VISUALIZATION SUPPORT FOR FUZZY SPATIAL ANALYSIS

Bin Jiang*, Ferjan Ormeling**, and Wolfgang Kainz*

*Department of Geoinformatics
International Institute for Aerospace Survey and Earth Sciences (ITC)
P. O. Box 6, 7500 AA Enschede, The Netherlands
Tel: +31 53 874 449, Fax: +31 53 874 335
Email: {bin, kainz@itc.nl}

**Department of Cartography, Universiteit Utrecht
P. O. Box 80115, 3508 TC Utrecht, The Netherlands
Tel: +31 30 531373, Fax: +3130 540604
Email: F.Ormeling@frw.ruu.nl

ABSTRACT

Visualization techniques benefit fuzzy spatial analysis in at least two aspects. One is in the field of exploratory analysis, and another is in the representation of uncertainty. This paper intends to discuss the first issue.

Fuzzy spatial analysis may be distinguished from conventional analysis in that the former is a form of concept analysis which is closer to natural language and the latter in most cases refers to numerical processing. Due to the fuzzy nature of the analysis approach, suitable visualization techniques to support the analysis process are highly needed. In this paper, the fundamentals of fuzzy spatial analysis are outlined and consecutively, the visualization tools supporting the exploration process are focused on. Finally, an approach towards a complete system framework for exploration is presented using some advanced techniques such as the object-oriented system building approach, Graphical User Interfaces (GUI) and hypertext techniques.

1 INTRODUCTION

There have been quite a lot of discussions on as well as practical contributions to exploratory spatial statistical techniques (Goodchild 1987, Openshaw 1990). It is gradually forming a new field in between Spatial Data Analysis and Visualization, and it is referred to now either as Exploratory Data Analysis (EDA) by Tukey (1977), or Exploratory Geographical Analysis (EGA) by Openshaw (1990). These two terms are based on the same assumption, that is that spatial data analysis (SDA) techniques need to be developed further in order to provide tools that allow us to discover patterns or structures unknown to us. It is only in a process of efficient exploration that potential patterns or anomalies can be recognized by analysts. Much research has been carried out in order to incorporate SDA into GIS (Tang 1992, Xia 1993). However, these EDA techniques are restricted to statistical analysis. We will attempt to develop the issue by emphasizing the potential of fuzzy spatial analysis.

The incorporation of linguistic notions into conventional spatial analysis leads to fuzzy spatial analysis (Leung 1984, Jiang, Kainz and Muller 1995, Jiang and Kainz 1994), which is closer to the way of human thinking. The fuzziness inherent in linguistic notions requires an effective visualization tool to support this exploratory analysis. In this connection, the following features of visualization would be needed extensively: 1) direct manipulation; 2) multiple perspective treatments; 3) real-time operation modes; 4) flexible online help.

"In the context of scientific visualization, 'to visualize' refers specifically to using visual tools (usually computer graphics) to help scientists/analysts explore data and develop insights. Emphasis is on purposeful exploration, search for pattern, and development of questions and hypotheses" (MacEachren and Monmonier 1992).

Visualization benefits fuzzy spatial analysis for purposes of discovery and better understanding of structures and patterns in at least two aspects. One is the dynamic exploratory process in which patterns and anomalies are easily identified. Another is the representation of uncertainty in an efficient way.

The purpose of the research presented in this paper is to develop a methodology for visualization tools to support fuzzy spatial analysis. To accomplish this goal, first the distinction between conventional spatial analyses and fuzzy analysis is discussed in section 2. The following section 3 shows the directions in which fuzzy spatial analysis operations need to be developed. Section 4 deals with exploratory tools. A complete system framework with an object-oriented approach will be discussed in section 5. The paper concludes with possible future research directions. It should be noted that the work is somewhat different from effort contributed to the visualization of data quality with fuzzy set theory (Van der Wel et al. 1994), although some principles and results obtained in this discussion can be equally applied.

2 CONVENTIONAL SPATIAL ANALYSIS VS FUZZY SPATIAL ANALYSIS

Conventional spatial analysis is a form of numerical analysis while fuzzy spatial analysis is a form of higher level analysis related to Artificial Intelligence (AI). What differentiates fuzzy spatial analysis from the conventional kind are the fundamental aspects of its exploration modes. These will be outlined first.

