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Research on the Dynamic Complex Spatial Network Relations in Spatial Database

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Abstract

Representation and analysis of the complex spatial network relations are of great significance in fields such as Geographic Information System, spatial database, spatial data mining and intelligent inference. As the existing research achievements cannot be used to deal with the dynamic complex spatial network relations effectively in reality, in order to make up for the deficiency of existing methods, the dynamic complex spatial network relations is studied in detail. The predicate representation methods of the strict and extended complex spatial network relations are proposed respectively. The dynamic logical hierarchical relationship and dynamic migration relationship of the strict spatial network relation are given. Furthermore, this paper lay emphasis on the study of the dynamic conversion and adjacent relevance of the extended complex spatial network, and some instance analyses are provided. The research achievements in this paper is rather suitable for dealing with issues about the representation, error correction and forecast of the dynamic complex spatial network relations, therefore, the ability of spatial database to deal with spatial relations of complex spatial object has been enhanced.

Keywords*: Spatial Database; Spatial Network; Network Relations; Representation of the Predication*

1. Introduction

As a vital aspect of spatial relations, the representing and reasoning technology has played crucial roles in many fields, such as spatial database, geographic information system, image processing, robot intelligence, data mining and spatial reasoning. The description and expression of complete and formal spatial relation semantics is the key to design spatial query language, the prerequisite to achieve effective spatial query and the basis of spatial analysis. It will directly affect the amount of information and validity of the spatial analysis. The basic task of spatial topological relation is to distinct different spatial topological relations with mathematical and logical method, give its formal description, and provide theoretical and technical basis for the construction of spatial query language and spatial analysis.

Thanks to the deeply study on the spatial topological relation made by both domestic and foreign, a series of research accomplishments has been achieved. For example, concerning the definite topology relations studies, many significant methods, including regional connection method, point set topology method, topology-metric parameter method, 2D-string, Voronoi and generalized cross model expression method have been put forward. In accordance with the uncertain topological relations, methods including the extension of exact relational model (extensions such as RCC model and nine delivery models), three valued logic, fuzzy sets and rough sets, *etc.* have been proposed. In recent years, as demands of practical application increasing, researches have been further extended to the topological relationship between regions with holes [2,3], qualitative

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spatial relation model used to deal with spatial information in commonsense [4], convex hull topological relation based on order [5], the conceptual neighborhood graphs of regional relation [6], query based on spatial relations [7], extended egg-yolk model of indeterminate regions [8], complex fuzzy spatial relations [9-11], and Vague regional relations [12-15], *etc.*

The existed research achievements that aimed at spatial topological relations cannot deal with complex spatial relations between spatial networks (referred to spatial network relation) as they are mainly concentrated on representing and reasoning spatial point object, line object and spatial relations of regional object. According to these problems above, the spatial network relation have been analyzed, the representation method and the condition for the establishment of spatial network relation are given, the reasoning method of spatial network relationship have been systematically studied, therefore, rules of reasoning repulsion and implication are proposed in the literature [16]. However, as the literature [16] has never analyzed the complex dynamic spatial network relations, once the spatial network is dynamically changed (such as position changes, the nodes and edges increase or decrease), the dynamic tendency of spatial network relation cannot be described or predicted precisely. In order to make up for the deficiency of the literature [16], this paper take advantage of the characteristics and establishment conditions of spatial network relation to divide the complex dynamic spatial network relation into strict type and extended type for discussion. The predicate methods for the two kinds of complex networks have been given respectively, the dynamic logic hierarchical relation and dynamic transfer relation of the strict spatial network relation have been studied. The transformation and relevance of the extended complex dynamic spatial network relation are further studied in this paper.

2. The Basic Definition

Definition 1 (Complex spatial network partitioning) [16] suppose there is a complex spatial network *CN*, as shown in Figure 1. The *CN* is consisted of the edge of network boundary CNL_b, the node of network boundary CNV_b, edge of inner network CNL_c and the node of inner network CNV_c. CNL_b, CNV_b, CNL_c and CNV_c constitute a partition of the complex network *CN*. CNL_b, CNV_b, CNL_c and CNV_c are described as the sub-region of *CN*. The network region is composed of CNL_b, CNV_b, CNL_c, CNV_c and network hole *CNH*. CNL_b, CNV_b, CNL_c, CNV_c combined with *CNH* constitutes a partition of *CNR*. CNL_b,CNV_b, CNL_c, *CNV* and *CNH* are called the sub-region of *CNR*. Unless special explaination, points of network region *CNR* will be recorded as *rp* in this paper.

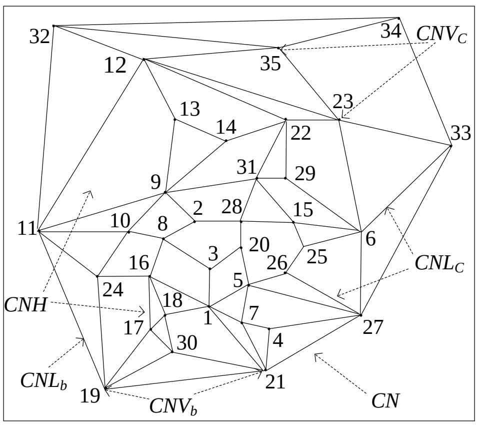


Figure 1. Instance of Complex Spatial Network

In this paper, if there's no special description, characteristics of the studied complex spatial network *CN* are as follows: the boundary of CN has a convex hull property; the three nodes of the network are noncollinear; the network edge can only be intersected at the network nodes; there will always exist a loop whenever any network nodes are passed, that is, there exists a network path $<CNV_i,\ldots,CNV_j,\ldots,CNV_i>, CNV_i \neq CNV_j$; the network node bears no self-loop.

