COGNITIVE LOGIC REPRESENTATION OF SPATIAL ASSOCIATION RULES OF KNOWLEDGE DISCOVERY FROM GIS DATABASE

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KEY WORDS: Spatial Association Rule, GIS, Cognition, Data Mining, Knowledge Discovery

ABSTRACT:

SDMKD (Spatial Data Mining and Knowledge Discovery) from GIS database is different from the general DMKD (Data Mining and Knowledge Discovery), which is dominated by properties of geographical spatial cognition. And the key to SDMKD from GIS database is how to define and extract the implicit knowledge from GIS database, amongst which spatial association rule is one of the important contents, which is widely concerned with knowledge representation and reasoning. So it is necessary to develop the relation model between the explicit knowledge and the implicit knowledge using some formalization method. In this paper, the cognitive process of SDMKD from GIS is analyzed. And on the basis of the spatial primitive concept guided by the three spatial frameworks and some research by the formers, integrating epistemic logic language and ILP (Inductive Logic Programming), we sum up almost all the possible logic regulations and logic predicates of GIS for mining spatial association rules from GIS database. Finally, the basic framework for mining spatial association rules from GIS database is proposed.

1. INTRUDUCTION

Data Mining and Knowledge Discovery (DMKD) is a hot problem with inter-disciplines. And Spatial Data Mining and Knowledge Discovery (SDMKD), whose main study object is spatial database or spatial data warehousing, is a branch of DMKD. And GIS database is one of the most important spatial databases, where enormous of information or knowledge is hidden. Additionally, GIS database is an abundant and potential resource to the intelligent spatial analysis and knowledge-based GIS. So SDMKD from GIS will heighten the application level of GIS and improve to develop Intelligent GIS (IGIS). However, SDMKD from GIS database is different from the general DMKD. And it is dominated by properties of geographic spatial cognition and geographic cognition. The key to knowledge discovery from GIS database is how to define and extract the implicit knowledge from GIS database, which is widely concerned with representation and reasoning of geographic knowledge. It is necessary to build up the relation model between the explicit knowledge and the implicit knowledge using some formalization methods.

Spatial association rule, one of the implicit knowledge of SDMKD and the important contents of SDMKD, is an implicit rule discovering spatial structure and spatial relationship of geographic phenomena and/or objects, especially adjacency relationship including topological continuity, distance relation, orientation relation and their combinations, etc. And spatial association rule also is one of the important implicit knowledge in GIS database. It can show the hierarchy structures and correlations between different subclasses of spatial data or spatial relationship with the more strict logic relation. Consequently, spatial association rule can be described and represented by cognitive logical language on the basis of geographical spatial cognition and geographic cognition. But now, more attention is paid almost only on two ways, one is how to enhance the algorithmic efficiency and the other is how to discover more rules based on the logical language or similar SQL. And less importance is attended to knowledge definition and formalization description.

Epistemic logic mainly aims to some formalization problems about knowledge and idea. So it can deal with the problems about logical properties and relations of some cognitive concepts on knowledge and idea. And it is one of the key tools discovered by the expert of artificial intelligence and computer scientist. Accordingly, it will enrich and perfect the basic theory and approach of SDMKD from GIS database to apply epistemic logic language and theory to describe and represent the spatial association rules from GIS database. In addition, it will make for the development of Geographic Information Sciences.

2. THE FOUNDATION —GEOGRAPHIC SPATIAL COGNITION

The main object of spatial association rule mining is GIS database. The organization and processing to GIS database transform the reality world into geographical spatial world stored in computer, which passes through the bit world. And all the process is showed in figure 1. Accordingly, SDMKD is a process of abstraction and representation to the real world. And the process of abstracting is the process of cognition to the real world, the process of representation is the process of re-showing the real world using computer theory and technology. Additionally, GIS database stores some tempo-spatial information about geographic phenomena. Consequently, the representation of GIS database contains the corresponding knowledge and contents of spatial cognition to geographic phenomena, which is a token of geographic spatial information and includes apperceive process, idea process, memory process and thinking process. Therefore SDMKD from GIS database is to generalize, abstract and re-process the geographic data stored

