Drawing the Gaps: Graphical Methods for Representing Geospatial and Temporal Uncertainty with Cultural Artifacts

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Abstract

Modern visualization tools can present geographic information system (GIS) data as a 3D rendering, facilitating a user's understanding of the geospatial relationships between terrain and cultural features. While this capability has been present for some time in professional GIS systems such as Arcinfo, it is now also available in commodity programs such as Google Earth. As is the case with most large knowledge bases, source data in GIS systems is often incomplete, contradictory, or otherwise uncertain. This paper describes an approach to indicating uncertainty in the location and lifespan of cultural features in GIS visualizations. Such indications of uncertainty are important even when source data comes from ostensibly reliable sources. They become nearly essential with community-supplied source data such as Google Earth's 3D Warehouse. Representing uncertain data in the same context with accurate data requires contrasting between the two as well as keeping the representation as perceptually facile as possible. We start by organizing uncertainty into a small set of broad categories that are useful to distinguish between in many GIS visualization applications. We then argue that the 3D display in GIS system should use specific graphical styles to depict different types of data uncertainty.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications

1. Introduction

A geographical information system (GIS) stores, manipulates, and displays natural and cultural features referenced by their location on Earth. Visualization techniques used in a GIS attempt to display data in ways that let users make full use of its functionality for decision-making and data analysis [WD04]. GIS systems by their nature integrate multiple source of information such as elevation, aerial photographs, and cartographic information about cultural features such as cities and roads. Often, explicit 3D models of buildings are added, since nadir-view imagery can not be used to generate the appearance of such structures from more natural viewing directions. In this paper we investigate how to graphically represent uncertainty in the 3D display of GIS data that includes a temporal dimension. Figure 1 shows an example of heterogeneous display syles integrated to present a consistent story and convey several levels of both spatial and temporal uncertainty.

In the recent years, non-expert use of GIS has increased due to the availability of commodity systems such as *Google Earth*, Microsoft's *Virtual Earth*, and NASA's *World Wind*. Because of the power of modern PCs these systems enable interactive explorations in 3D. Models of buildings and other man-made structures are a central part of these systems. Frequently photographs or internet articles are attached to such models to provide information other than 3D geometry. Our main interest in the 3D display capabilities of GIS systems is what happens when the database contains rich features indexed by time. For example, a house might have both a location on Earth as well as a construction date and a demolition date. Further it could have information about the evolution of its structure over time. It is natural to expect the capability for 3D browsing of locations on the Earth in any time period. Source data is often incomplete, contradictory, or otherwise uncertain. In sparse regions of the database, plausible de-

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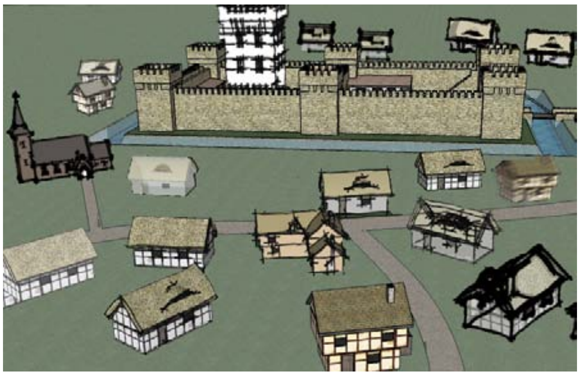

Figure 1: *Combining several graphical variables, in particular line sketchines and transparency, can be used to portray temporal or spatial uncertainty. The still surving castle is solid with no sketchy lines while the surrounding buildings present various degrees of uncertainty. The central tower was present but has since been destroyed so it is sketchy but opaque. There were probably a number of small cottages surrounding the castle, and these are uncertain in both space and time so are sketchy and transparent.*

tail might be graphically presented whose uncertainty is very high. One way to communicate the uncertainty of such data to users is to encode it into the 3D display of the uncertain objects. Historical examples of such uncertain data include the Lighthouse of Alexandia whose height is disputed, and the Mausoleum at Halicarnassus whose buidling date is controversial [Per04, CP90]. Note that those examples not only include uncertainty, but different types of uncertainty.