Numerical Analysis versus Concept Analysis

By stating that conventional spatial analysis is a form of numerical analysis while fuzzy spatial analysis is a form of concept analysis, we do by no means imply that concept analysis is the kind of qualitative analysis adhered to before the quantitative revolution in geography. The object of numerical analysis is data, and what is represented with graphics is also data. Due to the fuzzy nature of human thinking, the numerical analysis approach may mislead. A straightforward example is that two objects slightly different in value when on different sides of a crisp boundary value may be divided into two different classes. But instead of finding for instance an area with a slope of less than 30 degrees, in most cases, we would be interested in locating the area with relatively *gentle* slopes. By an efficient color scale, a pattern with the characteristic of '*gentle* slope' can be obtained. Taking a step further, the areas with *very gentle* or with *less gentle* slopes could be obtained as well.

Layer versus Sublayer

A layer is a subset of a multiple-element map, produced for spatial analysis purposes in the context of GIS. A sublayer is derived from a layer for the purpose of fuzzy spatial analysis. With the advent of digital technology, maps have been split up into sets of layers or coverages in GIS databases, and each layer corresponds to a type of thematic elements, like vegetation or transportation, etc. Layers have been playing a great role in spatial analysis, in answering series of queries relevant to reality. But they have limitations in answering and describing the fuzzy side of reality, and for that purpose sublayers are needed, which can be derived from the corresponding layers.

As we have already shown, there is no difference in nature between maps and layers except for their contents. However, sublayers are different from layers in the basic nature of what they represent. What the sublayers represent is uncertainty about one single concept indicated by a linguistic notion. Through intuitive representation, sublayers offer an analyst a more direct perception of the fuzzy side of the real world.

Probability versus (Un)certainty

Fuzzy spatial analysis is concerned with uncertainty or fuzziness and not with probability, although probability could also exist in some fuzzy linguistic notions, like *likely* and *most likely* etc. Conventional analysis is mostly based on probability theory, as what the layer represents still refers to the data or class in question. What exists in concept communication is primarily uncertainty, although it might also entail a probability issue. There is a well-known assertion in the field of mathematics that randomness is not equal to fuzziness. In the statement "show me the *gentle* slope area", what *gentle* implies has something to do with uncertainty about the concept of *gentle*, but rarely with probability.

Statistical Graphs versus Membergrams

Conventional exploratory analysis is based on statistical graphs such as histograms, scatterplots and scatterplot matrices. Fuzzy spatial analysis, as will be shown below, focuses on a series of sublayers that can be represented by color scales. Through the operations applied to a single sublayer or a set of sublayers, the analyst gets deep insight into fuzzy aspects of the real world.

(Un)certainty values ranging from zero to one can be represented graphically in a form similar to the statistical graphs, but because of differences in the nature of the contents, we refer to them as membergrams. Mathematically, they provide an intuitive representation and serve the task of visualizing the distribution of uncertainty. With membergrams, we can easily explore structures like fuzzy patterns, correlation and co-occurrences.

3 EXAMPLES OF EXPLORATORY OPERATIONS OF FUZZY SPATIAL ANALYSIS

Fuzzy spatial analysis changes our perspective from numerical analysis to concept analysis which is closer to human thinking in natural languages. The basic exploratory operations of fuzzy spatial analysis which have been discussed by Jiang and Kainz (1994) can be designed as a basic toolbox.

Operation on Primary Terms

Primary terms like *gentle*, *moderate*, and *steep*, are fundamental for fuzzy spatial analysis. Each of the primary terms usually constitutes a sublayer which appears in one window. Compared to layers in non-fuzzy spatial analysis, sublayers can perfectly describe these objects which belong not only to this level of the term but also to a higher level term. According to experience of domain analysts, for example, if 40 degrees is the ideal value for moderate slopes, then a value of 50 or 60 is most likely to be a vague one, which can be either regarded as moderate or as a steep slope. For such an operation, two components of a Graphical User Interface (GUI) are used to do the exploratory analysis. One is a dialog to adjust the shape of the membership function, and another is the child window required for a view of the sublayer. Fig. 1 is an example of this operation.

