

Visualizing uncertain underground information for urban management

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Abstract—We present approaches for visualizing uncertainty in an application context through techniques for the visualization of uncertainty. We also describe methods for the reduction of the complexity of the visualization to avoid cognitive overload. Uncertainty in both natural and man-made structures under ground is thus communicated to the user in an appropriate, non-threatening manner. The methods were evaluated during an end-user workshop of the research project DeepCity3D. The results of this workshop have led to various extensions to our uncertainty visualization approach in urban management.

1 INTRODUCTION

Cities are characterized not only by their surface constructions such as buildings and traffic infrastructure, but also by their underground structures (e.g. tunnels or geology). Data sets about geological formations contain uncertainty by nature, because measurements only provide information along drillings. The gathered information is turned into a geological shape which cannot be more than an approximation that is augmented by mathematical interpolation schemes. This naturally induces errors which lead to uncertainty on how the geological structure is actually shaped.

The types of uncertainty can be divided into spatial and non-spatial attributes. In order to visualize these attributes we investigate two different approaches for relevant types of uncertainty: the first approach is based on additional hull geometry for models that have uncertain location coordinates. The second approach is used for models that have non-spatial uncertainty such as currency or subjectivity. Combining the visualization of surface and subsurface data can lead to very complex scenes where the user might have problems finding the right information. In order to avoid information overload we also present an approach to reduce the visualization complexity. This can be of great help for decision makers, especially for stakeholders, who have to quickly decide based on data that contains significant amounts of uncertainty.

2 APPROACH

We first present an approach for uncertainty visualization in the geographic context, as it has been elaborated in the DeepCity3D project. A combined 3D visualization of data including surface and subsurface geometries as well as uncertainty information is realized. Taking the visualization perspective, we divide the types of uncertainty into two major categories—spatial and non-spatial uncertainty. Based on this differentiation, uncertainty is depicted as part of the visualization. We raise the awareness of non-spatial uncertainty by modifying the visual attributes, or adding glyphs or animation to the visualization [3]. With these methods we achieve an integrated visualization, considering above ground and underground structures as well as uncertainty in the data. As described above, we have to avoid overloaded displays which increase the complexity of the analysis task. We address this problem through methods that reduce the visual impact of irrelevant features.

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2.1 Spatial uncertainty

Pang proposes the display of the error range of a measurement through additional geometries [3]. For example, an object in 2D could be surrounded by a circle with a diameter proportional to the error range. Thus, the user would know that the real position of the object is somewhere close. We realize uncertainty visualization in 3D in a similar way: a visualized geometric object with a specified spatial error—e.g. defined by an error range—is augmented with a geometric hull enclosing the 3D object. The hull emphasizes the uncertainty in the location of the object. Thereby, it does not occlude the original object, which is guaranteed by making the hull translucent. Error ranges are typically noted in a database that contains the metadata for every object. In this case, the error ranges vary with the direction in the coordinate space. We show one possibility of depicting spatial uncertainty by adding geometric hulls to the visualization, similar to error ranges in 2D. An alternative can be achieved by modifying the visual attributes of the 3D objects. For example, we apply a color map to the error range and display geometries in colors that reflect their spatial uncertainty. Another case of uncertainty originates from different data sources that differ in the description of a certain object's location. In this multiple classification case, each possible position of an object is visualized in the scene by a representing geometry. Hence, one object in the data set is represented in more than one location. Such representing geometries are highlighted—e.g. via glyphs—or their visual attributes are changed depending on application-specific requirements. As an alternative to depicting several distinct geometries these representatives are aggregated to achieve a contiguous area of possible object locations. This can again be realized as an enclosure in form of a geometric hull.

2.2 Non-spatial uncertainty

Other uncertainty categories such as lineage, credibility, subjectivity, or interrelatedness cannot be described as concrete deviations of spatial correctness. Therefore, we call them non-spatial uncertainty categories. We emphasize that non-spatial uncertainty might result in spatial uncertainty. For example, the age of a measurement corresponds to the accuracy of the measurement instruments that have been used during that time period. Instead of using fixed error measurements as in the case of spatial uncertainty, we propose to partition non-spatial uncertainty variables into different categories or levels. However, it is also valid to categorize spatial uncertainty to achieve a common visualization across both types. The visualization's main purpose here is to raise the awareness of possible uncertainty in the data. Detailed information about the uncertainties stored in the database will be provided on demand via a glyph, a tooltip or a properties box.

In order to achieve this classification of uncertainty the heterogeneous values of each uncertainty category have to be mapped to a fixed number (e.g. 1-5) of uncertainty levels. This mapping is done by user-specific models or interaction. A configurable mapping allows users to adjust the software to their needs. As a major benefit of discretized uncertainty levels the number of required visualization methods can

be reduced. Each method can be applied to each uncertainty category in the same manner.