Definition 2(network point set and network element set) [16] data points on the network edge *CNL* and set of the network node *CNV* are called as network point set which is recorded as *CNP* for short. If no distinction, the object points in *CNP* set are recorded as np; the network edge *CNL* and the network node *CNV* in the complex spatial network *CN* are regarded as the basic consisting elements of it. The collection consisted of *CNL* and *CNV* is called as spatial network element set which is recorded as *CNG*, and elements in it are all expressed as ng. Same as this, the network edge *CNL*, the network node *CNV* and the network hole *CNH* could be defined as basic elements of the network region *CNR*.

Definition 3(same quality element and different quality element) [16] according to the two complex spatial network CN_x, CN_y and their corresponded network region CNR_x, CNR_y, the network edge CNL_x and CNL_y , network node CNV_x and CNV_y , network hole CNH_x and CNH_y are described as spatial elements with same quality in the CN_x and CN_y, and the network edge CNL_x and the network node CNV_y , the network node CNV_x and the network hole CNH_y, the network hole CNH_x and the network edge CNL_y are called as spatial elements with different quality in the CN_x and CN_y.

Definition 4(the network atomic spatial relations) suppose the "$\exists$"represents existence,"$\forall$"indicates arbitrary one, "$\neg$"represents negative, and "$\equiv_{\text{def}}$"indicates the definition of it. Then the network atomic spatial relations CNC is defined as follows:

CNC $(CN_x, CN_y) \equiv_{\text{def}} \exists np\ [np \in CNP_x \wedge np \in CNP_y]$

The network atomic spatial relation has three major properties:

(1) $\forall CN_x\ [\text{CNC}(CN_x, CN_x)]$

(2) $\forall CN_x \forall CN_y\ [\text{CNC}(CN_x, CN_y) \rightarrow \text{CNC}\ (CN_y, CN_x)]$

(3) $\forall CN_z\ [\text{CNC}(CN_z\ CN_x) \leftrightarrow \text{CNC}(CN_z\ CN_y)] \rightarrow CN_x = CN_y$

Among them, the property (1) indicates the reflexivity of the network atomic spatial relations; the property (2) illustrates the symmetry of it, that is, there exists network atomic spatial relation CNC between spatial network CN_x and CN_y, also the CNC must be existed between CN_y and CN_x.

Definition 5 (the network region atomic spatial relations)

SRC $(CNR_x, CNR_y) \equiv_{\text{def}} \exists rp\ [rp \in CNR_x \wedge rp \in CNR_y]$

3. The Dynamic Strict Complex Spatial Network Relations

In order to make a qualitative representation and classification of complex spatial network relations, this article takes advantage of predicate representation method to define the spatial network relations. This method could strictly define and classify the spatial network relations. Comparing with the spatial region relations, the spatial network relation is more complex and diverse. The Figure 2 shows the instance of the spatial network relations of the spatial network CN_1,CN_2 and CN_3. The spatial network relation between CN_1 and CN_2 is overlapping and the relation between CN_2 and CN_3 is disjoint.

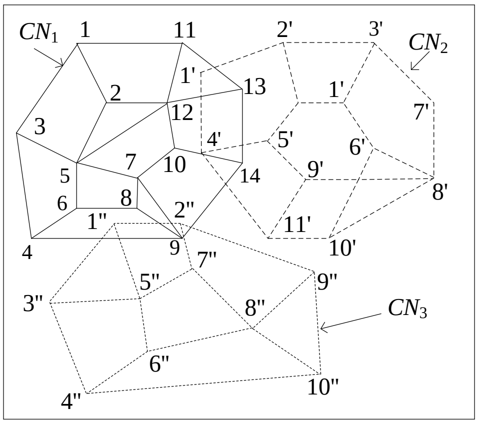


Figure 2. Instance of Spatial Network Relations

In this section, predicate representation of the strict spatial network relations have been provided firstly, and then 8 kinds of strict spatial network relations have been defined in details.

3.1. Representation of the Strict Complex Spatial Network Relations

On the basis of the network atomic spatial relation CNC and the network region atomic spatial relation SRC, taking advantage of predicate formula, this paper has further defined eight types of strict spatial network relations, including: CNDR(network separation), CEQ(network equality), CNOP(network overlapping), CONJ(network connection), CINTP (inner connection of network), CAITP(inner inclusion of network), CINTP^{-1}(network anti-inscribe) and CAITP^{-1} (network anti-inclusion), and so on.

1. $\text{CNP}(CN_x, CN_y) \equiv_{\text{def}} \forall CN_z\,[\text{CNC}(CN_z, CN_x) \rightarrow \text{CNC}(CN_z, CN_y)]$

2. $\text{CNPP}(CN_x, CN_y) \equiv_{\text{def}} \text{CNP}(CN_x, CN_y) \wedge \neg\, \text{CNP}(CN_y, CN_x)$

3. $\text{CNDC}(CN_x, CN_y) \equiv_{\text{def}} \neg\, \text{CNC}(CN_x, CN_y) \wedge \neg\, \text{SRC}(CNR_x, CNR_y)$

The predicate definition of CNDC indicates that in accordance with the definition of CNC and SRC, for the two spatial network CN_x and CN_y, if neither CNC or SRC is tenable, then the CN_x and the CN_y have no common element point, neither do their corresponded network regions CNR_x and CNR_y. Therefore, spatial relations of the spatial network CN_x and CN_y will in a separate station.

