STUDY ON THE UNCERTAIN DIRECTIONAL RELATIONS MODEL BASED ON CLOUD MODEL

TANG Xuehua [a, *], MENG Lingkui[a], QIN Kun [a]

[a]School of Remote Sensing Information Engineering, Wuhan University, 129 Luoyu Road, Wuhan, 430079, P.R.China-
tangxuehua@sohu.com, - lkmeng@whu.edu.cn, qqqkkk@263.net

KEY WORDS: Spatial analysis, Modelling, Computer Vision, Spatial modelling, Geography, Directional relations model, Uncertainty, Cloud model

ABSTRACT:

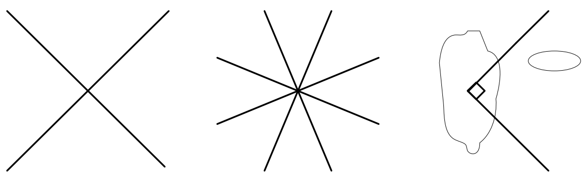
The directional relationship of spatial objects is an important spatial relationship of GIS, which is involved in spatial database query, spatial position, and spatial analysis etc. The directional relations in GIS are most commonly represented with qualitative representation model and quantitative representation model. The quantitative models represent direction relationships by angle (quadrant angle or azimuth), while the qualitative models use ordered classes. Traditional models of directional relations define a certain class of direction relationships between spatial objects in the basis of the concepts of the directional relations, such as A is east of B. These methods ignored the uncertainty of directional relations concepts. Based on the analysis of this uncertainty, this paper proposes a new directional relation model based on cloud model, which can availably represent the uncertainty of directional relations concepts. This model expresses the uncertain directional relations through calculating the subjection degree to the four cloud-models of basic directions, and provides a new more reasonable and correct method to analyze the directional relationships. Furthermore, it is an uncertainty conversion model between qualitative directional relation concepts and quantitative directional relation numerical values.

1. INTRODUCTION

As one sort of the important spatial relations, directional relations are tightly related to the spatial query and spatial reasoning. Generally, all of the current ways, which include cone-based model, 2D-String model, the models based on MBR (Minimum Bounding Rectangle), etc, describe direction relations based on the exact sorts of qualitative directional relations that the direction relations is represented with a certain directional sort in the final result. However, the description of directional relations in the fuzzy area between two basic directions is uncertain, thus leads to hard description for uncertain relations in precision with conventional models. Cloud model is a quality-quantity interchangeable model combining traditional fuzzy mathematics and probability statistics and realized the conversion between qualitative words and quantitative values (LI Deyi etc, 1995). A planar cloud model was used to describe the uncertainty of the directional relations by DI Kaichang(DI Kaichang, 2001), but there are no models and detail descriptions of directional relations based on the cloud model yet. Based on the cloud model and the traditional descriptions of directional relations, this paper concentrates on the uncertainty of the definition of directional relations and proposes a new cloud model of direction relations, which represents the uncertainty of directions by the certainty degree of the basic direction. Based on this model, we discuss how to express the directional relations between different kinds of reference object and kinds of primary object. To demonstrate the soundness of the model, some examples are given, and the advantages are discussed in the end.

2. ANALYSIS THE TRADITIONAL MODELS OF DIRECTIONAL RELATIONS

Early qualitative models for directional relations involve three main categories of cone-based model, projection-based model and Voronoi-based model (XIA Yu etc, 2007). The cone-based model partitions the space by using lines with an origin angle α (Fig. 1). Typical models include 4-direction model (Fig.1 (a)), 8-direction model (Fig.1 (b)) and triangle model (Fig.1 (c)). Such models get the exact definition of the directional relations in the case of point reference object, whereas may give misleading directional relations when reference objects are line and polygon.



