Visualization of Qualitative Locations in Geographic Information Systems

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ABSTRACT: A qualitative location (QL) refers to the reference of a spatial location using linguistic terms such as qualitative descriptions and qualitative spatial relations with other geo-referenced features. Qualitative locations will be increasingly more popular in the future, driven by theoretical, technological, and database developments. Multiplicity and uncertainty are two innate characteristics of QLs. In other words, a QL often has multiple target locations (multiplicity), and the target locations sometimes cannot be pinpointed exactly due to the qualitative nature (uncertainty) of the qualitative descriptions and relations. The presence of the characteristics imposes research challenges on visualization of QL in geographic information systems (GIS). In response to the visualization challenges we discuss four strategies—namely proportional symbol mapping, fog map, fuzzy 3D surface, and fuzzy-logic-based animation—for the visualization of QL referents in GIS. These strategies combine conventional mapping and advanced interactive visualization methods. Each of them is suitable for one or more scenarios, depending on the presence of either one or both of the two characteristics. All illustrations and related animations are also available at http://www.ggy.uga.edu/people/faculty/xyao/VisQL.html.

KEYWORDS: Visualization, qualitative location, uncertainty, GIS

Introduction

Two trends are seen recently in regard to locating geospatial features. On one hand, more accurate location information can be obtained thanks to modern surveying and mapping instruments and technologies. On the other there is a growing need to handle locations that are expressed in qualitative terms. A qualitative location (QL) in this paper refers to the reference of spatial locations using qualitative descriptions and/or qualitative spatial relations with other geo-referenced features. For example, a location or place can be expressed as "a nearby park," "a very congested intersection," "the post office near the intersection of X boulevard and Y street, right next to the McDonalds," "Appalachian Mountains," to name a few examples. Although the qualitative expressions of locations are frequently used in daily life, analyzing and visualizing them in geographic information systems (GIS) had not been discussed until several recent driving forces stimulated interests in it. These driving forces are coming from theoretical, technological, and database aspects.

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The theoretical driving force appeared before the technological and database driving forces came to full strength. It has been argued that the numerical, coordinate-based representation of spatial data is not suitable for the high-level conceptual information involved in many tasks that are generally conducted by humans without using numerical coordinates (Bittner and Stell 1998). Instead, language is a means to construct spatial mental maps and to convey spatial information (Franklin 1996). Research efforts related to modeling locations in a qualitative fashion appeared from various perspectives, including qualitative spatial reasoning (e.g. Frank 1992; Bittner and Stell 1998; Yao and Thill 2005a), studies of the relationship between natural language and perceptual representation of space (e.g., Lakoff 1987; Mark and Frank 1992), perception and cognition of space (e.g., Lynch 1960; Golledge 1998), as well as research projects involving place names and digital gazatteers.

More generally, the seminal work of *Naïve Geography* (Egenhofer and Mark 1995) particularly concerns the need of research to make GIS directly usable by naïve users, i.e., the average citizens who have never received major training in either geography or GIS (Egenhofer and Mark 1995). Naive users acquire commonsense knowledge about the spatial structure of the geographical world through experiences arrived at without concentrated effort. The knowledge may be incomplete or inaccurate at times, yet it still can be very powerful in making useful conclusions (Kuipers 2004).

The field of naïve geography broadens the horizon of geographic information science (GIScience) and links a wide range of research endeavors for consorted contribution. Examples of such research endeavors include those that lead to handling the naïve users' commonsense geographic knowledge and those that provide good human–computer interfaces for effective communication. Because naïve users often use qualitative expressions to refer to locations, it is desirable that GIS relax the rigid restriction of coordinate-based location description by allowing inputs of qualitative locations.

The qualitative trend is also propelled by the rapid advancement in computing and information technology (e.g., internet, mobile computing, handheld devices). As a result, we are entering an age when the use of geographical information is commonplace. More of the general public is beginning to use geospatial applications such as web-based GIS and location-based services (LBS). Many scholars have already noticed the gradual shift of interest from centralized expert-oriented GIS applications to decentralized everyone-oriented services (e.g., Günther and Müller 1999). Consequently, we will continue to see the accompanying shift in focus of GIS research and applications to the needs of citizens rather than professionals, as has happened over the past decade (Raper 2005).