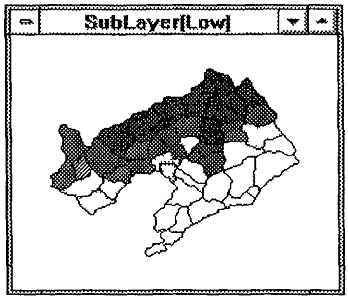

Fig. 1: Operation on primary term *low*

Operation with Negation

Negation is similar to the expression in daily communication, that what we want to know is the opposite of a certain property. For instance, instead of gentle slopes, we may want to get a pattern of *non-gentle* slopes. This would be worked out through an operator assigned by an icon which is arranged in a toolbox or is listed in the margin of the work area. Fig. 2 shows a result of the operation applied to *low* .

Operation with Hedges

Hedge operations are usually applied to the corresponding primary term when the degree of an expression is to be changed (Fig. 3). Instead of being interested in steep slopes, the analyst may wish to obtain *very steep* slopes. It can also be designed as an operator that includes reinforcing and weakening, just like a negation.

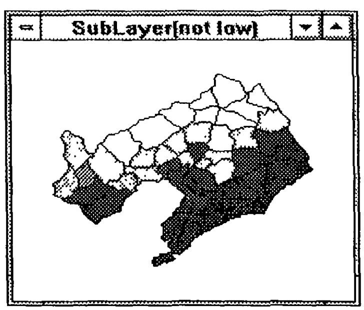

Fig. 2: Operation with negation *not low*

Operation on Connectives

Contrary to operations with hedges or negation, connective operations have at least two primary terms involved simultaneously. It is the most complex one among the set of operations, so its exploratory function is relatively difficult to perform. Sometimes, what we are interested in is neither gentle nor moderate, but *gentle and moderate*, or *gentle or moderate*. Another important application of connectives is fuzzy overlay in which combinations can be performed by a variety of operators (Jiang, Kainz and Muller 1995).

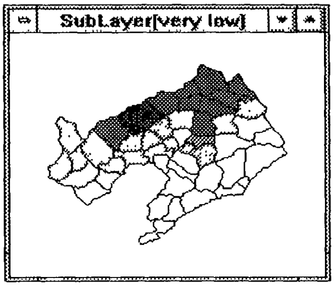

Fig. 3: Operation with hedges *very low*

4 EXPLORATORY TOOLS

Similar to statistical exploratory analysis, fuzzy exploratory analysis also has a set of tools to assist the analytical process. With these tools, the system can provide a better understanding about fuzzy aspects of reality.

Membergrams

Membergrams are similar in form to statistic graphs used for statistic exploratory analysis. However, what the membergrams indicate is the uncertainty (or possibility) distribution about assigning a set of objects to a certain attribute. They provide an intuitive visualization means to show the membership function. The following are a group of potential structures to be explored. They often serve the task of controller in exploratory analysis.

Fuzzy Pattern: this occurs in a single sublayer which has been derived from the layer and is represented with tints of gray. In this scheme, dark grey indicates a relatively full membership, and light grey indicates an intermediate membership or non-membership. It is much like the style of region-pattern masks introduced by Monmonier (1990). Fig. 1, Fig. 2 and Fig. 3 are examples of the fuzzy pattern representing regions in which dark areas have a higher certainty value than light areas.

Correlation: another question the analyst may be interested in is the correlation of two concepts in correspondence with different layers, say low pollution index and high forest coverage percentage. Two juxtaposed sublayers for simultaneous viewing will provide a rough answer about the relationships. The fact is that the visual comparison will only provide a superficial inspection; a deeper insight can be obtained through the precise calculation of the correlation coefficients. The exact correlation values should be shown in another window for inspection. To enhance the potential intuitive analysis, a suitable color scale could be used to represent the magnitude of coefficient values.

Co-occurrence: One of the important applications of overlay is to find the locations which satisfy certain conditions. The best solution is the provision of color mixture schemes in which each color represents one single condition. Intuitive representation can enhance the possibility for memorizing patterns. If there are few sublayers involved in the overlay operation, an analyst always wishes to obtain a general idea at a quick glance. In this connection, different color combinations (Olson 1987) provide alternative solutions.