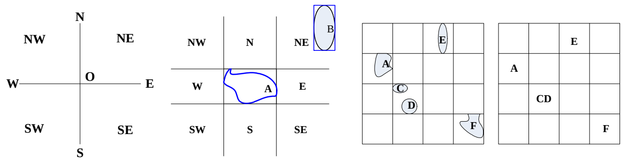
(a) (b) (c)

Figure 1. Cone-based model

The projection-based model partitions the space by using lines parallel to the axes (Fig. 2a) (Spiros Skiadopoulos etc, 2007). The commonly used models include MBR model (Fig. 2b), 2D-string model (Fig. 2c), etc. The MBR model is prominent among these models. It expresses the directional relations by the relations between the MBR of the reference object A and the primary object B. It intuitively partitions the plane around

* Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.

the reference objects into the nine areas based the projection-based model, which define the directional relation between the primary and the reference objects (Fig.2b). This model is more precise and expressive model than those approaches that approximate objects by using points or boxes. Its weakness is a large number of relations expressed in this model and unnatural partition, which partitions the reference space into the projection-based model by the lines parallel to the axes. Typically, people tend to organize surrounding space by using lines with an origin angle similar to the cone-based model.
Voronoi-based models describe the directional relations by the relations between the object and its Voronoi diagram. Such models offer the precise express of directional relations and are not affected by the geometrical properties of the object, such as shape and size etc.



(a) (b) (c)

Figure 2. Projection-based model

Depending on the adopted model, the directional relations between two objects is defined a certain partition ignored the uncertainty of the directional relations. For instance, consider Fig. 3: According to the cone-based model, B is east of A, C is northeast of A, D is northeast of A. Clearly, B is a neighborhood point to C and far away from D, whereas its partition of directional relation is different from C and same to D based on the 8-direction cone-based models, whereas we can not get these relations from this result. It means that the traditional model can not express the directional relations in the transition area between two basic directions because all of them are based on exactly partition area, and the final result is a exact sort through mathematic way, Whereas the most of area during the basic directions is dynamic uncertain and continuous to the directional relations, thus lead to hard partition for uncertain relations with conventional models. To solve this conflict, we should find a model to describe the continuity and uncertainty of the concept of directional relations.

3. BASIC CONCEPTS OF CLOUD MODEL

Cloud model is a quality-quantity interchangeable model combining traditional fuzzy mathematics and probability statistics, which can availably realize the conversion between qualitative words and quantitative values. It represents the fuzziness and randomness and the relations of uncertain concepts and knowledge in the real world and combine them into a model.

3.1 Definition of cloud model

Cloud model is a conversion model with uncertainty between a quality concept and its quantity number expression by means of analyzing concept based on natural language. The process of transformation is a stochastic event because of its randomness. And there is fuzziness in the course of defining the subjection degree of the certain drop. The probability distributing function can be used to describe the randomness and the fuzziness. If *U* is a quantity domain expressed with accurate numbers, and *C* is a quality concept in *U*, if the quantity value $x \in U$, and *x* is a random realization of the quality concept *C*, $\mu(x)$ is the membership grade of *x* to *C*, $\mu(x) \in [0,1]$, it is the random number which has the steady tendency:

$$\mu : U \to [0,1], \forall x \in U, x \to \mu(x)$$

The distribution of *x* in domain is called cloud model, which is briefly called cloud, each *x* is called a cloud drop (LI Deyi, 1995).

Cloud model represents an uncertainty concept by three parameters (expected value *Ex*, entropy *En*, hyper entropy *He*), which can indicate the whole characteristic of the quality conception *C*. Expectation *Ex* of the Cloud drops' distribution in domain, is the point which can best represent the quality concept and indicates the barycentre of cloud drops of the concept. Entropy *En* is the uncertainty measurement of the quality concept, which is decided by the randomness and fuzziness of the concept, and indicates the connection between the fuzziness and the randomness. Entropy *En* is a random measurement of the quality concept that the dispersion can be used to represent the quality concept; it is also the measurement of fuzziness that the value range can be accepted by the concept of the cloud drop. The same numeric characteristic of Entropy *En* indicates fuzziness and randomness, and embodies the connection between them. The super-entropy *He* is the uncertain measurement of entropy *En*, namely the entropy of the entropy. It indicates the coagulation conditions of uncertainty of all points which representing the concept in the number domain, namely the measure of coagulation of cloud drop.

