A novel direction relation reasoning model based Environmental Protection GIS

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Abstract. To make the complicated environmental protection work simple, environmental protection GIS is widely used. Direction relation reasoning is an important branch of spatial reasoning, it is also one of the most basic theoretical issues in the Environmental Protection Geographic Information System. This paper proposes a modelling method of combining the cone-shaped direction relation model with the direction relation matrix to determine the fuzzy direction relation between spatial entities on the basis of the cone-shaped direction relation model and direction relation matrix in Environmental Protection Geographic Information System, the advantages of the two models are fully utilized to overcome the disadvantages of them. Firstly, “central-region” is divided into nine equal internal sub-regions on the basis of the Minimum Bounding Rectangle (MBR) model. Then, the central-region of the direction relation matrix is divided again by using the cone-shaped direction relation model, and a fuzzy formal description model is given by taking point entity and area entity as research objects. The application of direction relation reasoning model in Environmental Protection GIS is helpful to improve the efficiency of judging the direction of pollution sources and the level of environmental protection.

1. Overview of spatial direction relation
Spatial direction relation reasoning is widely used in GIS or Environmental Protection GIS [1]. Qualitative spatial relations are the main research content of spatial reasoning, which include topology relation, direction relation and distance relation. Direction relation is one of the most basic and the most applicable spatial relations, it is also a hot issue of spatial reasoning in recent years. Spatial direction describes the information of relative position between the spatial entities, it includes three factors: target entities, reference entities and reference frame [2]. Attribute can be either quantitative or fuzzy concept of direction [3]. The common direction relations include front, behind, left, right, east, south, west, north, southeast, southwest, northwest and northeast, while these relations are fuzzy concepts. There are two main kinds of models for the direction relations between spatial entities, which are based on point and region.

Direction relation model is important method of computing and describing direction relations between spatial entities, it is the focus and difficulty of the research of spatial direction relation theory [4]. It mainly includes the minimum bounding rectangles (MBR) model [5], the cone-shaped model [6], the direction relation matrix model [7]. Existing models mostly concentrated in how to express the relations, reasoning is rare and lack of formal reasoning methods, most of the existing research is for the ideal spatial entities, we always ignore the complexity and uncertainty of the real world, related studies are all carried out at the theoretical level, but lack of practical application-oriented research [8]. The cone-shaped direction relation model is easy to calculate and realize. But, in this model, the
reference entity is abstracted as a point, and the influence of the shape and size of the entity on the direction relation is ignored. When the distance between the entities is far away from relative to its own size, the conclusions of direction relations are correct. Otherwise, the conclusions are often wrong. But many people are used to the "fan" direction division usually, that is, taking the reference entity as benchmark, the outward rays are used to divide space. This division-method is more intuitive and closer to human cognition[9][10]. A fuzzy membership function based on angle is introduced by this paper on the basis of cone-shaped model and direction relation matrix model to achieve fuzzy calculation and fuzzy description of the direction relation between of spatial entities.

2. Using cone-shaped model to describe spatial fuzzy direction relation

Definition 1: Atomic direction: direction relation is described by using discrete and distinguishable concepts words of the basic direction, such as East, South, West, North, North-East, South-East, South-West, these basic direction concepts are called atomic direction.

Definition 2: Cone-shaped directional region: spatial region of reference point entity is divided into eight spatial sub-regions according to eight direction concepts, which are East, South, West, North, North-East, North-West, South-East, South-West respectively, each direction concept corresponds to a unique spatial sub-region, which is called cone-shaped directional region.

The spatial entity is abstracted into a point entity with the cone-shaped method respectively. Set a point as the reference center to calculate angle from the target point to horizontal East direction of the reference center, directional relation between two entities is described according to the directional region of the angle, and this point is called centroid of entity usually. Therefore, the angle can be used to define the spatial eight direction relations. However, this method ignores the influence of the size and shape of spatial entities on the spatial relations between spatial entities, and the description of direction concept is not very accurate. It is shown in Figure 1.

![Figure 1. The model of cone-shaped direction](image)

Center of reference entity is $O$, $East$ horizontal direction is specified the positive direction. For any point $p(x,y)$ in space, starting from $East$ horizontal direction of the reference center, it is rotated clockwise and anti-clockwise respectively. Then, it calculates an angle from the reference center to the $P$ point and the horizontal direction of the reference center. The angle is specified the East direction as starting point: counter-clockwise direction rotates through the North and finally to the West, which is $0^\circ$ to $180^\circ$; clockwise rotates through the South and finally to the West, which is $0^\circ$ to $-180^\circ$.