The last couple of decades have witnessed a proliferation of databases which contain place names or other text-based, qualitative descriptions of locations. Examples are the digital gazetteer, text-based location information, and databases maintained by government agencies or by private companies. Certain spatial features (e.g., Appalachian Mountains) can not be referenced in a purely metric way due to their inherent indeterminacy of boundaries. Smith and Varzi (2000) made ontological distinctions between *bona fide* and *fiat* objects. Simply put, *bona fide* objects are those that have distinguishable boundaries in the underlying reality (e.g., houses and human beings), while *fiat* objects are results from human conceptualization and demarcation (e.g., political boundaries). Both *bona fide* and *bona fiat* objects can be represented in GIS databases fairly easily. Nonetheless there are some spatial objects (e.g., mountains) that lack many of the properties that characterize either *bona fide* or *fiat* objects (Smith and Mark 2003). For these natural objects, we cannot find clear-cut boundaries as required by conventional object-based models of geographical phenomena.

Two solutions are possible. One is to apply some kind of approximation and represent them the same way as conventional exact objects. The other solution is to clearly represent and reference the spatial objects linguistically, by giving them names and/or describing their locations with qualitative spatial relations. The first solution is more often used in GIS databases, while the second solution is widely seen in many non-GIS databases. Given the gigantic size of databases containing text-based location information, analyzing and visualizing them is a significant and challenging task.

The theoretical, technological, and data-driving forces are catalyzing the trends of handling and visualizing qualitative information in GIS. Particularly, for the rapidly growing popularity of GIS among naïve users, a future GIS should have the capability to visualize QLs, so as to relate them to other geo-referenced geographic information. Several studies have been conducted on handling queries with qualitative location information, but few, if any, have been directed to the communication of these query results to end users. In this paper, our concern is how to visually present QLs referents in GIS to the end users. Because most previous studies of modeling qualitative locations use fuzzy sets or some other measures that can be directly converted to fuzzy sets (e.g., Robinson 1990; Wang 2003; Yao and Thill 2005b), this paper builds on this thread of study and investigates visualization strategies of presenting fuzzy-logic-based representations of QL in a GIS environment.

Two prominent characteristics of QL, multiplicity, and uncertainty bring about research challenges of visualizing the results of QL queries. A QL may have one or both of the characteristics. The multiplicity characteristic is present if there are multiple corresponding features (referred to as "target features" from now on) in GIS for the QL referents. For example, a QL query phrased as "a nearby Italian restaurant" may find multiple matched restaurants in a GIS database. None of the multiple features is a perfect match, while each of them has a certain degree of suitability of being the target feature. In other words, multiple features are typically unequal in terms of level of suitability.

The second characteristic, uncertainty, refers to the uncertain boundaries of target feature(s). Several causes of uncertainty exist:

- The locations of some natural spatial features (e.g., mountains, rivers, town centers, to name a few) are inherently vague (Burrough 1996; Bittner 1999; Smith and Mark 2003);
- Some QLs (e.g. southeast region) cannot be pinpointed with exact boundaries due to the innate fuzzy nature of some qualitative expressions; and
- Uncertainty is caused by data inaccuracy, which has been discussed extensively in the literature.

Because the focus here is on the unique characteristics of QL visualization, we will not include discussion of uncertainty related to data quality, which is a general issue that applies to all kinds of locations. The unique nature of QL visualization dictates that users be given the exact or approximate location, as wellas the suitability of each candidate location. Because most GISs and other digital geospatial systems are inherently precise, this innate characteristic makes it a challenging task to display QL visually to the users for easy interpretation. In this paper, we will explore several strategies for effectively visualizing QL referents in GIS, and each is illustrated with some examples.

The remainder of this paper is organized as follows. The following section provides a cursory review of traditional cartography principles and the development of more recent visualization techniques, as well as prior efforts that have been made to depict spatial features with uncertain boundaries. Then we discuss four techniques (proportional symbol mapping, fog maps, fuzzy 3D surface, and fuzzy-logic-based animation) for visualizing QLs, focusing on multiplicity and uncertainty. Because each technique is suitable for different scenarios depending on the presence of one or both of the characteristics we examine, we present each technique and the scenario(s) for which the technique is suitable. We conclude the paper by discussing potential applications of the proposed work and making recommendations for future research.