The size of super-entropy indicates the dispersion and thickness of cloud indirectly. The super-entropy *He* is fixed by the randomness and fuzziness of entropy together. Considering its superiority to deal with uncertain problems, cloud model has been widely used in the field of data mining and artificial intelligence etc.

3.2 Normal cloud model

The algorithm of generative cloud is called cloud generator, which includes the normal cloud generator, the condition X cloud generator, the condition Y cloud generator and the inverse cloud generator. There are several cloud models through different cloud generators. The normal distribution is universal in the fields of social science and physical science and the normal cloud model is the basic cloud model and the effective tool for the description of the uncertainty of language. It would be applicable and universal in the representation of uncertain conception (LI Deyi, 2004). The algorithm of normal cloud generator is as follows (LI Deyi, 1995).

Input: the three digital characteristics values (*E*x, *E*n, *H*e) and the number of cloud drops *N*.

Output: cloud drops (x_i, y_i), x_i is the quantity values, y_i is the membership degree of x_i for the concept A.

Step1. Generate a normally distributed random number En' with mean En and standard deviation He;

Step2. Generate a normally distributed random number x with mean Ex and standard deviation absolute value of En';

Step3. Calculate $y = e^{-\frac{(x-Ex)^2}{2(En')^2}}$;

Step 4 y is certain degree of x belongs to the qualitative concept A, and {x, y} reflects the whole contents of this qualitative quantitative transform;

Step5. Repeat step 1-4 until N cloud drops are generated.

4. DIRECTIONAL RELATIONS MODEL BASED ON CLOUD MODEL

Cloud model may solve the description of the uncertainty of the definition of directional relations. In this section, we propose a directional relations model based on cloud model in order to express the uncertainty of the directional relations.

Firstly, people tend to organize surrounding space by using lines with an origin angle similar to the cone-based model and the cone-based partitions are more intuitive and descriptive. The cognitive plausibility of the cone-based model has been verified by studies in the field of interrelated sciences. Moreover, the cone-based partition is a typical approximation for the field of view of the human eye and camera lenses. For the above reasons, cone-based models have been used in computer vision, robot navigation, and GIS (Spiros Skiadopoulos etc, 2007). Thus we use the partition of cone-based model and combine it with cloud model.

In the previous research, four planar cloud models (Fig.3) were built to express the four basic directions in the basis of azimuth angle (DI Kaichang, 2001). Based on this model, the partition of direction relations between two adjacent primary objects in the quadrant NE and quadrant SE would be not accord to the way to natural partition. For instance: consider Fig. 4, the certainty degree of P1 to east is 0.407575 and the certainty degree of P2 to east is 0.065088，whereas their dispersion to east should be closer according to the natural conception. To deal with this problem, we create a new cloud model based on the dispersion angle instead of azimuth angle (Fig.5).