4. $\text{CEQ}(CN_x, CN_y) \equiv_{\text{def}} \text{CNP}(CN_x, CN_y) \wedge \text{CNP}(CN_y, CN_x)$

5. $\text{CNO}(CN_x, CN_y) \equiv_{\text{def}} \exists CN_z\,[\text{CNP}(CN_z, CN_x) \wedge \text{CNP}(CN_z, CN_y)]$

6. $\text{CONJ}(CN_x, CN_y) \equiv_{\text{def}} \text{CNC}(CN_x, CN_y) \wedge \neg\, \text{CNO}(CN_x, CN_y)$

7. $\text{CNOP}(CN_x, CN_y) \equiv_{\text{def}} \text{CNO}(CN_x, CN_y) \wedge \neg\, \text{CNP}(CN_x, CN_y) \wedge \neg\, \text{CNP}(CN_y, CN_x)$

8. $\text{CNDR}(CN_x, CN_y) \equiv_{\text{def}} \neg\, \text{CNO}(CN_x, CN_y)$

The predicate representation of CNDC and CNDR show us that the CNDR contains spatial network relation CONJ, and as the CNDC and the CONJ are mutually exclusive, that is these two spatial networks can never possess two kinds of spatial relations CNDC and CONJ at the same time. Thus, it indicates that the classification constraints of CNDC to these two spatial network relations are much stronger than that of CNDR.

9. $\text{CINTP}(CN_x, CN_y) \equiv_{\text{def}} \text{CNPP}(CN_x, CN_y) \wedge \exists CN_z\,[\text{CONJ}(CN_z, CN_x) \wedge \text{CONJ}(CN_z, CN_y)]$

10. CAITP(CN_x, CN_y) $\equiv_{def}$ CNPP(CN_x, CN_y) $\wedge \exists \neg$ CN_z 〔CONJ(CN_z, CN_x) $\wedge$ CONJ(CN_z, CN_y)〕
11. CNP-1(CN_x, CN_y) $\equiv_{def}$ CNP(CN_y, CN_x)
12. CNPP-1(CN_x, CN_y) $\equiv_{def}$ CNPP(CN_y, CN_x)
13. CINTP-1 (CN_x, CN_y) $\equiv_{def}$ CINTP(CN_y, CN_x)
14. CAITP-1 (CN_x, CN_y) $\equiv_{def}$ CAITP(CN_y, CN_x)

The predicate representation of strict spatial network relations indicate that if the spatial network CN_x and CN_y possess some kind of strict spatial network relations, then the respective spatial network sub- region CNL_b,CNV_b,CNL_c and CNV_c of CN_x and CN_y have strict coincidence and non-connection relationship, and the respective network hole region *CNH* of their corresponding network region CNR_x and CNR_y have no common elements with CNL_b、CNV_b、CNL_c and CNV_c which is corresponding with CN_y and CN_x.

3.2. Dynamic Strict Complex Spatial Network Relations

According to the predicate representation of strict spatial network relationship, we can obtain the dynamic logical hierarchical relationship between various strict spatial network relationship whose graph has been presented in Figure 3.

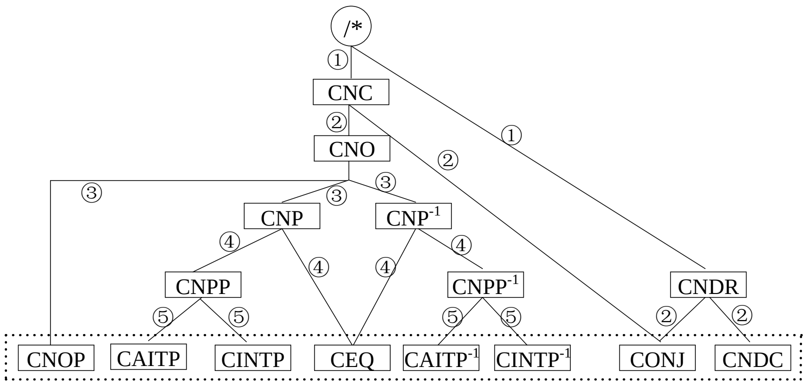
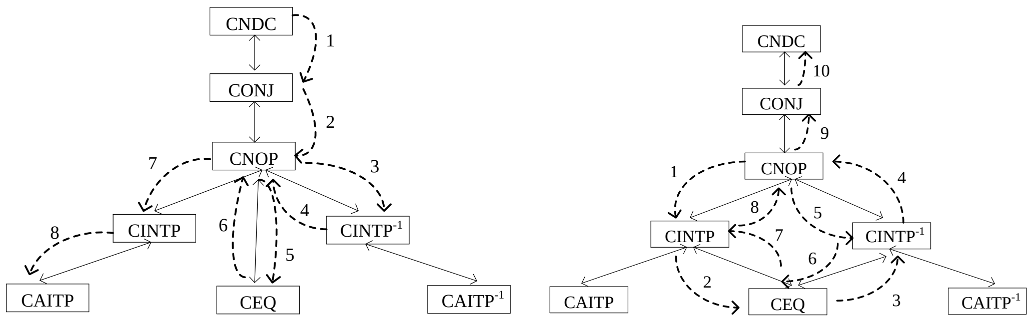


Figure 3. The Dynamic Hierarchical Graph of Complex Strict Spatial Network Relationship

In the Figure 3, "/*"represents the starting sign of hierarchical graph. Compare with spatial network relations of other layers in the Figure 3, these eight types of spatial network relations in the dashed frame have the property of mutual exclusivity and independence of relations. The spatial network relations can be divided in these eight types in accordance with the predicate representation of spatial relations. For instance, if the two spatial network have CONJ relationship, then they will contain CNDR or CNC relationship of the upper level. On the contrary, if the spatial network of the two spatial network is CNDR, then the précised spatial relation might be CONJ or CNDC, but it needs to be further judged and analyzed to ensure the accurate type which it belong. In this paper, relations such as CNDR, CNP, CNPP and CND that are defined by the predicate will be collectively called as intermediate relation.

