STUDY OF FUZZY UNCERTAINTY OF GIS PRODUCTS

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ABSTRACT:

The fuzziness-based uncertainty of GIS products is studied from objective and subjective aspects respectively in this paper. From the point of view of objective aspect, the fuzziness-based uncertainty of GIS products consists of items concerning the data sources of GIS products. From the point of view of subjective aspect, the fuzziness-based uncertainty of GIS products includes human's appraisal, description of GIS data and data quality. It is believed that researches on fuzzy uncertainty of GIS products are of great significances. These researches must be done with the emergency of new sources of fuzzy uncertainty.

1. INTRODUCTION

In recent years, GIS (Geographic Information System) has been developed rapidly, and it has been applied in more and more fields. GIS products such as DLG, DEM, DOM and DRG have been used as information commodity in daily life. At present, many countries have done a great deal of researches on the theories and applications of GIS. Among the researches, the study of fuzzy uncertainty of GIS product is regarded as the most difficult one (Bo, 2002; Shi, 1998). Thus far, the methods used are mainly the variance of the survey adjustment of observation theory. The main achievements are usually based on the randomness-based uncertainty. However, some researchers have already realized that GIS products not only have randomness-based uncertainty but also have fuzziness-based uncertainty. In this paper, the fuzziness-based uncertainty of GIS products from objective and subjective aspects is deeply discussed respectively.

2. FUZZY UNCERTAINTY ORIGINATED FROM OBJECTIVE CONDITIONS

In order to put GIS products into markets as commodity, accurate appraise on the accuracy of GIS products is a necessity. Researches on the fuzzy uncertainty of GIS products have the following significances:

1. Providing precision index of GIS products
2. Improving quality of GIS products
3. Implementing quality control of GIS products
4. Driving GIS products going into markets

Here, objective conditions mainly refer to the data needed by GIS products. This can be discussed in the following three aspects.

2.1 Fuzzy uncertainty caused from GIS data

2.1.1 Fuzzy uncertainty when acquiring GIS data

Although there are many sources when acquiring GIS data, four ways can be generalized as following (Deng et al., 2002):

1. Directly measuring position data of spatial objects. Fuzzy uncertainty caused from this aspect lies in the judgment on the boundary points of spatial objects.
2. Image interpreting and boundary digitalizing. Fuzzy uncertainty caused from this aspect originates in the judgment on the objects boundary on images.
3. Thematic classification and segmentation of remote sensing images. Fuzzy uncertainty caused from this aspect originates in the uncertain definition of thematic and errors when acquiring image data.
4. Sampling, interpolating and thematic classification. Fuzzy uncertainty caused from this aspect originates in the errors caused by attribute measurement, interpolation and attribute classification of feature points.

2.1.2 GIS fuzzy uncertainty caused by fuzziness in the description of metadata: Being the dictionary of GIS data, metadata is very important to GIS. Metadata must have the property of fuzziness because of the fuzziness of objective reality.

2.1.3 Fuzzy uncertainty caused by the transformation of spatial data: When raster data is transferred into vector data, the same raster may produce several vectors. Figure 1 is a raster map. The possible vector maps produced can be listed in Figure 2.

This kind of uncertainty resulted from the transformation between raster and vector, like this example, is one of the fuzzy uncertainties.

2.1.4 Fuzzy Uncertainty Caused by Missing Data: If attribute data of spatial entity is missing we shall not have a good command of this entity. This leads to cognitive deviation inevitably. This kind of cognitive deviation is one of fuzzy uncertainties.