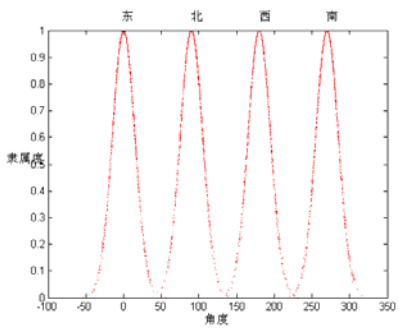


Figure 3. Four cloud models based on azimuth angle

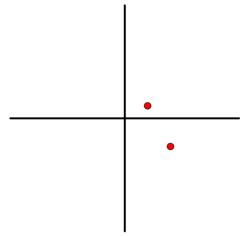


Figure 4. Two points dispersion to east

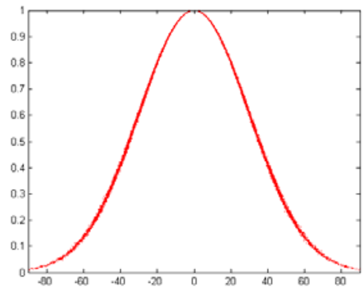


Figure 5. New cloud model based on departure angle

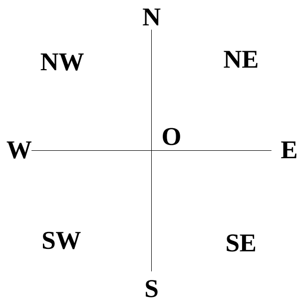


Figure 6. Quadrants of directional relations

Firstly, we discuss the description of directional relations when both the primary object and reference object are point objects. The model partitions the space around the reference point O into 4 exclusive areas by using the lines of four basic directions (Fig.6). And it expresses the certain standard of primary point to four basic directions based on the departure angle by four same single normal cloud models. Thus we can get four same directional relations cloud models (*E*x=0) (Fig.5). The departure angle, denoted by α', expresses the degree to the primary point adjacent to the basic direction and can have values in the interval $[-90^{\circ}, 90^{\circ}]$. In order to distinguish the direction of α' to the basic direction axis, we define the right to the basic direction is the positive direction and the left is the negative direction and signed it in the certain degree. When the primary point is in the basic direction, the concern degree to the basic direction is 1 and the concern degrees to the other directions are 0. Otherwise the primary point is in the field between two basic directions, we use the dispersion angle α' to calculate the concern degree to the relevant direction. So the directional relations model from A to B can be represented as:

Dir（A,B）$=(\mu_E,\mu_S,\mu_W,\mu_N)$

Set the primary point is not overlapped with the reference point, thus the algorithm of the certain degree of the primary point to every basic direction is as followings:

Step1: Calculate the azimuth angle α along clockwise order and east original axis;

Step2: Calculate the dispersion angle and certain degree:

Case 1: Primary point is in the basic direction:

$$\alpha = 0^\circ \rightarrow \mu_E = 1, \mu_S = 0, \mu_W = 0, \mu_N = 0$$

$$\alpha = 90^\circ \rightarrow \mu_E = 0, \mu_S = 1, \mu_W = 0, \mu_N = 0$$

$$\alpha = 180^\circ \rightarrow \mu_E = 0, \mu_S = 0, \mu_W = 1, \mu_N = 0$$

$$\alpha = 270^\circ \rightarrow \mu_E = 0, \mu_S = 0, \mu_W = 0, \mu_N = 1$$

Case 2: Primary point is not in the basic direction:

$$0^\circ < \alpha < 90^\circ \rightarrow \mu_E(\alpha' = \alpha), \mu_S(\alpha' = \alpha - 90^\circ), \mu_W = 0, \mu_N = 0;$$

$$90^\circ < \alpha < 180 \rightarrow \mu_E = 0, \mu_S(\alpha' = \alpha - 90^\circ), \mu_W(\alpha' = \alpha - 180^\circ), \mu_N = 0;$$

$$180^\circ < \alpha < 270^\circ \rightarrow \mu_E = 0, \mu_S = 0, \mu_W(\alpha' = \alpha - 180^\circ), \mu_N(\alpha' = \alpha - 270^\circ);$$

$$270^\circ < \alpha < 360^\circ \rightarrow \mu_E(\alpha' = \alpha - 360^\circ), \mu_S = 0, \mu_W = 0, \mu_N(\alpha' = \alpha - 270^\circ).$$

Based on the new model, the description of directional relations is more precise and expressive than previous models. The result of the example (Fig.4) is shown in Table 1. Clearly, we can get an exact direction relation between P1 and P2 through this model.

Method	Object	μ_E	μ_S	μ_W	μ_N
New cloud model	P1	-0.797282	0	0	0.062337
	P2	0.599720	-0.129358	0	0
Old cloud model	P1	0.065088	0	0	0.000001
	P2	0.407575	0.000013	0	0

Table1 Comparison between results of the new cloud model and the old cloud model

When the primary object is a line, the distribution of primary object is an interval instead of a point. Correspondingly, the representation of the primary object is an interval instead of a single result. The method to calculate the concern degree is similar to primary point. We define the model of primary line as follows:

$$Dir(A,B) = \{(\mu_E,\mu_S,\mu_W,\mu_N)_{min}, (\mu_E,\mu_S,\mu_W,\mu_N)_{max}, (\mu_E,\mu_S,\mu_W,\mu_N)_{cen}, (P_{SE}, P_{SW}, P_{NW}, P_{NE})\}$$

Thus we improve the model and get the algorithm of the certain degree of the primary line object as followings:

Set the primary line does not include the reference point.