In reality, as the spatial network will always change dynamically over time (change of position and shape, *etc.*), the corresponding spatial network relationship will also change dynamically. It's an important aspect of the analyzation of dynamic spatial network relation to find and process the continuous sequence set of dynamic spatial network relations. The spatial network relationship which contains continuous sequence of dynamic spatial network relationship has strict order and the adjacent network relationship can migrate dynamically and directly without going through other network relationships. Figure 4 (a, b) presents the dynamic migration graph and spatial network element(network node and edge) of spatial network relationship whose position has been changed respectively. In Figure 4, the spatial network relationship which can transform dynamically and adjacently is connected in two-way arrow directly.



(a) The Dynamic Migration Relationship whose Position Changes (b) The Dynamic Migration Relationship whose Network Element Changes

Figure 4. The Dynamic Migration Graph of Strict Spatial Network Relationship

A series of dynamic migration relationship of strict spatial network relationship can be described and predicted qualitatively by using the dynamic migration graph. For instance, in Figure 4 (a), the dotted line with arrow marked by serial number 1,2,…8 represents a path which is dynamically transformed from CNDC through CONJ and 7 type of continuous adjacent network relation to network relationship CAITP. The corresponding continuous sequence of dynamic spatial network relationship is {CNDC, CONJ, CNOP, CINTP-1, CNOP, CEQ, CNOP, CINTP, CAITP}. If it keeps changing, then the next network relation that can be qualitatively predicted must be CINTP. Figure 4 (b) can be analyzed similarly.

4. Extended Complex Dynamic Spatial Network Relations

4.1. Representation of the Extended Spatial Network Relations

As strict spatial network relations just consider the detail spatial relations of three sub regions which include edges and edges, vertices and vertices, network holes and network holes, their constraint upon spatial network relations are rather stronger. However, in practical application, spatial relations between sub regions of two spatial network are very complex. Thus spatial network relations have become complicated and various. In order to describe complicated and various spatial network relations, extended spatial network predicate representation are further presented in this section. On the basis of strict spatial network relations, extended spatial network relations are further studied and the complex spatial network is classified into 18 kinds.

1. CNP(CN_x, CN_y)

① R_CNP(CN_x, CN_y) $\equiv_{\mathrm{def}} \forall CNR_z$ [SRC (CNR_z, CNR_x) →SRC (CNR_z, CNR_y)] $\wedge \forall ng_x \forall ng_y$ ($ng_x \notin CNG_y \wedge ng_y \notin CNG_x$)

② N_CNP(CN_x, CN_y) $\equiv_{\mathrm{def}} \forall CN_z$ [CNC (CN_z, CN_x) →CNC (CN_z, CN_y)]

③ R_N_CNP(CN_x, CN_y) $\equiv_{\mathrm{def}} \forall CNR_z$ [SRC (CNR_z, CNR_x) →SRC (CNR_z, CNR_y)] $\wedge \exists ng_x \exists ng_y$ ($ng_x \lhd ng_y$

$\vee ng_y \lhd ng_x$] $\wedge \exists CN_z$ [CNC (CN_z, CN_x) $\nrightarrow$ CNC (CN_z, CN_y)]

"⊲" represents region local inclusion.

The detail spatial relations of spatial network which include edge and edge, node and node, network hole and network hole, node and network edge, node and network hole, network edge and network hole need to be analyzed comprehensively by the representation and definition of extended spatial network relations. According to the spatial relations of each sub regions, CNP(CN_x, CN_y) is expanded into three kinds of spatial relations, that N_CNP(CN_x, CN_y), R_CNP(CN_x, CN_y) and R_N_CNP(CN_x, CN_y) included.

2. CNPP(CN_x, CN_y)

① R_CNPP(CN_x, CN_y) $\equiv_{def}$ R_CNP(CN_x, CN_y) $\wedge\neg$ R_CNP(CN_y, CN_x)

② N_CNPP(CN_x, CN_y) $\equiv_{def}$ N_CNP(CN_x, CN_y) $\wedge\neg$ N_CNP(CN_y, CN_x)

③ R_ N_ CNPP(CN_x, CN_y) $\equiv_{def}$ R_N_CNP(CN_x, CN_y) $\wedge\neg$ R_N_CNP(CN_y, CN_x)

3. CNO(CN_x, CN_y)

① R_N_ CNO(CN_x, CN_y) $\equiv_{def}\exists CN_z$〔R_N_CNP(CN_z, CN_x) $\wedge$ R_N_CNP(CN_z, CN_y)〕 $\wedge\neg$ N_ CNO(CN_x, CN_y) $\wedge\neg$ R_ CNO(CN_x, CN_y)

② R_ CNO(CN_x, CN_y) $\equiv_{def}\exists CN_z$〔R_CNP(CN_z, CN_x) $\wedge$ R_CNP(CN_z, CN_y)〕 $\wedge\forall CN_e$〔N_CNP(CN_e, CN_x) $\wedge\neg$ N_CNP(CN_e, CN_y) $\wedge\neg$ R_N_CNP(CN_e, CN_y)〕 $\forall CN_d$〔N_CNP(CN_d, CN_y) $\wedge\neg$ N_CNP(CN_d, CN_x) $\wedge\neg$ R_N_CNP(CN_d, CN_x)〕