Prior Work

Visualizing Geographic Data

Visualization of geospatial data comes in various forms, including maps, graphs, charts, and pictures. They can be in two or more dimensions, statically or dynamically. Traditional thematic mapping techniques emphasize the communication function. These techniques make use of visual variables (Bertin 1983) to symbolize the distribution of spatial phenomena. Typical visual variables are size, spacing, orientation, texture, arrangement, shape, and color variables, such as hue, saturation, and value (HSV) of map symbols. For instance, the size variable is often used for proportional symbol maps and color variables for choropleth maps.

Recently, with the advances in scientific visualization and human–computer interaction, geographic visualization has transformed its sole communication function to the duality of communication and exploration. There are at least two perspectives of geographic visualization: the cartographic perspective and the data exploring/knowledge discovery perspective. Data exploring is supported by a rich collection of multi-dimensional, perspective, and dynamic visualization possibilities, in addition to making use of traditional cartographic techniques.

The underpinning cartographic techniques are enhanced by computing technologies. In such areas as dynamic visualization the enhancement is particularly dramatic. With a suitable GIS or visualization software, geospatial data can be dynamically presented through map animation. An animation could be used to emphasize changes over time, to present views from different perspectives, or to highlight different portions of a map at a time. Another notable enhancement lies in the interactions between users and the mapping environment. Better and easier human-computer interfaces are now available, enabling users to generate maps interactively and in a multimedia fashion. Paper-based atlases are challenged by their electronic counterparts which are empowered by computer systems permitting multimedia, human–system interaction and data exploration.

Furthermore, geographic visualization has often been bundled with spatial data mining and knowledge discovery, as it provides visual means to exploratory data analysis that prompts the discovery of patterns and relationships (Andrienko et al. 2001). Special visualization software tools have been developed as visual vehicles for data exploration and knowledge discovery (e.g., MacEachren et al. 1999; Slocum et al. 2000; Andrienko et al. 2001). In this respect, Gahegan et al. (2001) provide a summary and discussion of research challenges towards the integration of geographic visualization and geo-computation for geospatial knowledge discovery.

Visualizing Uncertainty

Geospatial data and models are representations of the reality, but not the reality itself. Inevitably, there are uncertainties associated with the representations. As discussed before, the uncertainties can be caused by several sources, including the quality of raw data, the manner in which the raw data are processed and described, and the nature of the represented spatial feature itself. A number of methods have been proposed to visualize data with uncertainty. One of the earliest contributions is made by MacEachren (1992) who suggested three methods:

- To display the distribution of an attribute and its associated uncertainty on separate maps next to each other;
- To display both the attribute and the associated uncertainty on the same map with multiple visual variables; and
- To use interactive mapping tools to toggle between the attribute and its associated uncertainty. It is noticed that the second option is similar to the cartographic method for multivariate mapping.

Several conventional visual variables have been used for depicting uncertainty. For instance, the color variables *value* and *saturation*, as well as random dots, are used in association with the *hue* variable to show uncertainty of a geographic feature (Jiang et. al. 1996). Dot density mapping is used for the display of such vague concepts as "downtown" (Montello and Goodchild 2003). However, some of these visual products are liable to misinterpretation. An example by McGranaghan (1993) uses *size* (width of stream lines in this case) to depict uncertainty of positions along streams. This map can be easily misinterpreted as the stream discharge (Slocum et al. 2005). An improvement can be achieved by using MacEachren's (1995) visual variables that are specifically designed for depicting uncertainty. MacEachren (1995) subdivided the new visual variable *clarity* into three visual variables: *crispness*, *resolution*, and *transparency*. Crispness refers to the sharpness of boundaries; resolution is the level of detail in the visual display of spatial data; and transparency is the degree in which a theme can be seen through a "fog" placed over the theme. The visual variable *transparency* or the visual variable color *value* is often adopted by geographers to depict uncertainty. In this way, the magnitude of the transparency changes with the fuzzy membership function over a theme.

In addition there are other unconventional methods of depicting uncertainty, which take advantage of the interactive, multimedia visualization capability of computer systems. Fisher (1994), for instance, adopted sound to convey data reliability in remotely sensed images. In the software the author developed, a user hears sounds of various durations while the cursor passes over an image with uncertain information. A long sound indicates a high reliability of the pixel which the cursor is currently passing by. Such a map is not able to present an overall pattern of reliability without human interaction.