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in GIS database and is a process of feedback from the computer world to the real world, also is a process of re-understanding to the geographic spatial world, thereinto the geographical spatial cognition hiding geographic thoughts plays important roles in how to implement SDMKD from GIS. And geographical spatial cognition is a token of geographical spatial information and is a course of logic though processing, which is involved with three kinds of spatial framework (Fabrikant & Buttenfield 2001): (a) geographic space, (b) cognitive space, and (c) Benediktine space, viz. cyberspace. The geographic space places emphasis on shape structure of geographic phenomena and/or objects, including geometric structure, topological structure and dimensional structure. But the cognitive space places emphasis on acquirement and learning of spatial knowledge, and gives prominence to the user's understanding to spatial representation. And Benediktine space places emphasis on the semantics of a phenomenon's properties and the semantics of relationships between phenomena based on the human-computer interaction, permitting associations between motion and semantic content. Additionally, geographic space is a continuous body with spatial homogeneity (Tobler 1970) and spatial heterogeneity (Goodchild, UCGIS 2003). So the absolute and relative locations of geographic phenomena and/or objects change with the time and scale in the tempo-spatial framework. Only the information of geographic phenomena after changing is re-organized, can its property be acquired. With time's elapsing, different geographic phenomena and/or objects gradually extend in space, which is the foundation of spatial autocorrelation. Accordingly, the implicit spatial association rules should be one of the main contents of SDMKD from GIS.

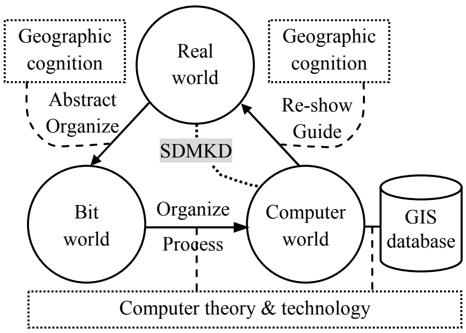


Figure 1. Cognitive process of data mining from GIS database

Knowledge about space is one of the earliest forms of knowledge that humans acquire (Taylor &Tversky 1996, Fabrikant & Buttenfield 2001). And cognitive representation about space is one of the important fields in Geographic Information Science (Montello 2000), which has formed the following cognitive image schemata (Fabrikant & Buttenfield 2001): (1) *container*, which has an interior, an exterior, and a boundary, (2) *Surface*, continuous data are modelled on a surface. Surfaces afford horizontal motion, (3) *near-far*, Features in a scene that are closer to the viewer are perceived to be more prominent than features farther away, (4) *verticality*, Graduated bar graphs, prism maps, and interpolated surface maps communicate the concept of "more is up, and less is down", (5) *path*, flow maps depicting networks envision the "source-destination" concept, (6) *link*, topological views of space describe the connectivity and adjacency of geographic features, (7) *center-periphery*, thiessen polygon maps delineate functional regions. The schemata mentioned above can be described by the following spatial primitive concepts: (1) *identity*, (2) *location*, (3) *direction*, (4) *distance*, (5) *magnitude*, (6) *scale*, (7) *time* or *change*. And the spatial primitive concepts mentioned above are the foundation of representation of spatial relation predicates, which are used to formally describe, represent and help to mine the spatial association rules from GIS database.

3. FORMAL REPRESENTATION

3.1 Some Regulations

It can not fully meet the requirements for the spatial predicate to describe and represent the spatial association rule from GIS database, especially for the representation of *true* or *false* value in course of the rules being engendered if only Inductive Logic Programming (ILP) (Popelinsky 1998, Malerba & Lisi 2001) is used. However, it is just right that epistemic logic (Zhou 2001), which mainly accounts for the problems about formalization of knowledge and idea and deals with the logical properties and logical relations of the cognitive concepts about knowledge and idea, can make up the limitation mentioned above. So, it is certain that the spatial association rule, including the course of the rules being originated, can be described and represented more effectively and more extensively if integrating ILP with epistemic logic. The language model describing the epistemic logic rules is composed of the following:

1. a non- empty-set W of possible world;
2. a dualistic relation R in W, which can be considered as a accessible relationship;
3. a domain function D with a volume domain D_w in each of possible world W;
4. an interpretative function I, which assigns the constant c of each logical language L_a to the entity I(c); and evaluates the n-ary predicate P of each L_a to a sub-sets I_w (P) of $(D_w)^n$ in the each of possible world $w \in W$.