③ N_ CNO(CN_x, CN_y) $\equiv_{def}\exists CN_z$〔N_CNP(CN_z, CN_x) $\wedge$ N_CNP(CN_z, CN_y)〕 $\wedge\neg\exists CN_e$ {〔N_CNP(CN_e, CN_x) $\wedge\neg$ N_CNP(CN_e, CN_y)〕 $\vee$ 〔$\neg$ N_CNP(CN_e, CN_x) $\wedge$ N_CNP(CN_e, CN_y)〕}

CNP, CNPP and CNO above is the basis of the following eighteen kinds of spatial network. Similar to the 3.2 section, it is an intermediate relation and bears inclusive rather than exclusive property with those 18 types spatial network relations.

4. CNOP(CN_x, CN_y)

① R_N_CNOP(CN_x, CN_y) $\equiv_{def}$ R_ N_CNO(CN_x, CN_y) $\wedge\neg$ R_N_CNP(CN_x, CN_y) $\wedge\neg$ R_N_CNP(CN_y, CN_x)

② N_CNOP(CN_x, CN_y) $\equiv_{def}$ N_ CNO(CN_x, CN_y) $\wedge\neg$ N_CNP(CN_x, CN_y) $\wedge\neg$ N_CNP(CN_y, CN_x)

③ R_CNOP(CN_x, CN_y) $\equiv_{def}$ R_ CNO(CN_x, CN_y) $\wedge\neg$ R_CNP(CN_x, CN_y) $\wedge\neg$ R_CNP(CN_y, CN_x)

According to these three kinds of extended spatial network relations of CNOP(CN_x, CN_y), N_CNOP(CN_x, CN_y), R_CNOP (CN_x, CN_y) and R_N_CNOP(CN_x, CN_y) are defined on the basis of the extended spatial network relations of CNO(CN_x, CN_y) and CNP(CN_x, CN_y). The three kinds of extended spatial network relations of CNOP(CN_x, CN_y) have stronger spatial constraint ability compared with that of CNO(CN_x, CN_y).

5. CNDC(CN_x, CN_y)

CNDC(CN_x, CN_y) $\equiv_{def}\neg$ N_CNOP(CN_x, CN_y) $\wedge\neg$ R_CNOP(CN_x, CN_y) $\wedge\neg$ R_N_CNOP(CN_x, CN_y)

6. CONJ(CN_x, CN_y) $\equiv_{def}$ CNC（CN_x, CN_y） $\wedge\neg$ N_ CNO(CN_x, CN_y) $\wedge\neg$ R_ CNO(CN_x, CN_y) $\wedge\neg$ R_N_ CNO(CN_x, CN_y)

7. CINTP(CN_x, CN_y)

① R_ CINTP(CN_x, CN_y) $\equiv_{def}$ R_CNPP(CN_x, CN_y) $\wedge\exists CN_z$〔CONJ(CN_z, CN_x) $\wedge$ CONJ(CN_z, CN_y)〕

② R_ N_ CINTP(CN_x, CN_y) $\equiv_{def}$ R_ N_CNPP(CN_x, CN_y) $\wedge\exists CN_z$〔CONJ(CN_z, CN_x) $\wedge$ CONJ(CN_z, CN_y)〕

③ N_ CINTP(CN_x, CN_y) $\equiv_{def}$ N_CNPP(CN_x, CN_y) $\wedge\exists CN_z$〔CONJ(CN_z, CN_x) $\wedge$ CONJ(CN_z, CN_y)〕

8. CAITP(CN_x, CN_y)

① R_ CAITP(CN_x, CN_y) $\equiv_{def}$ R_CNPP(CN_x, CN_y) $\wedge\neg\exists CN_z$〔CONJ(CN_z, CN_x) $\wedge$ CONJ(CN_z, CN_y)〕

② N_ CAITP(CN_x, CN_y) $\equiv_{def}$ N_CNPP(CN_x, CN_y) ∧┐∃CN_z〔CONJ(CN_z, CN_x) ∧ CONJ(CN_z, CN_y)〕

③ R_ N_ CAITP (CN_x, CN_y) $\equiv_{def}$ R_ N_CNPP(CN_x, CN_y) ∧┐∃CN_z〔CONJ(CN_z, CN_x) ∧ CONJ(CN_z, CN_y)〕

Spatial relations N_CNP^{-1},R_CNP^{-1} and R_N_CNP $^{-1}$ can be defined by N_CNP,R_CNP^{-1} and R_N_CNP $^{-1}$. Relations are defined as follows.

