Tackling uncertainty in combined visualizations of underground information and 3D city models

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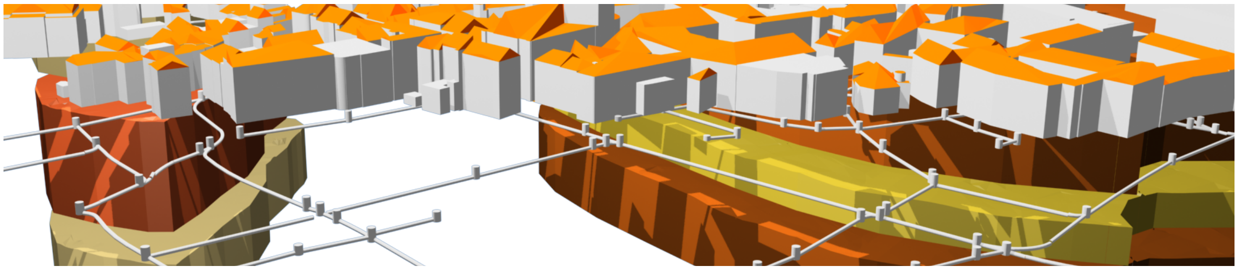

Abstract—Cities are under constant development. They are characterized not only by their surface constructions like buildings and traffic infrastructure, but also by their underground structures. Besides human-created lifelines, tunnels and quarries, there are also diverse geological formations. Underground information contains a lot of uncertainty by nature, because measurements provide information along drilling lines only. Additionally, man-made structures are often hardly documented. In this paper we will present ways to visualize such uncertainty in combination with exact surface structures from 3D city models in order to assist stakeholders in making decisions. We will evaluate existing techniques and describe the requirements imposed on uncertainty visualization.

Index Terms—Uncertainty visualization, underground visualization, geographical information systems, 3D city models, geoscience, geovisualization, data integration.

1 Introduction and Motivation

For a sustainable city development a comprehensive knowledge about surface and sub-surface structures is necessary. Surface information is mostly very accurate; especially cadastral data like building footprints or 3D city models. Underground information on the other side is in most cases very error-prone. For example, anticipating the flow of groundwater is a challenging task. It requires sound knowledge of the underlying geological structure, but boreholes give information only along the drilling lines. The shape of complex geological structures has to be approximated with interpolation schemes that naturally induce errors. This leads to uncertainty on how the geological structure is actually shaped.

Apart from that, most man-made structures under the surface are not very well measured. For example, in the past, information about the height of lifelines (like electric cables or communication lines) has hardly been documented. In even worse cases during construction the planned location of lifelines is modified slightly if certain geological circumstances are encountered. In this case, blueprints are often not corrected and thus do not reflect reality. Measuring lifelines later is in many cases too cumbersome and costly.

In this paper we will present an approach for uncertainty visualization, especially applied to the domain of underground information combined with 3D city models. We will investigate different approaches for all relevant types of uncertainty in that area. The combination with information from 3D city models is novel and gives insight in both geological and man-made structures at the same time. We will show that uncertainty can be reduced by incorporating exact surface data into the visualization. Apart from that, we will present an approach to reduce the complexity of underground visualization to avoid information overload. We propose this to be of great help for stakeholders who have to quickly make decisions based on uncertain data.

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2 Related Work

In the past, geological information was usually visualized in 2D (for example as maps with isolines), but 3D models become more and more important now. Several project results have already been published (e.g. the visualization of the Upper Rhine Graben or the Alps [5]). These projects mostly deal with problems that arise from converting 2D geological information to 3D. For example, mapping 2D isolines to 3D often leads to intersections in geological layers. None of these projects makes use of special visualization techniques to display uncertainty. Apart from that, they are limited to geology and do not include man-made structures.

Work about uncertainty visualization can be found in many research communties. In [3] MacEachren points out that uncertainty visualization is a topic in geographic information science (Geovisualization/GIScience) and scientific visualization/information visualization (SciVis/InfoVis). From these two domains he extracts nine categories which can contain sources of uncertainty (see figure 1).

Category	Attribute Examples	Location Examples
Accuracy/error	counts, magnitudes	coordinates, buildings
Precision	nearest 1000	1 degree
Completeness	75% of people reporting	20% of photos flown
Consistency	multiple classifiers	from / for a place
Lineage	transformations	#/quality of input sources
Currency	census data	age of maps
Credibility	U.S. analyst interpretation of financial records <...> informant report of financial transaction	direct observation of training camp <...> e-mail intercepttion with reference to training camp
Subjectivity	fact <...> guess	local <...> outsider
Interrelatedness	all info from same author	source proximity

Fig. 1. Uncertainty attributes as described by MacEachren [3].

