Predicting Rainfall of Agricultural Land by Applying Space Reasoning

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Abstract
Agriculture is the fundamental guarantee of other industries, and rainfall plays a very important role in agricultural development. Therefore, it is essential to use space reasoning to predict agricultural rainfall. Treat agricultural land as a region. In this article, we extend the 9-intersection matrix to 27-intersection matrix on the basis of RCC8 relations, propose a representation model between two disjoint regions and a simple region. We give the algorithm, get 31 kinds of topological relations between two disjoint regions and a simple region by specific procedure, and give schematic diagram of the 31 kinds of topological relations, verify 31 kinds of topological relations are achievable. In order to further research the topological relations between two disjoint regions and a simple region. In this article, we have completed the reasoning for topological relations between two disjoint regions and a simple region, and given the conceptual neighborhood graph. Through the representation model of topological relations established in this article, we can predict the rainfall situation on agricultural land, and give the probability of rainfall in different regions.

Key words: Agricultural Land, Spatial Topological Relations, RCC8, Intersection Matrix, Rainfall Forecast

1. Introduction
Spatial reasoning is the use of space theory and artificial intelligence techniques to modeling, describe and represent spatial objects, and is a subject that conducts the qualitative or quantitative analysis and processing for the spatial relations between spatial objects. It has comprehensive applications in the geographic information system (GIS) [1-3], the image database [4], pattern recognition, robot navigation [5, 6], and space database. For typhoons and rainfall forecasting, spatial reasoning also has comprehensive applications. China is a country that is most severely affected by tropical cyclones in the world, evenly 7 to 8 typhoons land each year. In the study of tropical cyclones [7, 8], track forecast of tropical cyclones made some progress, but the forecast for some unusual path still is not ideal. That rainfall associated with typhoons will cause great harm to crops.

In this article we specifically proposed a representation model between two disjoint regions and a simple region, this model is applied to predict the disaster-affected for two designated areas. That helps to improve the rainfall early warning and disaster assessment mechanism, has a guiding significance for the establishment of disaster prevention and early warning mechanisms to reduce disaster losses and casualties [9, 10].

2. The Representations Model between Two Disjoint Regions and a Simple Region
2.1. 9-Intersection Model
In 1991, Egenhofer et al. constructed 4-intersection model, as follows gave 4-intersection matrix, here \( A^0 \) means the interior of A and \( \alpha A \) means the boundary of A. Then we can get 16 spatial topological relations
Based on the 4-intersection model, the complement $A^c$ of region $A$ is regarded as the exterior of region $A$, we extended the 4-intersection matrix to 9-intersection matrix, as follows:

\[
\begin{pmatrix}
A^c 
& A^c \cap B 
& A^c \cap B^c 
& A \cap B 
& A \cap B^c 
& A^c \cap B \cap C 
& A \cap B \cap C 
& A^c \cap B \cap C 
& A \cap B \cap C 
\end{pmatrix}
\]

When considering objectives in the real world, we obtain 8 topological relations corresponding to above RCC8 relations. They are disjoint; meet; overlap; covered by; inside; equal; covers; contains, as shown in Figure 1:

**Figure 1.** 9-intersection model and 8 topological relations

2.2. The 27-intersection Model between Two Disjoint Regions and A Simple Region

Based on 9-intersection model, space region is divided into nine sections, as shown in Figure 2:

**Figure 2.** 9 parts of the space is divided

Similarly, three regions of $A$, $B$, $C$ can divide the space into 27 parts, in other word, we can get 27-intersection matrix, as follows:

\[
\begin{pmatrix}
A^c \cap B \cap C 
& A^c \cap B \cap C 
& A \cap B \cap C 
& A \cap B \cap C 
& A \cap B \cap C 
& A \cap B \cap C 
& A \cap B \cap C 
& A \cap B \cap C 
& A \cap B \cap C 
\end{pmatrix}
\]

Denote $A_0 = A^c$, $A_2 = \partial A$, $A_3 = A^c$, $A_0 = A^c$.