In contrast, Fisher (1996) uses animation to visualize uncertainty of dot locations in dot maps by continually changing the configuration of dots. As Slocum (2003) noted, most previous studies use 2D displays to depict uncertainty, with some exceptions. For instance, Jiang (1998) created a 3D surface by VRML to depict the vague concept of "town center." Clarke et al. (1999) employed a combination of color, animation, and visual depth to depict positional uncertainty in a virtual reality environment with immersive equipments and human–computer interaction. Slocum (2003) explored software tools to present a wall-size 3D display of uncertainty of multiple attributes.

To sum up, a variety of unconventional methods have been proposed and tailored for particular studies. However, while most studies focus on uncertainties of locations or attributes that are caused by inadequate data quality, few focus attention on the types of uncertainty that are unique to QL.

Visualizing Qualitative Locations

Let us look at a QL expressed as "a McDonalds near the intersection of X street and Y road" in a given city. To reference such a QL in a GIS, the QL must first find its referents in GIS in a way similar to a spatial query. The only difference involves those qualitative terms in QL that cannot be directly handled by current GIS. However, recent research found that by properly extending current GIS capabilities (Yao and Thill 2005a), the query process could proceed, and the results are formulated with fuzzy logic. Therefore, we will use "QL query result(s)" and "target feature(s)" interchangeably to refer to the referent(s) of a QL in GIS.

Incidentally, the query results of the above example may happen to meet the following two conditions: (1) only one such McDonalds satisfies the condition; and (2) the geo-referenced location of this feature is not uncertain (or the uncertainty level is acceptable, such that the uncertainty is neglected). If this is the case, the target location can be easily displayed on a map. However, due to the fuzzy nature of qualitative information, most often the query results do not satisfy both conditions. For example, we may find more than one McDonalds near the road intersection. Although multiplicity is seen in other quantitative queries (e.g., "find all primary schools within five miles"), it is different in QL query results. If the quantitative query finds three primary schools within five miles of a certain point, then the multiple schools are equally valid answers to the quantitative query.

However, for a QL query, the target features are usually not equal in terms of suitability. The counterpart QL query of the above quantitative example can be: "find a nearby primary school." We may find three primary schools at distances of two, five, and 5.3 miles, respectively. All three schools are possible target features. However, they are unequal in terms of suitability described as a "nearby" school. This inequality needs to be reflected in the visualization. The other characteristic, uncertainty, imposes an even greater challenge. This is because target locations of many QLs (eg., Hurricane-prone regions) cannot be pinpointed exactly due to the fuzzy nature of the qualitative descriptions and qualitative spatial relations.

The two characteristics of QL—multiplicity (multiple results) and uncertainty (inexact boundaries or locations)—thus call for particular attention when visualizing QL. Depending on the presence of these characteristics, three possible scenarios of QL query results are possible:

- Only multiplicity is present (i.e., multiple locations with crisp boundaries);
- Only uncertainty is present (i.e., one general area with uncertain boundaries); and
- Both characteristics are present (i.e., multiple locations with uncertain boundaries).

We will discuss four strategies to deal with the above three scenarios. Proportional symbol mapping is suggested for the first scenario (multiplicity). We propose two strategies, the fog map and a fuzzy 3D surface, for the second scenario (uncertainty). Finally, fuzzy-logic-based animation is suitable for both the first and the third scenario (a mix of multiplicity and uncertainty). The objective of these visualization strategies is to deliver information concerning the QL referents in an easy-to-understand way, while preserving the sophistication of modeling the qualitative information in the metric system.

The following discussion is based on the assumption that fuzzy membership grades are available to be associated with the target features of a QL query. We make the assumption for the following two reasons. Firstly, as qualitative descriptions and qualitative spatial relations have innate vagueness, fuzzy logic seems to be a natural choice for the modeling. Secondly, fuzzy logic has been widely adopted in computation models of qualitative spatial reasoning (e.g., Zadeh 1965; Robinson 1990; Guesgen 2002). Moreover, some other computational models of qualitative spatial reasoning give results (e.g., probabilities) that can be easily converted to fuzzy sets (e.g., Worboys 2001; Yao and Thill 2005b). These computation models are key to visualizing qualitative spatial relationships in coordinate-based GISs and other metric geospatial systems. Based on this assumption it is reasonable to assume the availability of fuzzy-logic-based results before visualization.