We use *Google Earth* as the platform for investigation. The program has already begun to support browsing over time as shown in Figure 2, and has an associated application *SketchUp* that enables straightforward creation and modification of GIS content. In addition, Google Earth allows users to expand their database of existing models, much like a graphical Wikipedia, so problems related with data accuracy abound.The example of uncertainty related to the Lighthouse of Alexandria is already present in Google Earth, as depicted in Figure 3. In this paper we present a set of methods to visually convey such uncertain information. We emphasize the case where that information is uncertainty in space and/or time. The particular styles we propose allow the simultaneous display of temporal and spatial uncertainty. A practical advantage of these styles is that they are visually distinct from those already typically used in current systems so they can be practically "retrofitted". Our contributions are a discussion of the types of uncertainty encountered in these emerging systems, and a demonstration that transparency and line style can be effectively used to represent and distinguish between temporal and spatial uncertainty while allowing uncertain data to be rendered in the styles already present in systems that do not represent uncertainty.

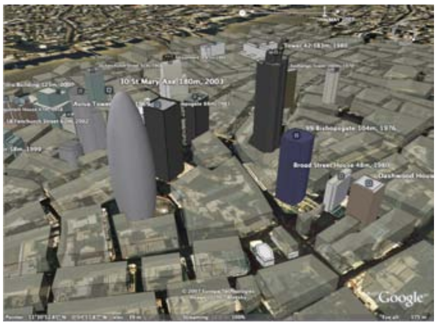

Figure 2: *Google Earth is a virtual representation of the Earth which allows users to interactively display and investigate geographic data such as satellite and aerial images as well as 2- and 3-D vector data (earthquake locations or water bodies.) Various geoscience -related datasets are freely available for representation in Google Earth. Users can perform basic measurements such as latitude, longitude, elevation and size thus providing capabilities similar to a GIS. A temporal component has been recently introduced in Google Earth 4 (4.0.2080). The example provided on the Google Earth websiste shows urban development in London in the 1950-2010 time span. Urban London can be seen evolving while users move a slide bar through time.*

Figure 3: *Several alternate representations available in Google Earth for the Lighthouse of Alexandria.*

2. Background

In this section we review the different types of uncertainty in a GIS system supporting time, as well as the different ways uncertainty have been graphically portrayed by previous researchers. To effectively portray uncertainty, and to distinguish between different types of uncertainty, a system of classification is needed. Of the different classifications proposed to represent uncertainty, most of them address how the uncertainty is first introduced. This includes uncertainty from measurement errors, user confidence, and other such subjective methods. Thomson et al. [THM*05] provide a comprehensive typology for visualizing uncertainty, introducing terms such as lineage, positional accuracy, attribute accuracy, logical consistency, and completeness. These terms, normally reserved for statistical analysis, are a useful beginning for classifying uncertain information. For our purposes, we focus on the dimension of the data that is uncertain rather than the origin of the uncertainty; the major distinction that needs to be made while browsing is between the temporal and spatial dimensions. An example of data with both spatial and temporal uncertainty is shown in Figure 4. For temporal uncertainty, we can associate an estimated probability between 0 and 1 that a structure exists at a particular time. For structures that have an interval of time associated with their completion, the probability can gradually increase from 0 to 1 over that interval. This is distinct from the construction interval over time which we view as changes to the building rather than partial existence. Spatial uncertainty is broadly any type of uncertainty that is not temporal. This will typically be in location or structural detail.

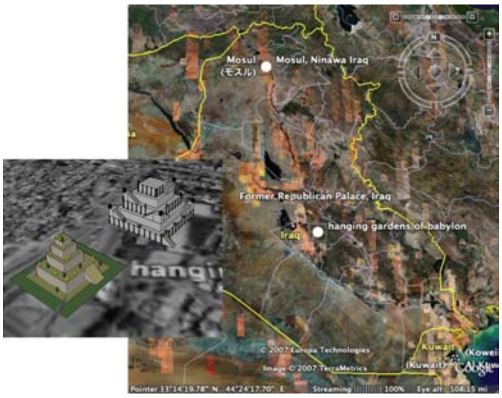

Figure 4: *The location of the famous Hanging Gardens of Babylon is debated. While some say that it was located in Babylon, 45 miles south of modern Baghdad, (Perrottet, 2004), others have recently argued that the gardens were in Nineveh, close to modern Mosul (New Scientist, 2005. In Google Earth there is one location associated with the Hanging Gardens of Babylon at a considerable distance of the other possible location (north of the map).*

There is no well-established visual conventions in representation for uncertainty in 3D models. Furthermore, the representation of temporal uncertainty alongside spatial uncertainty has not been addressed. For scientific data, Pang et al. [PWL97] propose classifying uncertainty into discrete or continuous values, and also into multivariate, vector, and scalar values. They explore using glyphs, geometry, and animation as tools to represent this uncertainty. Pang [Pan01] more recently focused on geospatial data uncertainty, but not with uncertainty in the cultural features such as the building of interest in our work. Johnson [JS03] also explores visual representations of uncertainty in scientific data, and adds volume rendering as a "haze" around the object to indicate uncertainty. Maceachren et al. [MRH*05] surveyed the visualization of uncertainty in GIS systems, but also did not deal with uncertainty related buildings. Symbols and glyphs are commonly used in such work, and have also been used in GIS systems including Google Earth. Buildings' level of detail can also implicitly indicate uncertainty (see Figure5).