Color-based Operation

Color has great potential in representing uncertainty just as observed by Zadeh (1973) who stated that "If we regard the color of an object as a variable, then its values, red, blue, yellow, green, etc., may be interpreted as labels of fuzzy subsets of a universe of objects. In this sense, the attribute color is a fuzzy variable, that is, a variable whose values are labels of fuzzy sets. It is important to note that the characterization of a value of the variable color by a natural label such as red is much less precise than the numerical value of the wavelength of a particular color". A fuzzy color system based on the recognition of identical hue as the same property or attribute may be constructed as a hue-layered color solid.

Against this background it can be surmised that, if a primary notion, for example 'low Pollution Index (PI)', is identified by a hue as red, a different degree of red with different lightness or saturation could then be used to represent (un)certainty about the concept 'low PI'. Thus based on user's preferences, certain color hues can be assigned to a primary notion. Once the provisional assignment of a given hue to a primary notion is established, the uncertainty can be represented by color, and further explorations can be seen as operations applied on color. We will refer to them as color-based operations. One of the important advantages is that this provides a real-time analytical tool.

Color is a useful tool to represent uncertainty about linguistic concepts. Fuzzy color specifications have been designed on a PC platform with 16 million colors. With the decreasing costs of personal computers, the cost of color was also reduced greatly. Once the uncertainty is visualized by color, the exploratory analysis can proceed in a real time manner.

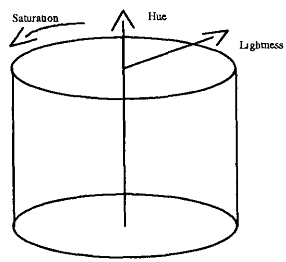

Fig. 4: The fuzzy color system used for representation of uncertainty

Color Solid: A color system used for the representation of uncertainty has been designed, in which, according to three psychological variables, all colors are rearranged to construct a new intuition-based color solid. In this model, full ranges of colors are organized to layers in terms of different hues (Fig. 4). The basic idea of the model originates from the metaphor that unitary hue is usually referred to as a homogeneous feature, as vegetation is represented by green, water by blue and so on. In addition, an uncertainty specification for each color facilitates the representation of uncertainty in fuzzy spatial analysis.

Uncertainty Specification: Along with the color solid, uncertainty is specified in equations (1), (2) and (3).

$$\mu_C(l)|_{Lum} = \frac{(1-\upsilon)^{\lambda-1} l^{\lambda}}{(1-\upsilon)^{\lambda-1} l^{\lambda} + \upsilon^{\lambda-1}(120-l)} \qquad [0,\ 120] \qquad (1)$$

$$\mu_C(l)|_{Lum} = \frac{(1-\upsilon)^{\lambda-1}(240-l)^{\lambda}}{(1-\upsilon)^{\lambda-1}(240-l)^{\lambda} + \upsilon^{\lambda-1}(l-120)} \qquad [120, 240] \qquad (2)$$

$$\mu_C(s)|_{Sat} = \frac{(1-\upsilon)^{\lambda-1}(240-s)^{\lambda}}{(1-\upsilon)^{\lambda-1}(240-s)^{\lambda} + \upsilon^{\lambda-1} s} \qquad [0,\ 240] \qquad (3)$$

The two parameters υ and λ serve for the purpose of visual equality in color scales. That is, the users can adjust the magnitude of the two parameters up to a certain level in which color scales satisfy the request of visual equality. On the other hand, the illustrations of Fig. 5 and Fig. 6 provide a good visualization method of how color could be perceived in conjunction with representation of uncertainty.