Proportional Symbol Mapping

When only the characteristic of multiplicity is present, the visualization task is to display multiple target features with crisp boundaries. Certain traditional cartographic methods are typically applicable to this situation, with unequal suitability (or membership grades) among the multiple target features being of special interest. We suggest that proportional symbol mapping, which uses *size* as the visual variable, is most suitable, especially when the locations are represented as points or areas.

For point or areal representations, the symbols center on the locations of the target point features or the centroids of the target areal features. Figure 1a illustrates the results of a "good French restaurant in the downtown area" QL. Figure 1b displays the results of a "luxury villa near the University of Gävle" QL. Both QLs contains qualitative modifiers (good, luxury), qualitative spatial relations (in, close), and vague spatial concepts (downtown, University of Gävle). The multiple results are modeled by fuzzy logic. Each target feature has a corresponding fuzzy membership grade. The size of a symbol is made proportional to the fuzzy membership grade associated with the corresponding target features.


(a) (b)

Figure 1. Two examples of proportional symbol maps depicting QL query results. a) *Good* French restaurant *in* the *downtown area*. b) Luxury villa *near* the University of Gävle.

If the locations have linear representations in the system, the width of the linear features is proportional to the fuzzy membership grade as shown in Figure 2a. However, as reported in prior studies, proportional symbol mapping on linear features could possibly be misinterpreted as some kind of magnitude (e.g., traffic volume or stream discharge) passing along the lines (Slocum et al. 2005). To avoid such misinterpretation, an alternative is to use the color variable *value* as the visual variable. This is illustrated in Figure 2b.

First let us assume that there is a fuzzy membership function of "town center" defined for the study area. In the fog map, the color variable value assigned to any location is proportional to the fuzzy membership grade of that location. A number of possibilities exist for reaching a fuzzy membership function for a QL. First, given the assumption made above, such a membership function can be directly derived from the computational model that has been used to answer the QL query. Alternatively, it is also possible to derive it from fuzzy member-


(a) (b)

Figure 2. Visual variables for depicting multiple QL query results for linear features: a) size b) color value.

ship grades obtained at discrete points by the use of spatial interpolation methods. In our hypothetical example, we first obtain 10 sample points with associated fuzzy membership grades being located within the "town center" of the city. Then we use simple kriging to derive the 2D fuzzy surface that will be used to create the color-scaled map (Figure 3a).

Fog Map

A fog map is a 2D depiction of color-scaled fuzzy boundaries being placed over a base map with certain degrees of transparency. The result looks like a layer of fog over a base map. Figure 3 is an example for the visualization of a QL "town center" of Gälve, Sweden. Figure 3a is the conventional color-scale map for the visualization of fuzzy boundaries.

The visualization in Figure 3a is quite effective at conveying the uncertainty of boundaries, yet

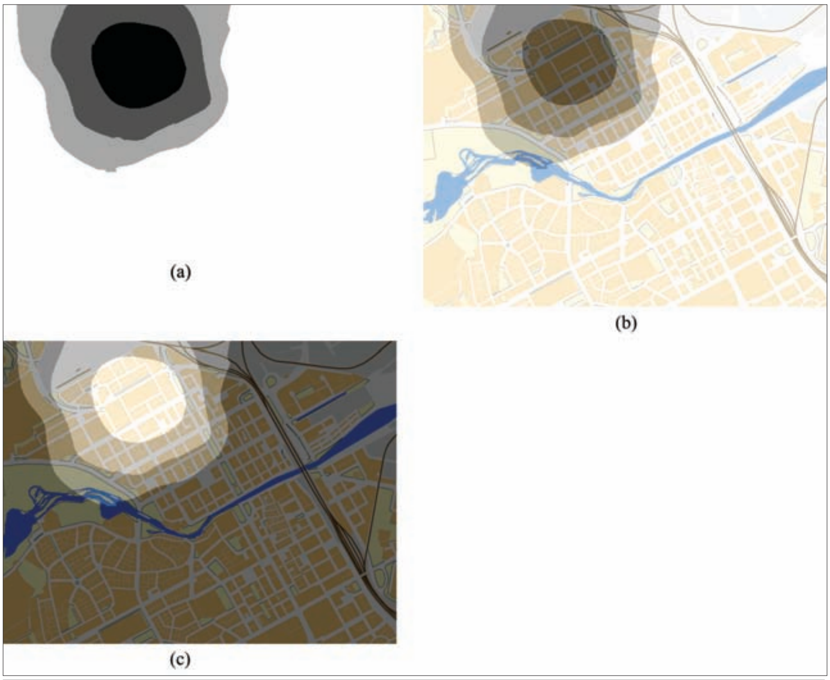

Figure 3. A fuzzy surface visualized by (a) color-scaled map to depict fuzzy boundaries; (b) fog map-1, which uses direct proportional color-scaled fog; and (c) fog map-2, which inverse proportional color-scaled fog (spot-light effect).