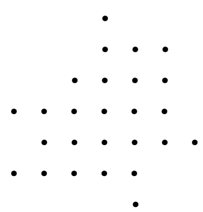
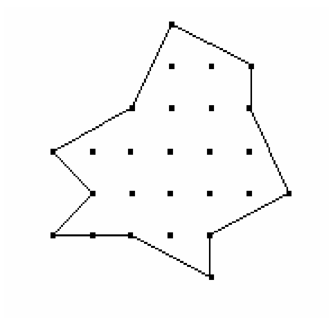
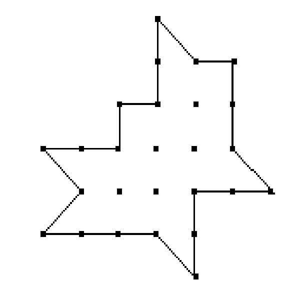


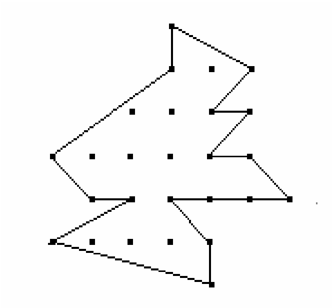
Figure 1. A raster map



(a)



(b)



(c)

Figure 2. Different vector maps obtained from the map in Figure 1.

2.1.5 Fuzzy Uncertainty Caused by Sample Resolution: This kind of fuzzy uncertainty is caused by the following ways:

1. When different layers of different resolution are overlaid
2. When high-resolution images are converted into low-resolution ones
3. When sampling points are not sufficient

An example will be illustrated here. When a 3×3 resolution image (in Figure 3) is converted into 1×1 resolution images, different images may be produced as shown in Figure 4.

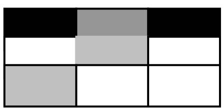


Figure 3. A 3×3 resolution image

(a)

(b)

(c)

Figure 4. Different images converted from the image in Figure 3.

2.2 Fuzzy Uncertainty Caused by Spatial Phenomena

2.2.1 Fuzzy Uncertainty of Spatial Data Caused by Fuzziness of Spatial Relation Description

1. Fuzziness caused by qualitative description of geographic phenomena's spatial relationship.

Inaccurate terms are often used when geographic phenomena is described. e.g., what is on the 'vicinity' of this town. The south side of the river is suitable for farming. Descriptions of geographic characteristics are often inaccurate. e.g., descriptions of boundary are often fuzzy because the classification boundaries joined together. These fuzziness consequently lead to fuzzy uncertainty.

2. Fuzziness caused by quantitative description of geographic phenomena's spatial relationship

Here, the fuzzy uncertainty can be caused specifically in the collecting, measuring, analyzing and transforming of geographic phenomena. e.g., errors are caused by digitizer and operation procedure when doing digitalizing. Also errors maybe caused by model simulation and calculation procedure when analyzing the spatial information. Graphic errors are caused when displacing, segmenting and merging the boundaries of graphics. Error accumulation and propagation are also caused when processing the graphic data, etc. All the errors can lead to inaccuracy, uncertainty and ambiguity of GIS when analyzing, describing and classifying geographical phenomena.

2.2.2 Fuzzy Uncertainty of Spatial Data Caused in the Process of Spatial Analyzing (Knowledge Reasoning Operation): Spatial analysis, which makes GIS different from other information systems, is one of the important characteristics of GIS. Essentially spatial analysis is knowledge reasoning operation, and the results of spatial analysis can provide the manager with decision support. Human's languages have ambiguity in most of time, some ambiguity words are often used, which make the results have fuzzy uncertainty.

2.2.3 Fuzziness Caused by Spatial Region Transition Belt: There are many kinds and classes of natural and human economic regions in the earth system space. These regions are often constituted with many essential factors, and the zones between the neighboring regions are of transition gradually. One zone on the transition belt has the character of the both neighboring regions, which shows the character of fuzziness.

In nature, the boundary of different regions is often the gradual procession of quantitative change to qualitative change. Or, the two factors (signs) are on effects at the same time while one of the factors increases, the other one decreases. Therefore, the actual natural boundary is often a wide or narrow belt. Transition types are marked on the belt when drawing maps (Liao, 1963). For example, there can be forest-grassland region between forest and grassland in natural region, and the tundra-forest region between tundra and forest. Also, there are many transition soil types when classifying soil types. Such as brown and grey forest soil, and brown and yellow soil, etc.