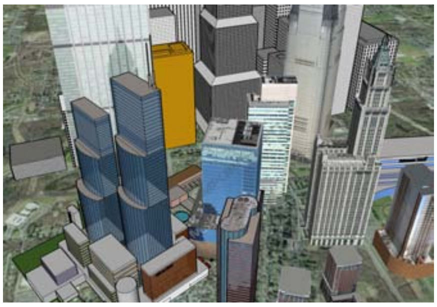

Figure 5: *The models uploaded in the 3D Warehouse vary in style and level of detail. Detailed figures may suggest a high degree of accuracy in the existend data though spatial or temporal uncertainy can still exist.*

Less work has been done on uncertainty related to buildings. Architects often use sketchiness to indicate completeness of design. This has been extended to indicate historical uncertainty [SMI99, ND04, PGG*05]. Zuk and Carpendale [ZC06] show an example of transparency and line width used for uncertainty in the *AncientViz* system first described in [SMI99]. The second category where new graphical primitives are created and uncertainty is embedded in the representation poses problems when trying to view the data independently. We propose an intermediate approach between the two taking into account the homogeneity of an existing system.

3. Proposed Graphical Conventions for Uncertainty

Our main interest is to simultaneously display uncertainty in time and space. Ideally, the visual styles would have the following properties:

1. the visual representation of temporal uncertainty should have a natural association with probability;
2. the visual representation of temporal uncertainty should look natural as the probability shifts between 0 and 1 due to temporal browsing;
3. the visual representation of spatial uncertainty should look clearly different from temporal uncertainty;
4. the visual representation of uncertainty should be visually distinct from features of buildings typically modeled by users.

The last item immediately discounts color and texture as properties that might be used to indicate uncertainty. Buildings come with such a wide variety of colors and textures that models with no uncertainty span the space of possibilities. Similarly, the level of detail of a model cannot be used as modelers often Şblock inŤ coarse approximations of buildings due to lack of time rather than lack of certainty. If lines are used, line thickness is problematic because

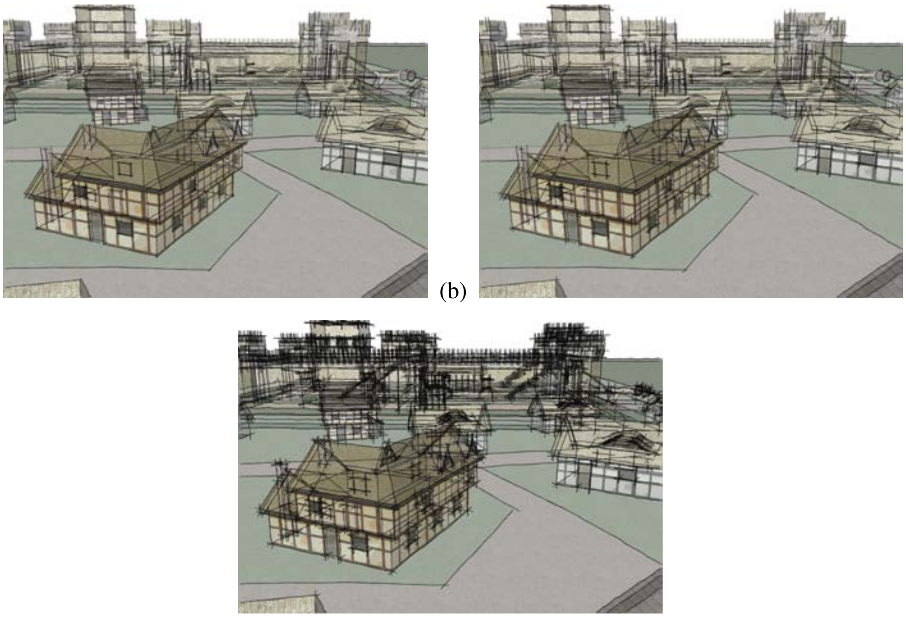

Figure 6: *Sketchiness varying with a constant transparency. The inn is known to have existed in the village however its exact location is unknown and several possibilities exist. Figures (a),(b), and (c) show a succession of levels of spatial uncertainty with an added temporal uncertainty (transparency).*