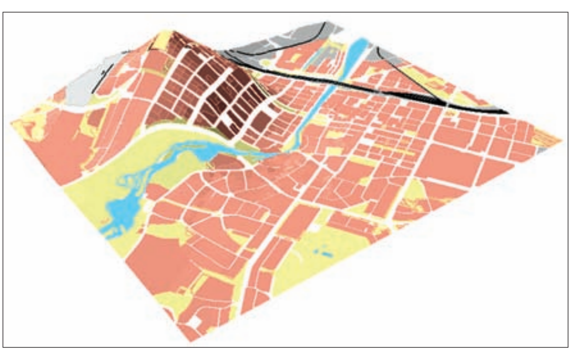

Figure 4. Fuzzy 3D surface of the QL "town center" of Gälve, Sweden.

it does not provide the necessary orientation information so that users can find what is where. The fog maps illustrated in Figures 3b and 3c improve this presentation. The fog maps allow readers to look through the layer of uncertain boundaries and find referenced spatial features in the underlying base map. The level of transparency varies across the space. The degree of transparency at any given location is made proportional to the level of suitability expressed by fuzzy membership grades associated with that location.

Two alternative ways exist for computing transparency from fuzzy membership grades: direct proportion and inverse proportion. Figure 3b uses direct proportion. It shows that locations with higher levels of suitability get darker fog, and vice versa. When using inverse proportion to compute the level of transparency, locations with higher level of suitability get lighter fog (Figure 3c), which has a spotlight effect on the QL referents. A shortcoming of the fog map is that at least part of the base map is not clearly visible. Using a fuzzy 3D surface can avoid this problem.

Fuzzy 3D Surface

In this visualization strategy, a 3D surface is constructed based on the fuzzy membership function which describes the level of suitability of every location likely to be considered a target location of the QL query. The height of any location indicates the level of suitability (or "fuzzy membership grade"). Using the same data and QL expression as shown in Figure 3, we can construct the fuzzy 3D surface shown in Figure 4. The membership functions were obtained in the same way as above.

The fuzzy 3D approach has several advantages. First, the underlying base map can be clearly seen without the view-interfering symbols or fog layers placed on it. Second, the strategy permits straightforward interpretation, as it is quite intuitive to use the visual variable *height* to indicate the suitability level. Third, it allows interactive exploration by users in the computing environment. Currently, it is rather convenient to generate three-dimensional volumes on any computer platform due to advances in computer graphics. In addition, the fuzzy 3D approach can be combined with the navigation and fly-by functionalities of most commercial GIS packages to enable more dynamic and interactive visualization. Users will have a true sense of flying over or walking through a study area. The high level of interaction could potentially enhance the understanding of fuzzy boundaries and qualitative locations.

Fuzzy-logic-based Animation

If multiplicity is present in the query result, regardless of the presence of the uncertainty characteristic, fuzzy-logic-based animation can be used to dynamically visualize QL referents in GIS. In other words, this strategy is suitable for the multiplicity only scenario (scenario 1) and a mix of multiplicity and uncertainty (scenario 3). Animation is a relatively new yet widely adopted technique of visualization. The term "cartographic animation" or "map animation" refers to the "cartographic displays having a succession of maps pertaining to the same area whose content changes in relation to the independent variable—time" (Weber and Buttenfield 1993). Each map in the animation is called a frame. Several visual variables have been specifically formulated for cartographic animation in the literature. Suitable visual variables include duration, rate of change, order, display moment, frequency, and synchronization (DiBiase et al. 1992; MacEachren 1995).

In the fuzzy-logic-based animation, each frame is a static display of one of the multiple target features of a QL. We can use one of the three previously discussed strategies for the visualization in each frame, depending on whether the characteristic of uncertainty is present. In other words, if there is uncertainty involved in the target locations, either a fog map or a fuzzy 3D surface can be constructed for each frame; otherwise, one can use proportional symbol mapping for each frame.