Step1: Computing two tangents of the primary line object according to reference point and calculate the certain degree of the tangents $(\mu_E,\mu_S,\mu_W,\mu_N)_{min}$ and $(\mu_E,\mu_S,\mu_W,\mu_N)_{max}$;

Step2: Calculate the centroid of the primary line;

Step3: Calculate the certain degree to the centroid of the primary line $(\mu_E,\mu_S,\mu_W,\mu_N)_{cen}$;

Step4: Calculate the proportion of the length of every part, divided by basic directions: $(P_{SE}, P_{SW}, P_{NW}, P_{NE})$.

The two tangents inflect the scope of the line object. And the centroid of line confines this scope. We can infer the distribution of line in the direction space based on the proportion of length in every tile. Used the model to example 2 (Fig.7), the result is:

Dir (O, L) = {(0.513308, -0.192668, 0, 0), (-0.127073, 0, 0, 0.597053), (-0.883065, 0, 0, 0.044649), (0.4, 0, 0, 0.6)}

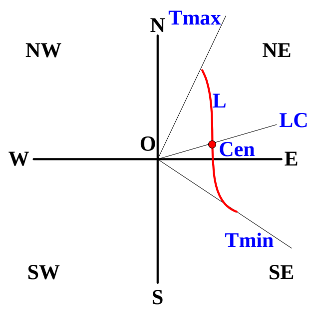


Figure.7 The model of line primary object

The model of primary polygon object is similar to primary line object. The unique difference is the last group of parameter is the proportion of the area of every part, divided by the basic directions, instead of the length. Used the model to example 3 (Fig.8), we can get the result is:

Dir (O, P) = {(0.248609, -0.410328, 0,0), (-0.945719, 0, 0, 0.028104), (-0.069751, 0, 0, 0.804629), (0.45, 0, 0, 0.55)}

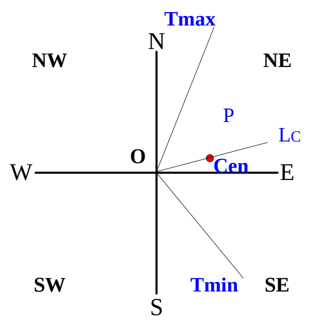


Figure.8 The model of polygon primary object

When the primary object is a line or a polygon, the reference object is approximated by its MBR, and the space around the reference object is partitioned into eight areas based on the point model (Fig.9, Fig.10). There are four areas of basic directions, which the concern degree to relevant basic direction is 1. The way to calculate the certain degree is similar to the precious approaches based on different origin point(O_{SE}、O_{SW}、O_{NW}、O_{NE}). For example: When primary point is in the tile of NE, we calculate the certain degree based on the origin point O_{NE}.

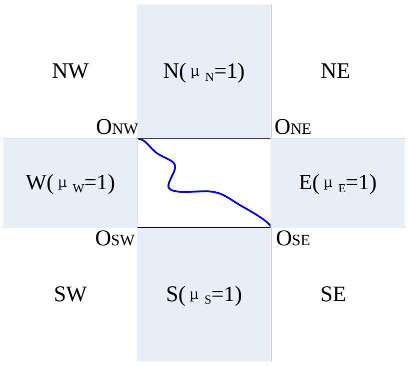


Figure.9 the partition of the space of line reference objects

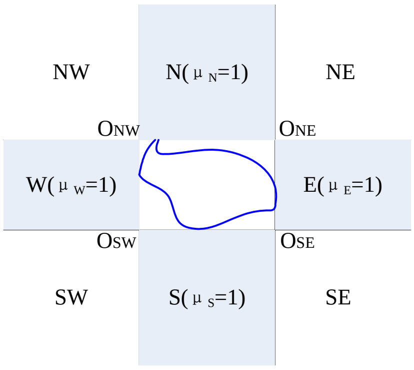
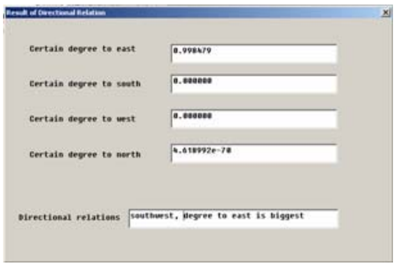


Figure.10 the partition of the space of polygon reference objects

5. EXAMPLE OF APPLICATION

To prove the feasibility of this model, we created a query system of directional relations. In the example shown as Fig.11a, we can get the direction relations between two cities and a reference result (Fig.11b).