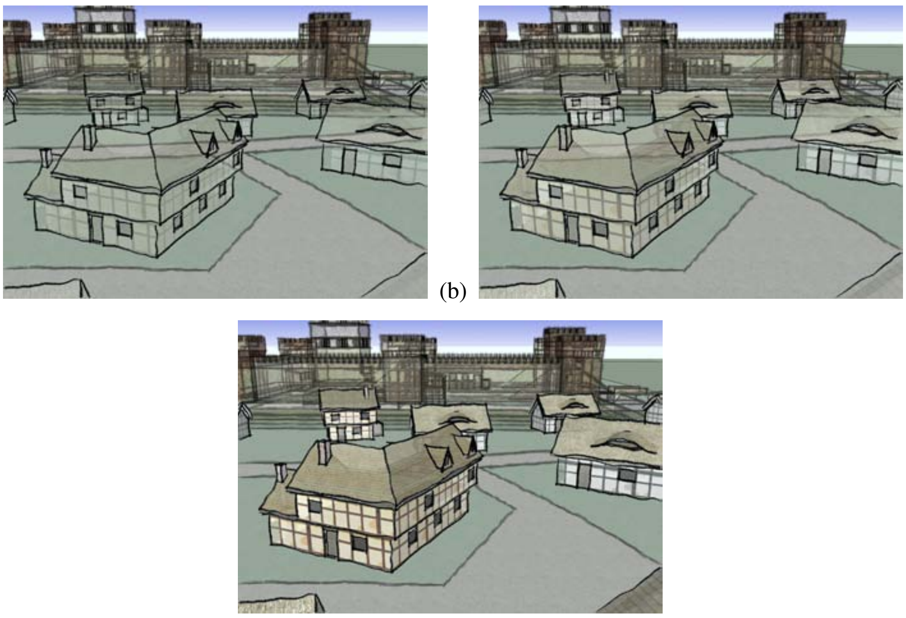

Figure 7: *Transparency varying with a constant sketchiness. The sequence of images shows the increase in the reliability of the data through time. Buildings in Figure (a) have a high level of temporal uncertainty. As time passes, the buildings become more solid indicating how certain the data for a given time point is.*

many line widths are often used within the same model. Two likely candidates for indicating uncertainty are transparency and sketchiness of line. Neither is used extensively in real buildings. Glass building have partial transparency, but having whole structures including beams etc. be transparent is not natural so can be assumed to be an "available" representation. Lines are used for buildings, but these are usually clean straight lines, so sketchiness is a natural way to distinguish a building, and it is a natural mapping to explain. Animation is another possibility for uncertainty. However, we wish to avoid that if possible because it will attract the viewer too aggressively to the uncertain parts of the model. If we use sketchiness and transparency, there are two natural questions. First is which is mapped to temporal uncertainty? Since transparency, unlike sketchiness, has a natural zero to one mapping, we believe it should be used for temporal uncertainty. The second question is whether sketchiness and transparency can be integrated into conventional renderings without being visually dominated by each other or the parts of the model that are not uncertain. This second question is empirical, and we thus we attempted to test the interaction for a test model of a castle and village. Figures 6 and 7 show that transparency and sketchiness can both be present without being too visually distracting. They further show that the two visual characteristics can be manipulated independently so that both spatial and temporal uncertainty can be independently represented.

4. Discussion

This paper has argued that 3D Earth browsing systems will increasingly allow browsing in time, and that these systems have both temporal and non-temporal uncertainty. We believe such uncertainty should be visually represented in a manner that allows the user to continuously browse with continuous graphical updating. We have advocated using transparency to indicate temporal uncertainty because of the natural mapping from 0-1 opacity to 0-1 probability of existence at a given time. We have argued for sketchiness to indicate other forms of uncertainty. We have shown that it is possible to use both sketchiness and transparency in conjunction with each other to simultaneously display and distinguish between temporal and spatial uncertainty.

There are a number of important issues we have not addressed. One is how the content from a user community is managed which shares many characteristics on the online encyclopedia debates. Another is how to indicate a controversy between two locations as opposed to two separate but uncertain buildings. Adding symbolic information is likely a good approach in that case.

Integration of traditional web pages, georeferenced historical and recent photos, and Earth browsing systems is likely to be a critical process to improve the fluidity of exploration. Such integration will make it easier to associate sources and types of uncertainty to their graphical representations. Perhaps most importantly, we have focused on buildings without reference to landscape features. It is not clear whether our techniques generalize. A forest could be processed with our techniques, but things less analogous to buildings such as crop types might need something other than transparency.

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