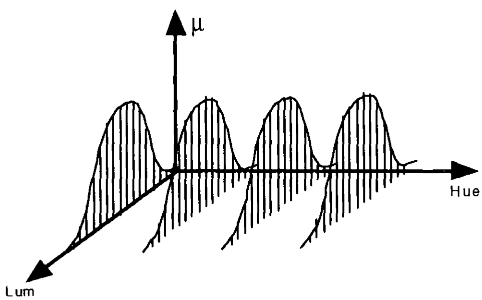

Fig. 5: Uncertainty specification corresponding to equation (1) and (2)

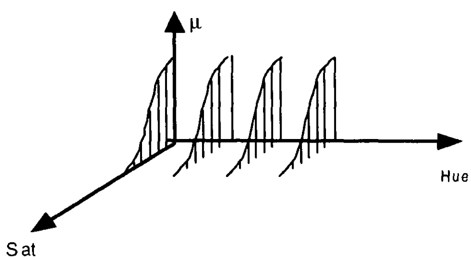

Fig. 6: Uncertainty specification corresponding to equation (3)

5 A SYSTEM FRAMEWORK FOR FUZZY EXPLORATORY ANALYSIS

In this section, we design a framework for exploratory analysis which is mainly oriented to the fuzzy spatial analysis. The framework is also applied to conventional non-fuzzy spatial analysis.

The whole system framework consists of four parts, and there is message communication between parts as the two way arrow indicate in Fig. 7. The framework actually is a object-oriented architecture, which uses the well-known Model-View-Control (MVC) model, first introduced for object-oriented development in the Smalltalk-80 language (Strand 1993).

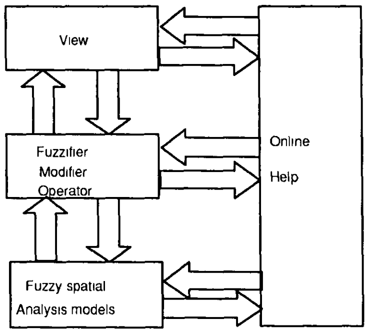

Fig. 7: A system framework for fuzzy exploratory analysis

View

View is the interface of the system for end-users, which is supported by a Graphical User Interface (GUI). Presently, there are a number of GUI standards available like Microsoft Windows initial SDK or OSF/Motif.

A Multiple Document Interface (MDI) offers the multiple visual perspectives simultaneously for deep insight and comparison in fuzzy exploratory analysis. There is one principal window serving as the entry of the system with various child windows to represent different layers and sublayers. These windows could also be regarded as an interface with the database in which any change of data in the database will be reflected in the windows while the analysis is progressing. Basically, there are two kinds of windows, one is the graphics-oriented window in which attribute data are visualized with color or symbols, and which offers intuitive visualization; and the other provides purely attribute data, which are visualized in graphics-oriented windows simultaneously. It is allowed to switch between these different windows when required.

Control

The control serves the exploratory function, by supporting different interface components such as dialog, icon, etc. According to the architecture of fuzzy spatial analysis, it is mainly three kinds of controls that need to be taken into account.

1) Fuzzifier: It is the principal component to do fuzzification. It can be designed as a modeless dialog to make the exploratory results appear on the corresponding views in real-time.
2) Modifier: It mainly indicates the linguistic hedges in fuzzy spatial analysis. In addition to modeless dialog, a slider bar could serve the task of the modifier.
3) Operator: For the operator, there are basically two kinds, one is the unary operator, and another is a binary operator.

Model

Model is the term for full fuzzy spatial analysis including fuzzy overlay model, fuzzy buffer model, fuzzy search model etc.

Online Help

Online help provides not only the instructions to use the software itself, but to use the help of analysis methods as well. For a successful exploratory analysis system, online help is critically important to facilitate the exploratory process. Preliminary, there are three basic modules to be considered (Fig. 8).

1. Terminology and notations: for a new system, it is essential to offer the analyst some basic concepts about the system. In our prototype system FOAT:W, for example, a set of definitions like fuzzification, sublayer, first certainty, second certainty is presented (Jiang, Kainz and Muller 1995).
2. Commands: It gives details about the operation of the system.
3. Interpretation: It provides detailed explanation about the strategy of visualization in online style. If the above two items are commonly available to other kinds of system, this one is available uniquely for exploratory analysis systems.

The online help of existing software consist mainly of texts or documents, but for exploratory analysis in GIS graphics will be highly incorporated.