9. N_ CAITP $^{-1}$ (CN_x, CN_y) $\equiv_{def}$ N_ CAITP(CN_y, CN_x)
10. R_ CAITP^{-1} (CN_x, CN_y) $\equiv_{def}$ R_ CAITP(CN_y, CN_x)
11. R_ N_ CAITP^{-1} (CN_x, CN_y) $\equiv_{def}$ R_ N_ CAITP(CN_y, CN_x)
12. R_N_CNP $^{-1}$ (CN_x, CN_y) $\equiv_{def}$ R_N_CNP(CN_y, CN_x)
13. R_CNP^{-1} (CN_x, CN_y) $\equiv_{def}$ R_CNP(CN_y, CN_x)
14. N_CNP^{-1} (CN_x, CN_y) $\equiv_{def}$ N_CNP(CN_y, CN_x)
15. R_CNPP^{-1} (CN_x, CN_y) $\equiv_{def}$ R_CNPP(CN_y, CN_x);
16. N_CNPP $^{-1}$ (CN_x, CN_y) $\equiv_{def}$ N_CNPP(CN_y, CN_x)
17. R_ N_ CNPP $^{-1}$ (CN_x, CN_y) $\equiv_{def}$ R_ N_ CNPP(CN_y, CN_x)
18. R_ CINTP^{-1} (CN_x, CN_y) $\equiv_{def}$ R_ CINTP(CN_y, CN_x)
19. N_ CINTP $^{-1}$ (CN_x, CN_y) $\equiv_{def}$ N_ CINTP(CN_y, CN_x);
20. R_ N_ CINTP $^{-1}$ (CN_x, CN_y) $\equiv_{def}$ R_ N_ CINTP(CN_y, CN_x)
21. CEQ(CN_x, CN_y) $\equiv_{def}$ N_CNP(CN_x,CN_y) ∧ N_CNP(CN_y, CN_x)

As extended CEQ predicate representation is same with strict CEQ predicate representation, so the spatial equivalence relation is unique between these two spatial networks.

4.2. Extended Complex Dynamic Spatial Network Relations

As the structure and location of spatial network could be changed dynamically, therefore, spatial network relations have the ability to transform between each other. In this section, the transformation diagram of extended complex dynamic spatial network relations is given (Figure 5).

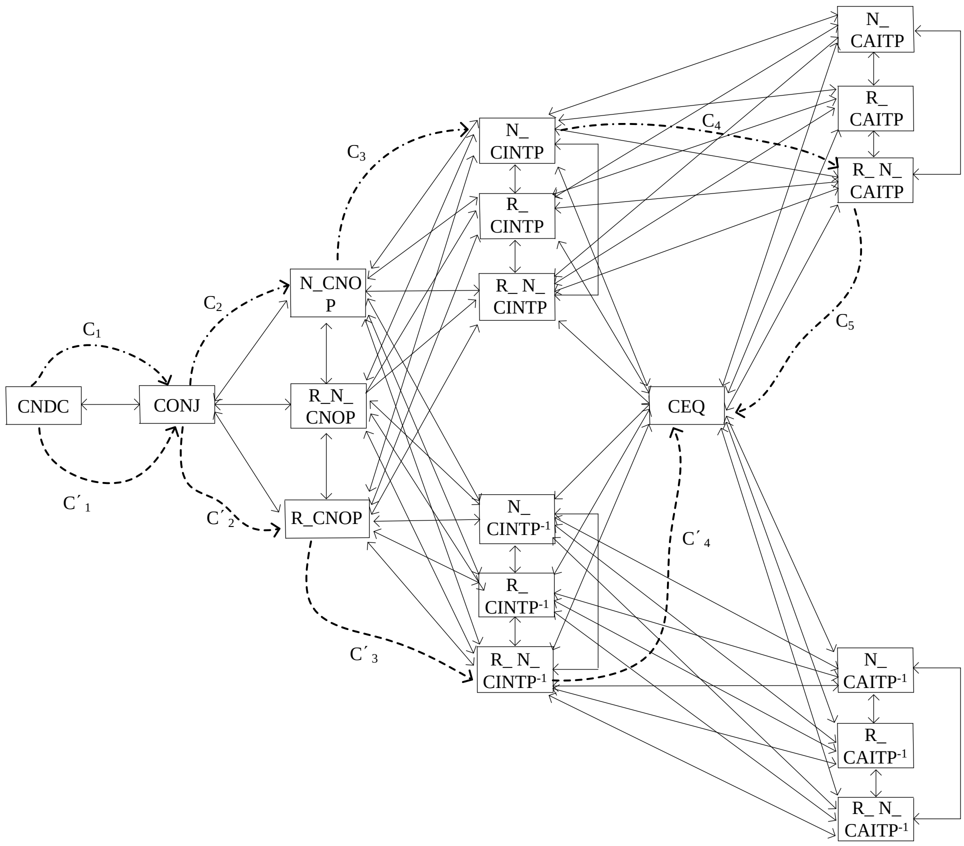


Figure 5. The Transformation Diagram of Extended Complex Dynamic Spatial Network Relations