Similar lists can be found in other publications. For example, [1] describes quality aspects derived from the domain of 3D city models. The work also contains quality estimation methods and defines a

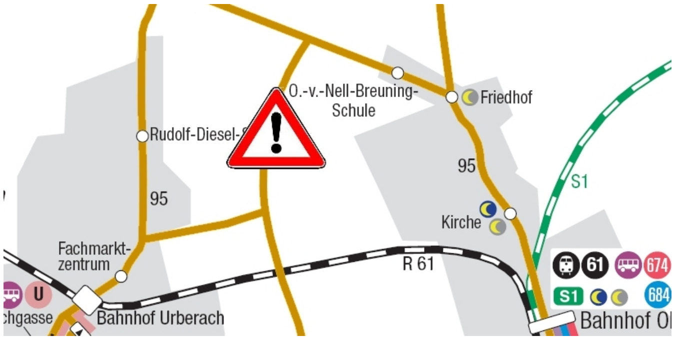

Fig. 2. Uncertainty displayed by adding a glyph.

formalism to describe uncertainty in 3D geodata. Especially the definition of lower and upper limits (error range) for horizontal and vertical positional accuracy can be applied to the domain of underground visualization (see section 3).

For the visualization of uncertainty various concepts exist. In [4] Pang et al. describe several methods. Adding glyphs like warning signs is one option. In figure 2 we show an example of such a visualization: the map tells the reader that it is uncertain whether the depicted street exists or not. Another method for uncertainty visualization is changing attributes like color, texture or translucency. It is also common to add or modify geometries. For example, an object can be inflated, so it covers the whole space where the actual location could be. Finally, animation offers the possibility to change attributes over time. This method can be used to emphasize important information in complex or unclear scenes (e.g. under ground).

3 Our Approach

In this section we will discuss the different sources of uncertainty and propose ways to visualize them. Information with very low or even no uncertainty can be displayed directly. Besides all surface information like 3D buildings, this also holds for manholes, boreholes and points where underground structures (e.g. lifelines, pipes or tunnels) penetrate the surface.

Things like accuracy and precision can be visualized by augmenting the object with a geometry that relates to the specified error range. Such error ranges are typically noted in the form $\varepsilon = \pm 50cm$, for example if a lifeline is somewhere between its interpolated position plus/minus $50cm$. This range can be displayed as a 3D hull with a diameter of $1m$ or as a dimension line respectively. In our visualization, we also reduce uncertainty by incorporating exact surface data. We especially consider points where underground objects penetrate the surface and where data becomes more confident. For example, the interpolated hull's diameter can decrease the closer it gets to the surface.

The completeness of a data set can be visualized by geometries that represent probably non-existent objects (like in figure 2). Such geometries can be augmented with glyphs or their attributes can be changed depending on application-specific requirements (see section 3.1).

Other quality aspects like lineage, credibility, subjectivity or interrelatedness are more or less qualifiable and not quantifiable. Hence, it is reasonable to also augment concerned objects with special glyphs or to emphasize them. The actual visualization should be application-dependent, since the importance of these quality aspects can be rated distinctly by different users.

Apart from uncertainty visualization, we propose a combination of underground data with 3D city model information. Due to the – in most cases – good knowledge about the quality of surface structures, a combined visualization can help decision makers in some situations. For example, in case of flooding in the city area, fire workers need to know which basements are under water. Therefore they need information about the location of basements (certain surface information) and the ground water level beneath (uncertain sub-surface information) which affects the sewage system.

3.1 Information overload

Regarding uncertain data we display the full range of possible locations for all uncertain objects. Besides, the visualization includes several glyphs and implicit information induced by color, transparency or even animation. In such an environment the user quickly becomes overstrained. Since the visualization may also be used for decision making in time-critical situations, it is crucial that information overload is avoided. This can be achieved by emphasizing certain objects, whereas other ones are put in the background or even hidden. For example, important information can be displayed in red whereas unimportant things are visualized in greyscale or made transparent.

In this context, it is very important that the visualization is configurable to the user's needs. The user should be able to define special requirements which will then be considered in the visualization (for example, the user may find out that all objects from a certain source are untrusted and so he chooses them to be displayed in bright red). Furthermore, the user should be able to hide irrelevant information so he can concentrate on things that are really of interest for his work.

4 Conclusion

City development is not only about surface structures but also about the underground. Current work about 3D geology modeling or uncertainty visualization only covers specific aspects. In this paper, we go one step further and combine techniques from different areas. We apply uncertainty visualization to underground information in order to help city planners. Such a visualization gives them the means to judge the risks as well as the opportunities of city development under ground. Apart from that, we propose a combined visualization with data from 3D city models to support city planners and decision makers in time-critical situations. Incorporating exact surface data can also reduce underground uncertainty. Information overload can be avoided by a user-configurable visualization that emphasizes important features.

Another important aspect in this area is the problem of navigating through a 3D scene under ground. There can be a lot of information but only a few reference points the user can use to orient himself. In this context a 3D city model might also help. Furthermore, integrating and harmonizing heterogeneous data sets containing information about underground and surface structures is also a challange. Both topics will be investigated in future work.

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