Order $M_{ij} = A_i \cap B_j \cap C_k$, $i,j,k = 0, 1, \ldots, 2$

Then above 27-intersection matrix can be regarded as $M$. 

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Definition 1: For region A, define \( s(A) = \begin{cases} 1 & \text{if } A \text{ is not empty} \\ 0 & \text{if } A \text{ is empty} \end{cases} \). Then \( M \) is regarded as \( M_{n} \).

\[ M = \begin{pmatrix}
M_{n11} & M_{n12} & \cdots & M_{n1n} \\
M_{n21} & M_{n22} & \cdots & M_{n2n} \\
\vdots & \vdots & \ddots & \vdots \\
M_{nn1} & M_{nn2} & \cdots & M_{nnp} \\
\end{pmatrix} \]

So we can represent the topological relations between two disjoint regions and a simple region by a 0-1 matrix.

2.3. Properties of 27-Intersection Model between Two Disjoint Regions and a Simple Region

Definition 2: We define an operation \( \lor \) on the set \( \{0, 1\} \), Table 1 below:

| \( \lor \) | 0 | 1 \\
|---|---|---|
| 0 | 0 | 1 \\
| 1 | 1 | 1 \\

For any \( m \times n \) 0-1 matrices \( A = (a_{ij})_{m \times n} \) and \( B = (b_{ij})_{m \times n} \), we define \( A \lor B = (c_{ij})_{m \times n} \). So we can get \( s(A \lor B) = s(A) \lor s(B) \). Order RCC8 to \( \Omega \), among

\[ \Omega = \begin{pmatrix}
0 & 0 & 1 \\
0 & 0 & 1 \\
1 & 1 & 1 \\
1 & 0 & 0 \\
1 & 0 & 0 \\
0 & 0 & 1 \\
\end{pmatrix} \]

For any two simple regions \( X \) and \( Y \), the corresponding matrix of their topological relations must belong to the set \( \Omega \), so we can get theorem 1:

Theorem 1: Two disjoint regions \( A \) and \( B \), and a simple region \( C \), corresponding relations between any two matrices must satisfy the following formula:

\[ \begin{pmatrix}
\frac{1}{2} \cdot s(M_{111}) & \frac{1}{2} \cdot s(M_{112}) & \frac{1}{2} \cdot s(M_{121}) \\
\frac{1}{2} \cdot s(M_{112}) & \frac{1}{2} \cdot s(M_{122}) & \frac{1}{2} \cdot s(M_{212}) \\
\frac{1}{2} \cdot s(M_{211}) & \frac{1}{2} \cdot s(M_{212}) & \frac{1}{2} \cdot s(M_{222}) \\
\end{pmatrix} = \begin{pmatrix}
A \cap B \cap C & A \cap B \cap C & A \cap B \cap C & A \cap B \cap C \\
\partial A \cap B \cap C & \partial A \cap B \cap C & \partial A \cap B \cap C & \partial A \cap B \cap C \\
A \cap B \cap C & A \cap B \cap C & A \cap B \cap C & A \cap B \cap C \\
\end{pmatrix} \in \Omega, \]

Here \( s(M_{111}) = s(M_{111}) \lor s(M_{112}) \lor s(M_{121}) \lor s(M_{122}) \lor s(M_{211}) \lor s(M_{212}) \lor s(M_{221}) \lor s(M_{222}) \lor s(M_{222}) \lor s(M_{222}) \lor s(M_{222}) \lor s(M_{222}) \lor s(M_{222}) \).
Since the intersection of two sets is either empty or nonempty, we can obtain the following theorem.

Theorem 2: The topological relations between two disjoint regions and a simple region given by 27-intersections model are exclusive and complete.