2.2.4 Fuzziness Caused by Distribution of Spatial Objects and Phenomena: This kind of fuzziness can be presented as inaccuracy, uncertainty and ambiguity of the distribution of spatial objects and phenomena. For example, a wheat field may change into a cotton field with conversion of seasons. Even though a point can be represented in geographic or Cartesian coordinates, errors maybe occurred because of errors of surveying equipments and operations. If two kinds of crops are intercropped on the same field ambiguity may emerge. All the uncertainty, in accuracy and ambiguity will bring fuzziness to the distribution of graphical phenomena.

2.2.5 Fuzziness Caused from Spatial Procession and Spatial Relationship: Because the earth system is very giant and complicated to humans, many spatial phenomena happened in ground of the earth have fuzziness. Thus far, human only have the hypothesis on the forming procession of natural phenomena. For example, because humans haven't yet fully understood the mechanism of the influence of ionosphere on GPS surveying, these influences can only be handled and analyzed by means of hypothesis models.

2.2.6 Fuzzy Uncertainty Caused by Complexity of Geographical Phenomena: Complexity of geographical phenomena includes the following aspects (Femke, 2001):

1. spatial self-interrelationship
2. spatial anisotropy
3. diversity of spatial dimension
4. variation of spatial boundary

All these aspects inevitably cause fuzzy uncertainty because of the incompatible theory of complexity and accuracy.

2.2.7 Fuzzy Uncertainty Caused by the Number of Dimensions: Spatial entities may have different structure in different space. Some entities may have definite boundaries in two dimensions, while have no definite boundaries in three dimensions. For example, the boundary between two countries may be definite on the ground while it may be fuzzy under and above the ground.

2.3 Fuzzy Uncertainty Caused by Actual Conditions

2.3.1 Fuzzy Uncertainty Caused by Integrated Entities Which Are Constituted with Simple Entities: In GIS entities can be classified into point, line and area objects. Some entities can be constituted with simple entities (Sun, 2000). Although a single entity is ascertained, the integrated entity may have fuzziness (Wang, 1999), which can be called group fuzzy uncertainty. There are integrated entities in GIS everywhere, so fuzzy uncertainty exists.

2.3.2 Fuzzy Uncertainty Caused by Function Enhancement of GIS and Advance of Technology: During the long-term production, people concluded a theory of incompatibility (He, 1983). That is to say that the ability of precision will decrease when the complexity of a system increase, complexity and accuracy will be mutually exclusive when they grow up to some extent. Therefore, the degree of precision will be lower if the complexity becomes higher. Complexity often means that there are so many factors that practitioner can only grasp the key factors and omit less important factors. However，this may make the definite concepts in itself turns to be fuzzy.

GIS is on the way of multi-function, advanced technology and multi-factor, which coincides with incompatible theorem. Therefore, fuzzy uncertainty is the inevitable.

2.3.3 Fuzzy Uncertainty Caused by the Measurement and Representation of Spatial Information: Whatever precise surveying methods and equipments are employed, it is inevitable that fuzziness and uncertainty will occurred. Representation methods also have fuzziness and uncertainty when representing spatial objects.

2.3.4 Fuzzy Uncertainty Caused by Propagation of Spatial Information: The information of spatial objects is obtained by means of either direct measurement or calculated through the information of other spatial objects. For the latter, the information of the spatial objects is determined by the spatial information of other spatial objects, which lead to fuzziness and uncertainty. and their spatial information is determined by the spatial information of other spatial objects that is measured directly.

More discussions can be found in (Altman, 1994; Qin, 2000; Wang et al., 2004).

3. FUZZY UNCERTAINTY CAUSED BY APPRAISAL OF GIS PRODUCTS

This kind of fuzzy uncertainty is mainly resulted from human's appraisal and description of GIS products.

3.1 Fuzzy Uncertainty Caused by Description of GIS Data and GIS Products

For example, when analyzing the quality of GIS data, the degree of defect of attribute data can be divided as the following: general, serious and significant (Liu, 2001). Obviously this kind of classification has fuzziness in itself. Another example is that the quality of GIS products is often appraised as the following: excellent, good, moderate, eligible and ineligible. This kind of classification also has fuzziness in itself either.

