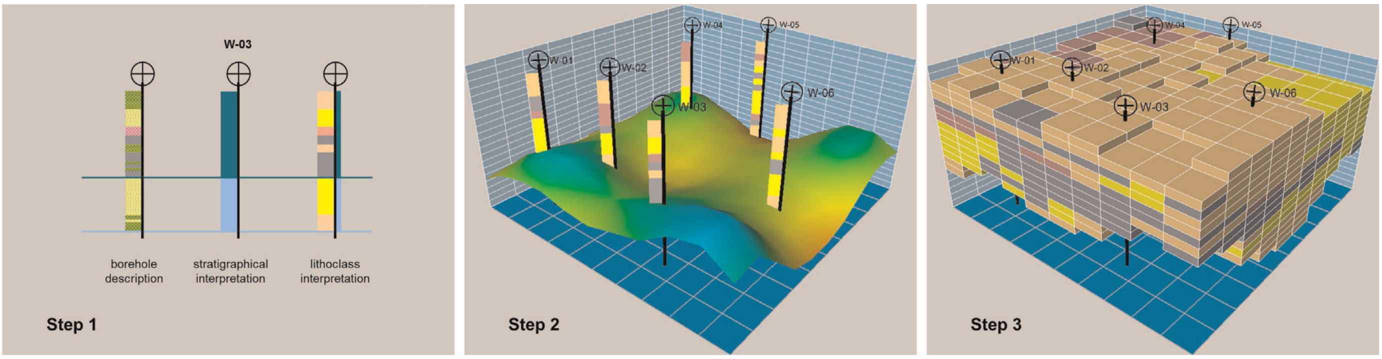

Fig. 1. Voxel modeling work-flow (van der Meulen et al., 2013). Borehole information is coded lithostratigraphically and as lithological classes (Step 1). 2D modeling of basal lithostratigraphical unit boundaries (Step 2). 3D modeling of lithological classes (Step 3).

property modeling, designed in such a way that it provides the best possible representation of the geological features, given the available data and expert knowledge. The work-flow includes quality checks on both input data and modeled output, and the supply of 2D and 3D uncertainty estimates. However, errors in the geological plausibility of the modeled output are much more difficult to capture. Whether for example variation in position of a bounding surface or the geometry of a fluvial sand body is geologically realistic is very difficult to assess using computational algorithms only. Checking models for this type of errors is therefore carried out on a manual basis by geological experts, which is an extremely time consuming process.

3. Attention model

The model used for estimating attended areas from gaze data is an attention model, based on the dynamical model of visual attention as described by Bosse et al. (2009, 2012). The model produces attention values for each predefined area (pixel) of an examined image. For every point in time during inspection, an attentional unit is divided across pixels of the image where the pixel at the center of gaze receives the largest value while pixels surrounding this pixel receive a value that decreases with the distance they are from the center of gaze. This reflects the idea that while people usually attend to the gaze location rather than to the visual periphery, attention is not directed at a single pixel but at an area. In addition, gaze history is taken into account. The attention model includes a decay function that represents the rate at which attention as given to a single pixel dissipates over time. This ensures that locations that are gazed at for a long time are considered to have received attention while locations that are briefly skipped over are not considered to have received attention. The attention model has three free parameters. Parameter γ defines the rate at which attention decreases with increasing distance from the center of gaze. Parameter λ defines the rate at which attention decays over time. Finally, parameter α is a threshold used to convert the gradual output of the attentional model into binary values reflecting whether an observer attended a specific area or not.

3.1. Attention value

The attention model of Bosse et al. (2009, 2012) defines different (discrete) areas over visual stimuli (e.g., images, movies and displays), which each have a specific quantity of attention on each time point. This quantity is called the *attention value*. The sum over all quantities in each area is assumed to be constant:

$$A(t) = \sum_{x,y} AV(x, y, t) = 1 \tag{1}$$

where $A(t)$ is the total amount of attention at time point t and $AV(x, y, t)$ is the attention value for area (x,y) at time point t. Areas are defined as 1×1 squares within an $M \times N$ grid spread over each visual stimulus.

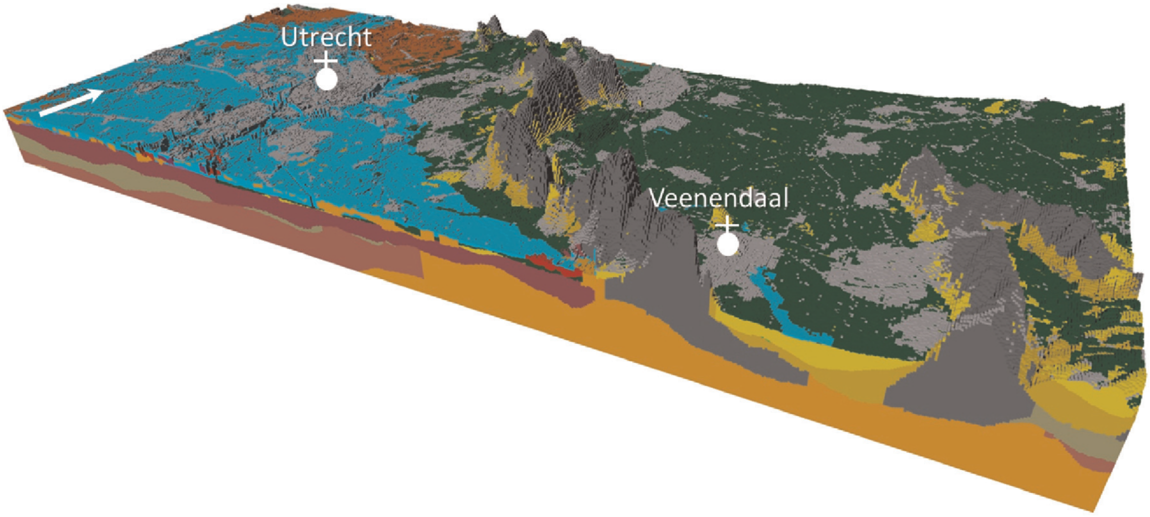

Fig. 2. Block diagram showing part of the GeoTOP model output for the Utrecht and Gelderse Vallei area (surface area: 62 × 24 km; model base: 50 m below Dutch Ordnance Datum; vertical exc. 75 ×). Colors represent different GeoTOP model lithostratigraphic units. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)