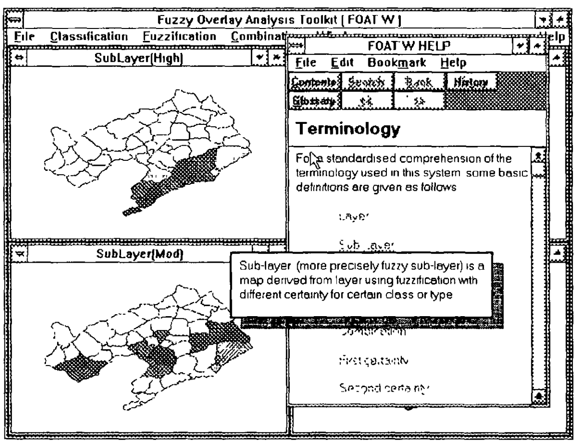

Fig. 8: An online help implemented in FOAT:W

6 CONCLUSION

The framework presented in this paper needs to be expanded further for practical implementation. Parts of it and the prototype system FOAT:W have been implemented, and although the functions are only partly available, they have shown the promise that it is possible to produce a powerful visualization support for fuzzy spatial analysis. The FOAT:W will be extended to a practical visualization tool in the near future in the following aspects:

1. Integration: It will be integrated into existing GISs based on some standardized GUIs as OSF/Motif, X-Windows, especially for MS-Windows and MS-Windows NT.
2. The color-based operation proposed in this paper opens up many new possibilities for exploratory analysis.

3. The option of online help promises substantial potential in the development of exploratory analysis systems. In addition to the nonlinear text, graphics can greatly improve the capacity for exploratory analysis.

REFERENCES

Goodchild, M. F. (1987). A Spatial Analysis Perspective on Geographical Information Systems, *Int. J. Geographical Information System*, Vol. 1, pp. 327-334.

Jiang, B. and Kainz, W., (1994). Fuzzification as a Basis for Fuzzy Spatial Analysis. *Proceedings of IAI'94*, Wuhan, P.R. China, pp. 294-302.

Jiang, B., Kainz, W., and Muller, J. C. (1995). Fuzzy Overlay Model -- Overlay Operation Incorporated with Linguistic Notions, to be published.

Leung, Y. (1984). Fuzzy Sets Approach to Spatial Analysis and Planning -- A Nontechnical Evaluation (Occasional Paper), The Chinese University of Hong Kong.

MacEachren, A. M. and Monmonier, M. (1992). Introduction, Special Issue of *Cartography and Geographic Information Systems*, Vol. 19, No. 4, pp. 197-200.

Monmonier, M. (1990). Summary graphics for Integrated Visualization in Dynamic Cartography, *Cartography and Geographic Information Systems*, Vol. 19, No. 1, pp. 23-26

Olson, J. M. (1987). Color and the Computer in Cartography, In: Durrett H. J. (ed.) *Color and the Computer*, Academic Press Inc., pp. 205-219.

Openshaw, S. (1990). Spatial Analysis and Geographical Information Systems: a Review of Progress and Possibility, In: Scholten H.J., and Stillwell J.C.H. (eds.) *Geographical Information System for Urban and Regional Planning*, Kluwer Academic Publishers. pp. 153-163.

Strand, E. J. (1993). Model-View-Controller Architecture Expedites Embedded Application, *GIS World*, Oct. 1993, pp. 20-21.

Tang, Q. (1992). A Personal Visualization System for Visual Analysis of Area-based Spatial Data, *Proceedings of GIS/LIS'92*, pp. 767-776.

Tukey, J. W. (1977). *Exploratory Data Analysis*, Addison-Wesley.

Van der Wel, F. J. M., Hootsmans, R. M. and Ormeling, F. J. (1994). Visualization of Data Quality. In: MacEachren A. M. and Taylor D. R. F. (eds.) *Visualization in Modern Cartography*, Pergamon Press, pp. 313-331.

Xia, F. F. and Fotheringham, A. S. (1993). Exploratory Spatial Data Analysis with GIS -- The Development of the ESDA Module Under ARC/INFO, *Proceedings of GIS/LIS'93*, pp. 801-810.

Zadeh, L. A. (1973). Outline of a New Approach to the Analysis of Complex Systems and Decision Process, *IEEE Trans. System, Man, and Cybernetics*, SMC-3, pp. 28-44.