3.2 Fuzzy Uncertainty Caused by the Fuzzy Concepts of Spatial Data

Because of the limitation of human's cognition ability, many geographic concepts still have no unified definition. For example, the boundary of grassland, moving to forest or desert gradually, is not always definite. This is true to the boundary determination of soil unit and the vegetation form classification. Different operators may get different classification result. All these fuzzy information exists objectively. If the data are not suitably dealt with in GIS, they may have fuzzy uncertainty inevitably.

3.3 Fuzzy Uncertainty Caused by Quality Viewpoint

There are two kind of quality viewpoint in the practice of quality management. The first one is 'coincidence quality viewpoint'. Another one is 'usability quality viewpoint'. From the viewpoint of the first one, the quality of GIS products is appraised by the facts that whether the quality is coincide with the specified quality standards. Therefore, this is a viewpoint in the narrow sense. By contrast, the latter one is a viewpoint in the broad sense. Here, usability refers to the total demands of characteristics and properties that are suitable for users' demands that include products, procession and services. This kind of quality viewpoint is the viewpoint of 'users' appraisal first'.

Zhu Lan, the international authority on quality management, pointed out that, for users, quality is 'usability' rather than specification coincidence. In the end, users seldom know what the specifications are. Usually, users' appraisals of quality are based on whether the products in hand have usability and whether the usability can last long time. This kind of 'usability quality viewpoint' is the viewpoint on the basis of 'users are the main body'. In 'usability quality viewpoint' user's psychological factors of judge are strengthened while specification coincidences are weakened.

From the viewpoint of 'usability quality', quality has the property of fuzziness because users' feelings and psychological factors are emphasized. This can be indicated that there are not only two entirely different choices of 'usability' and 'no usability' when appraising quality from usability angles.

For example, for a 1:1,000 scale topographic map produced by a company, one of the most important quality usability indexes is positional accuracy. Then, how should we consider the concept of 'high positional accuracy'? According to 'coincidence quality viewpoint' the answer may be considered as such that mean square error of a point is not larger than 1dm. That is to say that any 1:1,000 scale topographic maps, on which mean square error of any points are not larger than 1dm, will be high precision products. Otherwise, the 1:1,000 scale topographic maps, on which mean square error of any points are larger than 1dm, will not be high precision products. As a result, 1:1,000 scale topographic maps on which mean square error of points is 0.999dm will be considered as qualified high precision products, while the maps on which mean square error of points is 1.001dm will be considered as unqualified. This entirely different of 'usability' and 'no usability' is obviously unreasonable. From this we can find that 'usability quality' considering quality fuzziness is better than entirely different 'coincidence quality'.

4. APPLICATION FIELDS OF FUZZY UNCERTAINTY OF GIS PRODUCTS

The aim of studying the fuzzy uncertainty of GIS products is to appraise the quality of these products. Since the appraisal method used is mainly the theory of errors that is often used in survey adjustment, fuzzy uncertainty is not taken into consideration. It can be concluded from above analysis that GIS products not only have randomness-based uncertainty but also have fuzziness-based uncertainty.

For GIS products, theories of fuzzy mathematics are used to analyze their quality considering not only the randomness but also fuzziness. Fuzzy randomness theory can be used to appraise their quality scientifically, rigorously and authentically. Thus far, studies on fuzzy uncertainty are mainly applied in the products of DLG and DEM, etc. Fuzzy relation and fuzzy multilevel synthetic appraisal theory are used to appraise GIS products. The appraisal results are better than that of the traditional methods (Hu, 2004).

5. CONCLUSIONS

The fuzzy uncertainty of GIS products is deeply discussed in this paper from the aspects of GIS data and the aspects of human's appraisal and description of GIS products. Since the generation of GIS production may concerns many other factors, such as the quality of the instruments, software and others factors, this paper just gives partial demonstration about the GIS product fuzzy uncertainty. With the development of science and technology, other new sources of fuzzy uncertainty will be found. Therefore, researches on fuzzy uncertainty must go ahead.

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