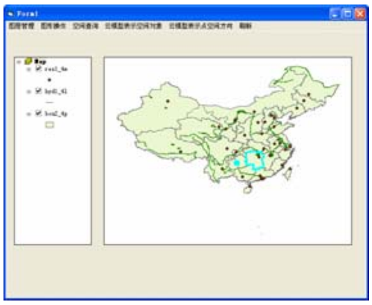
(a)



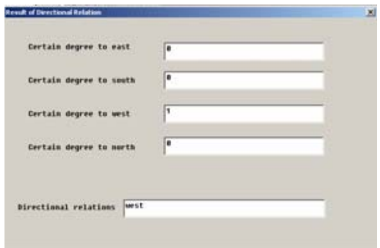
(b)

Figure.11 Example of reference point and primary point

The example shown in Fig.12 is an example between a reference polygon and a primary point.



(a)



(b)

Figure.12 Example of reference polygon and primary point

6. CONCLUSIONS

In this paper, we have introduced a new model of directional relations based on cloud model. Based on the definition of certain degree to basic directions, the model is a effective tool to represent the uncertainty of the directional relations and make the result of direction relations closer to fact. We have given different methods according to different kinds of reference objects and primary objects and applied them to the example. This model is more feasible and exact than traditional models based on the results of experiments. Further research could concentrate on the study of complicated for 1) create the model of complicated reference polygon; 2) create the model of primary polygon; 3) improve the relevant algorithms.

REFERENCES

[1] Di Kaichang, 2001. Spatial data mining and knowledge discovery. Wuhan University Press, Wuhan， pp.79-80.

[2] DENG Min, 2006. Discussion on Statistical Model of Direction Relation Between Spatial Objects in GIS, Geomatics World, 5(2004), pp.70-76

[3] Frank A, 1996. Qualitative Spatial Reasoning: Cardinal Directions as an Example, International Journal of Geographic Information Systems, 10 (3): 269 -290.

[4] LI Deyi, MENG Haijun, SHI Xuemei, 1995. Membership clouds and membership cloud generator. COMPUTER R & D, 32 (6), pp.16-21.

[5] LI Deyi, LIU Changyu, 2004. Study on the universality of the normal cloud model. Engineering Science. 6(8), pp.28-34.

[6] LI Deyi, 2000. Uncertainty in knowledge representation. Engineering Science, 2 (10), pp. 73-79.

[7] LIU Changyu, LI Deyi, PAN Lili, 2004. Uncertain knowledge representation based on cloud model, Computer Engineering and Applications, pp. 32-35.

[8] L IU Yu, GONG Yongxi, ZHANG Jing, GAO Yong, 2007. Representation and Reasoning of Spatial Relations in Geographical Space, Gegraphy and Geo-Information Science, 23(5), pp.1-6.

[9] LIU Changyu, LI Deyi, DU Yi, HAN Xu, 2005. Some Statistical Analysis of the normal cloud model. Information and Control, 34(2), pp.236-248.

[10] Spiros Skiadopoulos, Nikos Sarkas, Timos Sellis, Manolis Koubarakis, 2007. A Family of Directional Relation Models for Extended Objects, IEEE TRANSACTIONS ON KNOWLEDGE AND DATA ENGINEERING, 19(8), pp.1116-1129.

[11] XIA Yu, ZHU Xinyan, LI Deren, QIN Kun, 2007. Research on spatial directional relation description model, Science of Surveying and Mapping, 32(5), pp.94-97.

[12] Yan H., Chu Y., Li Z, Guo R., 2006. A quantitative description model for direction relations based on direction groups, Geoinformatica, 10(2), pp. 177- 195.