Let’s assume that the angle between the line from the target point to the reference entity center $O$ and the $East$ horizontal direction of the reference center is $\alpha$, the fuzzy eight-direction membership function of any point $p$ is shown in formula (1).
3. Using direction relation matrix model to describe spatial fuzzy direction relation

Minimum Bounding Rectangle (MBR), which is used to define spatial direction relations between entities with the projection line of entity, and it represents spatial direction relations of target entities and the reference entities approximately by the MBR of reference entities. Therefore, it is not sensitive to shape and size of target entities and reference entities.

Definition 3: Directional region of relation matrix: according to shape, size and extent of the reference entity in space, spatial region of reference entity is divided into eight directional regions and one indistinguishable region by use of four lines of MBR, eight atomic-directions and familiar direction concept such as No1, NEo1, Eo1, SEo1, So1, SWo1, Wo1, NWo1 and Oo1. These spatial sub-regions have been described as cone-shaped directional region. Among them N, NE, E, SE, S, SW, W, NW represent eight directions respectively, Oo1 has been described as indistinguishable region.

\[
R(O_2, O_1) = \{NW_{O_1}, N_{O_1}, E_{O_1}, SE_{O_1}, SW_{O_1}, S_{O_1}, W_{O_1}, NW_{O_1}\} \text{ is direction relation of } O_2 \text{ relative to } O_1. \text{ It is shown in Figure 2.}
\]

![Figure 2. The model of direction relation matrix](image_url)

Let’s assume that \( O_1 \) is a reference entity, and \( O_2 \) is target entity, spatial direction relation between \( O_1 \) and \( O_2 \) can be represented by the spatial direction relation matrix of directional region, it is marked as \( R(O_1, O_2) \) and shown in formula (2).

\[
R(O_1, O_2) = \begin{cases} 
NW_{O_1} \cap O_2, & N_{O_1} \cap O_2, & NE_{O_1} \cap O_2 \\
W_{O_1} \cap O_2, & O_{O_1} \cap O_2, & E_{O_1} \cap O_2 \\
SW_{O_1} \cap O_2, & S_{O_1} \cap O_2, & SE_{O_1} \cap O_2 
\end{cases}
\]

(1)
The each element value of direction relation matrix is 0 or 1 because the value is Boolean. Therefore, it is not suitable for the fuzzy description of the direction relations between fuzzy entities. The paper proposes that fuzzy membership function of direction relations in spatial directional region to different types of entities with direction relation matrix, there are fuzzy membership functions of line entity and area entity respectively.

Let’s assume that \( dir_{ij} \) represents for the subspace region of \( i^{th} \) row and \( j^{th} \) column in spatial direction relation matrix respectively, the formal description of \( dir_{ij} \) is shown below: \( dir_{ij} \in \{ \{NW_{O1}, N_{O1}, NE_{O1}\}, \{W_{O1}, O_{O1}, E_{O1}\}, \{SW_{O1}, S_{O1}, SE_{O1}\} \}, 0 \leq i, j \leq 2 \). Let’s assume that \( O_1 \) is reference-entity, the fuzzy membership function of area entity \( O_2 \) represents with the area of intersection between entities, and it is shown in formula (3).

\[
\mu_{mbr-ij}^{area}(O_1, O_2) = \frac{area(dir_{ij} \cap O_2)}{area(O_2)}
\]  

Let’s assume that \( O_1 \) is reference-entity, the fuzzy membership function of line-entity \( O_2 \) represents with the length of intersection between entities, and it is shown in formula (4). Among them, the \( len \) function is to calculate the total length of the line entity.

\[
\mu_{mbr-ij}^{length}(O_1, O_2) = \frac{len(dir_{ij} \cap O_2)}{len(O_2)}
\]  

Finally, the fuzzy membership function can be expressed as formula (5).

\[
\mu_{mbr-ij}^{fij}(O_1, O_2) = \frac{\bigcup_{i=0}^{2} \bigcup_{j=0}^{2} f(dir_{ij} \cap O_2)}{f(O_2)}
\]

In the above method, after adding fuzzy membership function, the spatial direction relation is described accurately numerically according to the membership value. When \( O_2 \) is in indistinguishable region, such as in indistinguishable region \( O_2 \) of entity \( O_1 \), no matter what \( O_2 \) is in anywhere of \( O_1 \), it can’t describe the direction relation between target entity \( O_2 \) and reference entity \( O_1 \). There is non-compliance with description of orientation relation in the real world.

4. Combining the cone-shaped method with the direction relation matrix to determine spatial fuzzy direction relation.

This paper proposes combine the meticulous reservoir description of cone-shaped method and the rough description of MBR direction relation matrix, in order to more accurately represent the orientation relations of the entities, and using the cone-shaped method once again divided the central region of MBR direction relation matrix. \( O_1 \) is reference entity, \( O_2 \) is target entity, the direction relation description of \( O_2 \) relatives to \( O_1 \).