2.4. Constraints of 27-intersection Model between Two Disjoint Regions and a Simple Region

Theorem 1 gives a necessary condition to a 0-1 matrix corresponding to a topological relation. Therefore is not a 0-1 matrix can represent a topological relation, some 0-1 matrix cannot be achieved. Now we add constraints to get topological relations that can achieve.

Restricted condition 1: A 0-1 matrix corresponding to an achievable topological relation must satisfy the three formulas.

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

Restricted condition 2: For simple bounded regions, \( A^+ \cap B^- \cap C^- \) must be nonempty, i.e. \( m_{222} = 1 \).

Restricted condition 3: The regions A and B are disjoint, so we can get the following expression:

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

According to the above three constraints, we can give specific algorithm, and then get the topology diagram.

2.5. Schematic Diagram of Topological Relations between Two Disjoint Regions and a Simple Region

The main idea of algorithm:

(1) Each cube is given in the form of row vector \([a_1, a_2, \ldots, a_{27}]\), then we can obtain \(2^7 \) 0-1 cubes in theory, that is a matrix A of \(2^7\) row vectors;

(2) Scan the matrix A row by row and sign all of the row vectors of A satisfying all the restricted conditions;

(3) Save all of the row vectors of A satisfying restricted conditions to matrix B and output the results.

31 0-1 matrices were gotten through the program, according to the 31 kinds of topological relations matrix, we specifically draw this 31 schematic diagram of topological relations, as shown in Figure 3(Specifically we give the corresponding topological relations and the corresponding matrix), verified 32 0-1 matrices can uniquely correspond to the topological relations between two disjoint regions and a simple region.
3. The Reasoning of Topological Relations

We specially give the schematic diagram of the 31 kinds of topological relations between two disjoint regions and a simple region in 2.5; now complete the reasoning of topological relations [11]. Representing the topological relations between region A and region B by using $R(A, B)$, similarly representing the topological relations between region A and region C by using $R(A, C)$, and representing the topological relations between
region B and region C by using R (B, C). By the study of topological relations, the reasoning table of topological relations can be gotten, as shown in Table 2. Through this table if we know a topological relation, we will simply be reasoning unknown topological relations.

<table>
<thead>
<tr>
<th>R(A,B)</th>
<th>R(A,C)</th>
<th>R(B,C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>disjoint</td>
<td>disjoint meet overlap covered By inside equal covers contains</td>
<td></td>
</tr>
<tr>
<td>meet</td>
<td>disjoint meet overlap covered By inside</td>
<td></td>
</tr>
<tr>
<td>overlap</td>
<td>disjoint meet overlap covered By inside</td>
<td></td>
</tr>
<tr>
<td>covered by</td>
<td>disjoint meet overlap covered By inside</td>
<td></td>
</tr>
<tr>
<td>inside</td>
<td>disjoint meet overlap covered By inside</td>
<td></td>
</tr>
<tr>
<td>equal</td>
<td>disjoint</td>
<td></td>
</tr>
<tr>
<td>covers</td>
<td>disjoint</td>
<td></td>
</tr>
<tr>
<td>contains</td>
<td>disjoint</td>
<td></td>
</tr>
</tbody>
</table>

### 4. The Conceptual Neighborhood Graph Between Two Disjoint Regions and A Simple Region

This section the conceptual neighbourhood graph of 31 topological relations between two disjoint regions and a simple region is given, as shown in Figure 4, using the straight line connected two circle represents two topological relations between by step into each other. The digital serial number corresponding to the circle is a schematic diagram of topological relations in Figure 3.

![Figure 4. The conceptual neighborhood graph of 27-intersection model](image)

### 5. Application

#### 5.1. Two Disjoint Areas and Rainfall Area are Abstractly Considered as Two Disjoint Regions and a Simple Region

The region to be studied in this article is shown in Figure 5, we study the possible rainfall situation in Hengchun and Taipei, Hengchun is regarded as the region A, Taipei is regarded as the region B, rainfall region is regarded as region C. Therefore, the problem is converted to study the topological relations between the two disjoint regions A, B and a simple region C.