The typical approach for visualizing the discussed uncertainty levels is realized via a diverging color map. The texture and/or the color of each object is replaced by a single color depending on the uncertainty level of the selected uncertainty category. The user can interactively select different uncertainty categories to be visualized for each object category—e.g. geology, buildings, sewage networks. These methods inform the user that the presented data cannot be used as-is, but requires special attention.

2.3 Avoiding information overload

A display that is overfilled with a large amount of heterogeneous visual information quickly overstrains the user. Since the visualization may also be used for decision making in time-critical situations, it is crucial that information overload is avoided [1]. This can be achieved by emphasizing relevant objects, whereas irrelevant objects are put in the background or hidden. The most appropriate visualization depends on both user and task. From the large amount of information that is potentially available in the scene only a few reference points are typically used. Being able to choose these categories that should be visible and others that should be hidden allows for a quick pre-selection of relevant structures.

In some cases, the user is just interested in a special area, just consisting of a small part of a whole city. To define this area of interest, we propose a method that enables the user to mark special regions within the scene that are particularly interesting. The user selects a rectangular part in a 2D map that automatically reduces the visibility of the surrounding scene in the 3D visualization by increasing its translucency to a user-defined level. Previously selected object categories will be excluded from this procedure and keep their visibility. This method gives an architect the possibility to specify a geographic region he or she is particularly interested in. Again, irrelevant data types can be switched off. This helps to evaluate the design on a small-scale focus but keep the important connections to the world around it visible.

3 EVALUATION

Within the DeepCity3D project, a user-driven workshop was held to validate and evaluate preliminary results. In order to facilitate diverse opinions and lively discussions, experts from different domains were invited. Among these were representatives from several municipalities, people from catastrophe management and geologists.

In contrast to many other user groups, geologists do not only already have ready-to-use data sets, but also use them in their daily work. However, things are different for man-made structures, for which commonly used data structures do not exist yet.

The workshop showed that the expert users are well aware of the uncertainty in their data even without visual representation. However, they agreed that it would be significantly easier, especially for novices or users from other domains, if discrepancies in the data could be seen on the display.

A system that integrates underground and uncertainty information would allow software users to judge risks in urban management better than today. In order to make reasonable decisions, a visualization of uncertain information should use different degrees to highlight objects. The workshop participants agreed that three degrees are sufficient: “certain”, “uncertain” and “validated”. For some objects (e.g. certain rock structures) more degrees could be useful, but categorization then needs to be done manually. For them, no exact measure of uncertainty can be given, but an expert can distinguish different levels of uncertainty and thus create a categorization. For many other entities, a binary indicator “certain” vs. “uncertain” was already sufficient.

4 CONCLUSION

We discussed a way to combine surface and subsurface geotechnical data in a 3D visualization augmented with aspects from uncertainty visualization. Quite a few approaches have already been undertaken in terms of integrated visualization and in uncertainty management,

but often tailored to a specific problem area. We apply uncertainty visualization to underground information in order to help city planners make decisions. Different approaches guarantee appropriate representation of additional information. Such visual representations provide the means to judge the risks as well as the opportunities of city development below the ground. Combining underground visualization with data from 3D city models supports city planners and decision makers, for example in time-critical situations. The adaptability of the visualization modules helps avoiding cognitive overload. The amount of information can be customized by the user to emphasize important features and reduce unneeded features to a minimum. A workshop with domain experts helped us evaluate our visualization methods based on our use-case scenarios and to adapt the software to the users’ needs. The participants agreed that an integrated visualization of uncertainty leads to a significant benefit in their daily work.

5 FUTURE WORK

We presented geometric hulls to visualize spatial uncertainty. This methodology works well for geometries that hold constant values of uncertainty for their entire body. However, for some objects it is reasonable to decrease or increase the error range in specific sections. For example, locations where underground objects penetrate the surface can be measured more precisely and accurately (see Figure 1). The data has increased confidence in that area. To account for that, the

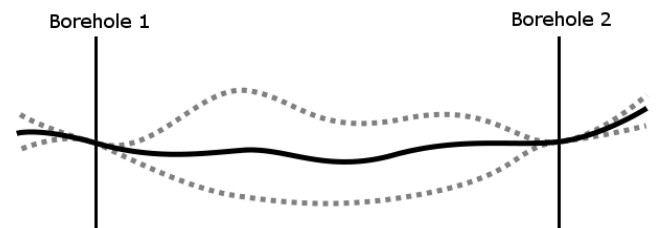


Fig. 1. Sketch of possible hulls for a geologic layer. The black line depicts the unknown actual location. The dotted lines represent the maximum estimated deviation which gets smaller at the boreholes where the exact values are measured.

interpolated hull’s diameter should decrease the closer it gets to measured, accurate points. This topic will also be investigated in future work.

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