To create the animation, the visual variable *duration* is used, followed by improvements to achieve a better visual effect. Let us first look at the basic animation with the visual variable *duration*. Duration, as a visual variable for animation, refers to the length of time that a frame of an animation is displayed. We make the duration of a frame proportional to the magnitude of the membership grade of the target feature that is displayed in the frame. Thus, a target feature with a higher membership grade will be displayed longer. Consequently, the chance this frame (and the associated target feature) is seen by users at any given time is greater.

Suppose there are n target features resulting from a QL query. Let μ_i denote the membership grade of the ith target feature, and d_i denote the planned duration of the ith target feature in the animation. We can then determine the magnitude of d_i using Equation (1):

$$d_i = k\mu_i \qquad i = 1,\ldots,n \tag{1}$$

where k is constant, serving as a scaling factor.

The scaling factor k could be determined once the duration of one iteration, i.e., the time for all target features to appear once and only once, is known. Suppose T is the duration of an iteration, we can then derive k using Equation (2):

$$k = \frac{T}{\sum_{i=1}^{n} \mu_i} \tag{2}$$

Here, the denominator is the sum of the membership grades of all target features. If all spatial features in the area of interest are taken as target features, the denominator equals 1 and thus k is the duration of the iteration. This situation, however, rarely happens. Normally only some of the features whose membership grades pass a certain threshold are selected to be the target features of a QL query. Consequently, the denominator will be less than 1 and k will be a figure larger than T.

We suggest keeping the viewpoint unchanged throughout the animation. Lobben (2003) categorizes animation methods into four groups: time-series, areal, thematic, and process animation. An animation using *duration* as the visual variable belongs to the category of areal animation, which in prior applications changes the viewpoint in the animation to emphasize the existence of a phenomenon at a location on each frame. We do not think this is advantageous in our case. With viewpoints changing constantly to highlight different areas on different frames, it would be difficult for users to have a constant overview of the multiple target features and their relative locations. Thus we have modified the traditional use of areal animation and keep the viewpoint unchanged in all frames.

Figure 5 shows four consecutive frames of our illustrative animation (the actual animation can be found at http://www.ggy.uga.edu/people/faculty/xyao/VisQL.html). This animation visualizes the QL referents "shopping areas in Gävle" in a GIS application. There are four target features, each displayed in one of the frames. To provide a better schematic view of the entire area and the approximate locations of all target features, we use a two-layer 3D display in each frame. The upper layer highlights the uncertain boundaries of one target feature, while the lower layer provides an overview base map and a rough center point of all target features of the query result. The duration of the frames is determined by Equations (1) and (2).

The most obvious advantage of fuzzy-logic-based animation over such static visualizations as the fog map and 3D surface lies in its clarity. When multiple target features with uncertain boundaries are displayed in a static visualization, the boundaries may overlap. The fuzzy-logic-based animation solves this problem as it highlights one spatial feature in one frame. Another noteworthy advantage is that this animation attracts the users' attention to one target feature at a time, while the chance for a user being attracted to a particular spatial feature is proportional to the fuzzy membership grade of that particular spatial feature. If the user needs to make a quick choice from among the possible target features (e.g., a quick query with a mobile phone), she or he may choose the currently displayed feature in such a strategy. In this case, a target feature with a higher membership grade will more likely be chosen.

Conclusions

Qualitative locations are becoming more and more important in GIS and other geospatial applications driven by theoretical, technological, and database developments. Current applications of GIS have already experienced a shift in focus from expert-oriented GIS to "everyone GIS," and the change is dramatic, thanks to the easy access to GIS data via distributed systems through computer networks or location-aware devices. The visualization of QL will empower the general public to make better use of their spatial knowledge and to reinforce it with GIS. Reasoning and visualizing QL can also assist in linking metric spatial data with text-based location data.

We discussed four visualization strategies to depict the query results of a qualitative location characterized by multiplicity and uncertainty. To decide which strategy is better for a certain scenario, it is necessary to find which characteristics are present in the query results. Spatial data visualization strategies for text-based location information can contribute tremendously to the provision of geographic information services via cell phones and PDAs, as well as to other GIS applications in which intuitive computer–user communication is important. Furthermore, QL analysis and visualization can also contribute to exploratory data analysis and knowledge discovery in databases where text-based location information is significant.