![Figure 5. The regional map](image)
5.2. Affected Probability of the Target Region

Based on 5.1 content, we see that the topological relations between rainfall region and two specified disjoint target region and 31 kinds of topological relations are a one-to-one correspondence. Notice, to adapt to the uncertainty of typhoon landing, we stipulate that the rainfall situation associated with typhoons is completely natural and random, so we think that the probability of occurrence of 31 kinds of topological relations between two disjoint areas and rainfall area is equal, namely the probability of each situation is 1/31.

To region B, for example, we study the situation which region B is influenced by the rainfall [12], accordingly region A is similar. By the study of schematic diagram of the topological relations, we found that when the topological relations of region B and region C is disjoint, meet, region B is not affected by the rainfall, according to Table 2, there are 13 kinds of situations both cases occurs, respectively, corresponding to the number 1, 2, 9, 10, 14, 15, 16, 20, 21, 25, 26, 27, 28 of the Figure 3, so the probability is 41.93%.

When the topological relation of region B and region C is contains, covers, overlap, region B is partly affected by the rainfall, according to Table 2, there are 7 kinds of situations three cases occurs, respectively, corresponding to the number 6, 7, 8, 13, 19, 24, 31 of the Figure 3, so the probability is 22.58%.

When the topological relation of region B and region C is inside, coveredBy, equal, region B is perfectly affected by the rainfall, according to Table 2, there are 11 kinds of situations three cases occurs, respectively, corresponding to the number 3, 4, 5, 11, 12, 17, 18, 22, 23, 29,30 of the Figure 3, so the probability is 35.48%.

It is worth noting that, when the specified target region is not affected by rainfall area, does not mean that the residents of the specified target region cannot take protective measures. It is different that the topological relations of region B, C is disjoint and the topological relations of region B, C is meet, as shown in Figure 6, (a) Figure corresponds to the schematic diagram of number 1of Figure 3, (b) Figure corresponds to the schematic diagram of number 2of Figure 3. Although two schematic diagrams of topological relations represent that the specified target region is not affected by rainfall, but they are very different in essence. When the situation which corresponds to (a) Figure happens, the residents of the designated target region cannot take protective measures. According to the conceptual neighborhood graph, we can find that (a) Figure can be transformed to (b) Figure; target region still is not affected by rainfall. However, when the situation which corresponds to (b) Figure happens, the residents of the designated target region must take protective measures to reduce property damage.

5.3. Predict the Rainfall Situation by the Reasoning Table of the Topological Relations and the Conceptual Neighborhood Graph

According to the reasoning table of the topological relations, we can predict the possible rainfall situation. When we know the possible rainfall situation of an area, we can study the possible rainfall situation of the other area. For example, when we know R(A, B)=disjoint and R(A,C)=overlap, then R(B,C) can be obtained ,they are disjoint, meet, overlap, coveredBy, inside.

According to the conceptual neighbourhood graph, we can further study the rainfall situation, namely when we know the rainfall situation of an area, we can study further rainfall situation. For example, when we know that the situation corresponding to the number 25 of figure 3 happen, namely contains(A,B), disjoint(A,C), then the next rainfall situation corresponds to the number 26 of figure 3,namely covers(A,B),disjoint(A,C).

6. Conclusions

In this article, we established a representation model between two disjoint regions and a simple region, got schematic diagram of the 31 kinds of topological relations between two disjoint regions and a simple region, and specially gave the reasoning table of the topological relations and the conceptual neighbourhood graph between two disjoint regions and a simple region. This specific theory is applied to predict the rainfall of two disjoint areas, we got the rainfall probability of a specific area, and we can predict the rainfall situation by reasoning.
table and conceptual neighborhood graph of topological relations, to facilitate the residents to take further prevention measures, is of great significance for reducing disaster losses.

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References