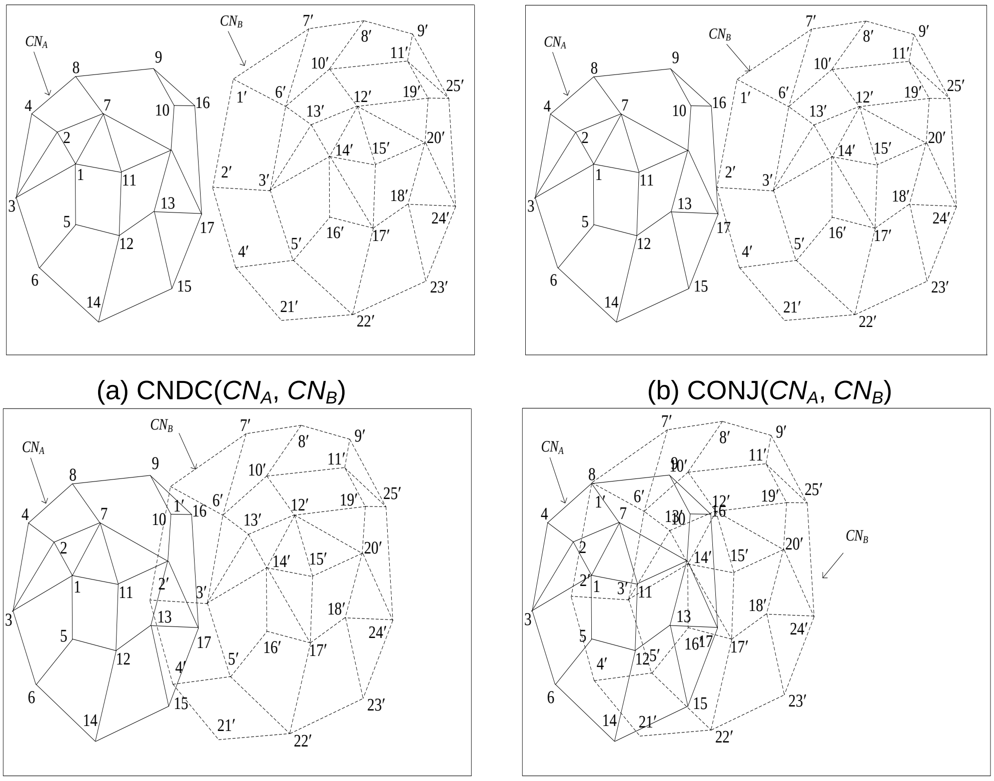
Using the transformation diagram of spatial network relations, when the structure and location of spatial network change dynamically, spatial network relations in the next stage can be predicted and judged. For example, CN_x and CN_y are two spatial network, two spatial network relations trans formation path (as shown in Figure 5) could be obtained in accordance with location, size and structure vary with time. Path <c_1, c_2, c_3, c_4, c_5> shows that spatial network CN_x and CN_y are in a seperate position(CNDC) at the beginning. Then, CN_x moves towards CN_y and after the connection (CONJ) and network overlapping (N_CNOP), it enters into the inner side of CN_y. First, Network(N_CNIP) is incribed in CN_y and regional Network(R_N_CAITP)is contained in CN_y. After being amplified, CN_x has equivalent overlapping relation (CEQ) with CN_y. Path <c_1, c_2, c_3, c_4, c_5> shows that CNx and CNy have been through deviation(CNDC), connection(CONJ) and network overlapping (R_CNOP), after the CN_x is being amplified, CN_y will inscribe (R_N_CINTP^{-1}) with CN_x. After going through variation of reduction, the CN_x finally has the equivalent coincidence relation with CN_y.

Based on the spatial network CN_x and CN_y, in order to manage spatial network relation and make an effective prediction about the approaching spatial relations. The transformation path of spatial network relations will correspond to an information table of spatial network relations. In the information table, there will contain variation informations of network node(including spatial network boundary node CNV_b and spatial network inner node CNV_c), spatial network edge(including edge of network boundary CNL_b and edge of inner network CNL_c), spatial network hole CNH, and spatial movement informations CNx and CNy(including movement direction and velocity)of spatial network every time when spatial relations are transformed. The change of spatial network node, network edge and network hole mainly determines the change of network inner structure. The movement of spatial network mainly determines the location change of spatial network. The change of structure and spatial location make spatial network relations in a position of dynamic change. Using the transformation path of spatial network relations and the path information table, dynamic spatial network relations can be analyzed and processed better.

5. Case Analysis

In practical application, higher requirements are proposed to describe and analysis complex dynamic spatial network relations. Section 2-4 study the complex dynamic spatial network relations in details. Based on the theoretical research, the relevant instance model is further given in this section.

Suppose that two complex spatial network CN_A (Road Network Model) and CN_B (pipeline network model) are in the spatial region, the spatial network relations of CN_A and CN_B at t_1,t_2,t_3 and t_4 moment (t_1,t_2,t_3 and t_4 have order) are as shown in Figure 6. A key point to study the dynamic interaction of *CNB* and *CNB* in spatial network is to determine the dynamic network spatial relation of them. The determination and prediction of dynamic network spatial relations are significant for researching the interaction, mutual restriction, spatial network line multiplexing, *etc.* of spatial network relations.



(a) CNDC(CN_A, CN_B) (b) CONJ(CN_A, CN_B)

(c) R_CNOP(CN_A, CN_B) (d) R_N_CNOP(CN_A, CN_B)

Figure 6. The Example of Spatial Network Relations

Based on the theoretical study of 3,4 section in this paper, the spatial network relations of network spatial relation model at t_1,t_2,t_3 and t_4 moment are CNDC, CONJ, R_CNOP, R_N_CNOP and R_ N_ CAITP in accordance with the information of network edge and vertex of CN_A and CN_B. The predicate representations of spatial relation are:

1) CNDC (CN_A, CN_B) : ¬ N_CNOP (CN_A, CN_B) ∧ ¬ R_CNOP(CN_A, CN_B) ∧ ¬ R_N_CNOP(CN_A, CN_B) ;

2) CONJ(CN_A, CN_B)：CNC(CN_A, CN_B) ∧¬ N_ CNO(CN_A, CN_B) ∧¬ R_ CNO(CN_A, CN_B) ∧ ¬ R_N_ CNO(CN_A, CN_B) ;

3) R_CNOP： R_ CNO(CN_A, CN_B) ∧ ¬ R_CNP(CN_A, CN_B) ∧¬ R_CNP(CN_B, CN_A) ;

4) R_N_CNOP ： R_ N_CNO(CN_A, CN_B) ∧ ¬ R_N_CNP(CN_A, CN_B) ∧ ¬ R_N_CNP(CN_B, CN_A).