There are many interesting issues for future research endeavors related to the visualization of QL. We give just a few examples. Just like with all other visualization methods, the effectiveness of these proposed strategies may vary among application scenarios. The differences among individuals in perception and cognition, as well as training in map reading, can all influence the efficacy of a certain visualization strategy. In future, it is necessary to evaluate the effectiveness of these strategies through human subject surveys. In addition, more visualization strategies that complement other multimodal human–computer communication models need to be explored.

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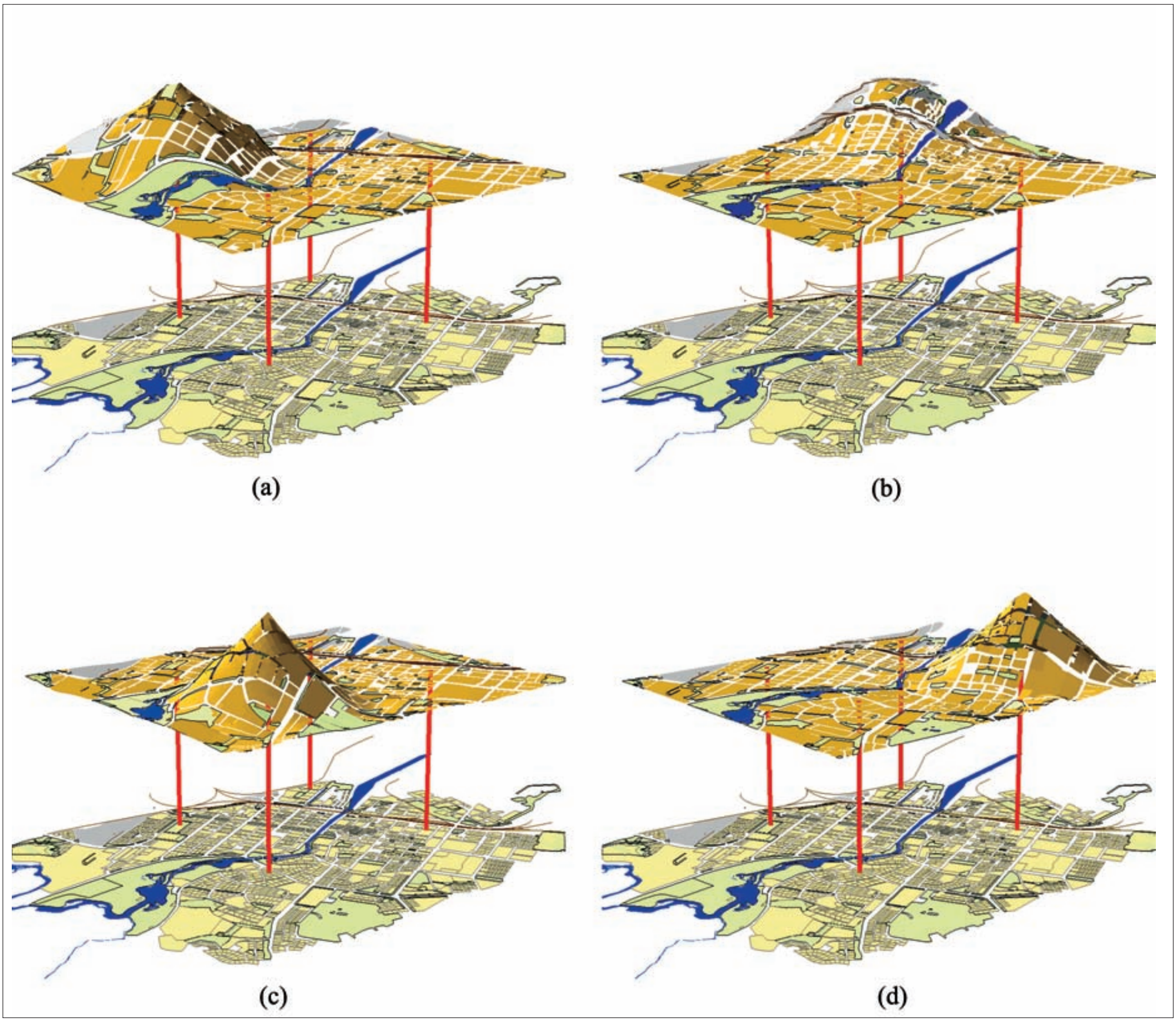

Figure 5. Four consecutive frames of a 3D animation.

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