Steps of the implementation of algorithm:

Step1. First of all, types of entities need to be judged. If entity \( O_1 \) and \( O_2 \) are both point, then, according to the cone-shaped calculation method of Formula 1, the fuzzy membership degree of fuzzy direction relation is calculated directly through the angle. If \( O_1 \) is a point, and \( O_2 \) isn’t a point, there are shown in figure 3. \( O_1 \) is the center point of reference entity, the whole space is divided into eight directional regions, the set of eight directional regions is shown below \( area = \{ area(E_{O1}), area(NE_{O1}),...area(S_{O1}), area(SE_{O1}) \} \). Then, the intersection of eight directional regions of \( O_2 \) and \( O_1 \) is calculated respectively, the fuzzy membership degree of each direction is described as \( \mu_{Dir(O_1, O_2)} = \{ (area_i \cap area(O_2)) / area(O_2) \}, area_i \in area, i = \{1,2,\ldots,8\} \), the directional region corresponding to the maximum value of fuzzy membership degree as fuzzy direction of \( O_2 \) is relative to \( O_1 \).
Figure 3. The cone-shaped model of point entity and area entity

Step 2. If $O_1$ isn’t a point. Then Minimum Bounding Rectangle of entity $O_1$ is obtained, the space is divided into nine subspace-regions by the Minimum Bounding Rectangle according to the above method of direction relation matrix. When $O_2$ is a point, and it is not in the Minimum Bounding Rectangle of $O_1$, the direction relation region of $O_2$ is the fuzzy direction of $O_2$ relative to $O_1$. When $O_2$ is a point, and it is in the Minimum Bounding Rectangle of $O_1$, let’s assume that $C_{O1}$ is center point $O_1$, $L_1$ is a line from $C_{O1}$ to $O_2$, $L_2$ is the horizontal line of the $C_{O1}$, $\theta$ is the angle of the line $L_1$ and the line $L_2$. Split point, which is intersection-point such as $a,b,c,d,e,f,g,h$ between the extension line starting from $C_{O1}$ and passing through the dividing point $(1/3)$ of the central region boundary and each direction line and intersection-point such as $i,j,k,l$ between directional lines, it is shown in figure 4.

Figure 4. The direction relation matrix model of point entity and area entity

The fuzzy membership function, of which is direction relation calculation of $O_2$ relative to $O_1$, it is shown in formulary (6).
Step3. Both of $O_1$ and $O_2$ aren’t points, according to the above method of direction relation matrix, the Minimum Bounding Rectangle of $O_1$ is obtained firstly, $MBR(O_1)$ is the minimum boundary directional region of entity $O_1$, it is shown in figure 2. The percentage is calculated, which is the area that $O_2$ intersects with the nine spatial sub-regions of $O_1$ divided by the area of $O_2$. If $O_2$ accounts for the largest proportion of the Minimum Bounding Rectangle of $O_1$, according to the above formula 6 to calculate the percentage of $O_2$ and each internal direction relation region as the membership degree of fuzzy direction relation respectively. If $O_2$ accounts for the smallest proportion of the Minimum Bounding Rectangle of $O_1$, the percentage of $O_2$ and each exterior direction relation regions is calculated and compose a fuzzy direction relation matrix. According to the fuzzy membership degree, the fuzzy direction relation $O_2$ relative to $O_1$ can be judged. Let’s assume that $dir_j$ is any one of eight directional regions, among them $dir_j \in \{area(NW_{O_1}), area(N_{O_1}), area(NE_{O_1}), area(E_{O_1}), area(SE_{O_1}), area(S_{O_1}), area(SW_{O_1}), area(W_{O_1})\}$, $1 \leq j \leq 8$, and the fuzzy membership function is shown in formula (7).

$$
\mu(O_1,O_2) = \begin{cases} 
\mu_{taper-dir}(O_1 \cdot cen, O_2 \cdot cen), (MBR(O1) \cap O_2) \geq (dir_j \cap O_2) \\
\mu_{mbr-l}(O_1,O_2), \text{others}
\end{cases}
$$

5. Conclusion

Environmental protection has gradually received widespread attention. The combination of GIS technology and environmental protection has become a major trend in environmental management, the application of GIS in environmental protection in order to improve the level of environmental protection and create a good ecological environment [11]. This paper proposes a modelling method of combining the cone-shaped direction relation model with the direction relation matrix to determine the fuzzy direction relations between spatial entities on the basis of the cone-shaped direction relation model and direction relation matrix in Environmental Protection Geographic Information System, and a fuzzy formal description model is given by taking point entity and area entity as research objects. The analysis shows that the direction relation reasoning model can effectively judge direction relations between uncertain spatial pollution sources. The author will further research more complex geographic phenomena of existing many different geographic features in an area entity and fuzzy direction relations by experiment.
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