Obviously, the spatial network relation of CN_A and CN_B is characterized by changeful from t_1 to t_4 time quantum and its spatial network relation is precise at t_1, t_2, t_3 and t_4 moment. However, on many occasions, the data information is often inaccurate and even missing, thus the dynamic spatial network relations continuous sequence set that obtained is often erroneous. For instance, 5 group of dynamic spatial network relations continuous sequence which are obtained according to the data information of 5 time quantum (10 moments are included in each time quantum) are listed as follows:

L_1={t_1: CNDC, t_2:SONJ, t_3:R_CNOP, t_4:R_CNOP, t_5:CEQ, t_6:R_CAITP, t_7:R_CAITP, t_8:N_CNOP, t_9:R_CINTP, t_{10}:R_CNOP}

L_2={t_1: N_CNOP, t_2:R_N_CNOP, t_3:R_CNOP, t_4:N_CNITP, t_5:N_CAITP, t_6:SEQ, t_7:R_CAITP^{-1}, t_8:SEQ, t_9:R_CINTP, t_{10}: SEQ }

L_3={t_1: R_CINTP, t_2: R_N_CAITP, t_3: R_N_CAITP, t_4:R_CNOP, t_5:CNDC, t_6:SONJ, t_7: R_CNOP, t_8:N_CNOP, t_9: SONJ, t_{10}: CNDC }

L_4={t_1: R_N_CAITP^{-1}, t_2: R_N_CINTP^{-1}, t_3: R_ CNOP, t_4:R_CNOP, t_5: R_N_CNOP, t_6: SONJ, t_7: R_N_CNOP, t_8:N_CINTP, t_9:R_CAITP, t_{10}:SEQ}

L_5={t_1: SONJ, t_2:CNDC, t_3: SONJ, t_4:N_CNOP, t_5: N_CNOP, t_6:N_CINTP^{-1}, t_7:SEQ, t_8:N_CINTP, t_9:R_CINTP, t_{10}: R_CAITP }.

According to the research results in Section 4, the dynamic changes of spatial network relations which is represented by dynamic spatial network relations continuous sequence set L_2, L_4, L_5 is correct. However, the continuity of dynamic changes cannot be shown well due to the deletion and error of spatial network relations in L_1 and L_3. The spatial network relation is R_CNOP at t_4 moment in L_1 and SEQ at t_5 moment. According to the Figure 5, R_CNOP and SEQ cannot be transformed directly, the transformation between them has to through one of the relations in {R_CINTP, N_CINTP, R_N_CINTP, R_CINTP^{-1}, N_CINTP^{-1}, R_N_ CINTP^{-1}} at least. Thus, the following two decision-making situation are obtained:

Situation1. The spatial network relation at moment t_4 or t_5 has error and the information has to be recollected for determination.

Situation2. If the spatial network relations at moment t_4 or t_5 is correct, then a new moment is added between the moment t_4 and t_5 for analyzing in order to seek the new spatial network relations.

Situation 1 is the condition when the existing data information has errors and needs to be revised; Situation 2 is the improper selection of time points leads to the loss of the dynamic spatial network relation, which needs to be complemented. The anomaly in different conditions may finally cause the different corrected result for a continuous sequence of dynamic spatial network relationship. For example, the new sequence sets L_1' and L_1'' after corrected in situation 1 and situation 2 are respectively:

L_1'={t_1:CNDC, t_2:SONJ, t_3:R_CNOP, t_4:N_CINTP, t_5:SEQ, t_6:R_CAITP, t_7:R_CAITP, t_8:N_CNOP, t_9:R_CINTP, t_{10}:R_CNOP}

L_1''={t_1:CNDC, t_2:SONJ, t_3:R_CNOP, t_4:N_CINTP, t':R_N_CNITP, t_5:SEQ, t_6:R_CAITP, t_7:R_CAITP, t_8:N_CNOP, t_9:R_CINTP, t_{10}:R_CNOP}.

In the issue of predicting and judging some complex dynamic spatial network relations, the situation1 and situation2 are always coexist, so comprehensive analysis is necessary. According to the instance, the research results proposed in this paper is suitable for processing some complex dynamic spatial network relations.

6. Conclusion

The existing research achievements of the spacial network are mainly focus on the structure, characteristics and mathematical calculation of the spatial network. Studies on spatial spatial network in the spatial database are mainly focus on the connectivity of spatial network, the spatial network information storage, fields of location, cluster and query of object in spatial network, but it's not suitable for dealing with representing and reasoning issues of complex dynamic spatial network relations.

In order to make up deficiency of the existed method when processing complex dynamic spatial network relations, the complex dynamic spatial network relations have been studied in details in this paper. According to the characteristics and establishing conditions of network relations, complex dynamic spatial network relations are divided into the strict complex dynamic spatial network relations and extended complex dynamic spatial network relations. The predicate method that represents the two types of complex network relations are proposed and the dynamic logical hierarchical relationship and dynamic migration relationship of strict spatial network relation are given. The conversion and adjacent relevance of extended complex dynamic spatial network relations are further studied. Theoretical research and case study shows that using the research results from this paper can analyze and process complex dynamic spatial network relations in a better way. The network relations that change with time will be better predicted. The research results have enhanced the ability of spatial database and geographic information system to process complex spatial relations. Future research focus will be concentrated on the following two points:

1. The representation and reasoning technology of spatial network relations whose nodes is uncertain.

2. The research on complex spatial network relations which is combined with the 3DR44 model.

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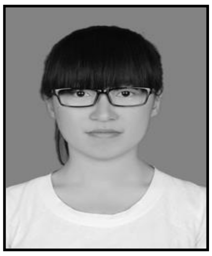

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