The conjunctions in common use in describing models with epistemic logic contains *and* ($\wedge$), *or* ($\vee$), *not* ($\sim$), *implication* or *condition* ($\Rightarrow$), *bidirectional condition* ($\leftrightarrow$), *equal to* ($=$) and so on. And the quantifiers in common use contain the *universal quantifier* ($\forall$), *existential quantifier* ($\exists$) and so on. The correlative definitions of spatial association rules as follows (Popelinsky 1998, Malerba & Lisi 2001, 2002):

1. Let non-empty-set of possible world in SDMKD be GIS database *SDB*, represented by $G(S)$. Then we denote the object sets in hand S, $S \subset G(S)$. And we denote the concrete object in s, $s \in S$. Subsequently, a corresponding concrete object sets, viz. an observation sets, is defined as $O[s]$. It is given by equation (1) (Malerba & Lisi 2002), $O[s] \subseteq G(S)$. The sets of the total correlative objects in SDMKD is defined as R, and the corresponding i-th sets is marked as R_j, $R_j \subset R$, $R \subset G(S)$. The corresponding task-relevant object is r_i, $r_i \in R_j$, $R_j \subset R$. Finally, let the Background Knowledge be *BK*.
$$O[s] = O[s \mid s] \vee \{O[r_i \mid s] \mid \exists tuple\,\theta \in G(S) : \theta(s, r_i)\}_{1 \le i \le n} \quad (1)$$
where, $O[s|s]$ contains spatial relations between s and some task-relevant object r_i, and $O[r_i|s]$ contains spatial relations between r_i and $s' \in S$.
2. Let $A=\{a_1,a_2,\ldots,a_n\}$ be a set of *atoms*, the linkage between different atoms in A is defined as *atomsets*. The pattern sets L is a group of *atomsets* based on A. The key atom dominates the pattern $P \in L$. To a pattern P we assign an existentially quantified conjunctive formula *eqc*(P) obtained by turning P into a Datalog query. If *eqc*(P) is true in $O[s] \vee BK$, a pattern P covers an observation $O[s]$.
3. Let O be the set of spatial observations in $O(S)$ and O_p denote the subset of O containing the spatial observations

covered by the pattern *P*. The support of *P* is defined as $\sigma(P)=|O_p|/|O|$.

4. The other definitions about spatial association rules, P⇒Q(*s*%, *c*%), the support *s*% and the confidence *c*% can be seen in papers by Malerba & Lisi (2002).

3.2 Rule predicates

Logic predicate is one of the important contents to describe and acquire the spatial association rule in formal. The apodosis rules can be acquired through various equivalent relations performed by predicate logic. Then the deductive inference can be used to figure out the problems. Based on the spatial primitive concepts mentioned in the section 2, we propose the following seven kinds of possible predicates used to describe, represent and help to mine the spatial association rule from GIS database (see table 1):

1. Epistemic modal predicates, including *certain* (□) and *possible* (◇). So P⇒ Q(s%,c%) could be decomposed as follows:
   (1) if *s*=100, then □(P⇒Q), viz. it is *certain* that P⇒Q comes into existence;
   (2) if 0<*s*<100, then ◇(P⇒Q), viz. it is *possible* that P⇒Q perhaps comes into;
2. General tense predicates, including *always in the future* (*G*), *always in the past* (*H*), *perhaps in the future* (*F*), and *ever* (*P*). For example,
   (1) □G(P⇒Q) means it is *certain* for P⇒Q to come into existence *always in the future*;
   (2) ◇G(P⇒Q) means it is *possible* for P⇒Q to come into existence *always in the future*;
3. GIS temporal predicates. Time is one of the important spatial primitive concepts and the formation of spatial association rules of GIS goes with a certain temporal environment, being involved with the temporal topological relations of GIS, including the following (Egenhofer & Golledge 1998): (1) the temporal topology with offset structure, (2) the temporal topology with linear structure, and (3) the temporal topology with circle structure. The three relations may be represented by the following temporal predicates: *before*/*after*, *equal*, *start*/*finish*, *meet*, *overlap*, *end*, *during*.
4. GIS spatial predicates. Location, direction and distance are three of the spatial primitive concepts, also the most important components to describe, represent and acquire the spatial association rule from GIS database. Accordingly, GIS spatial predicates are divided into three classes: (1) topology predicates, (2) direction predicates, and (3) distance predicates, the detailed can be seen in table 1.
5. Correlation predicates between point, line and region, viz. predicates representing spatial relations between point objects, line objects and region objects, denoted by the following: *point-to-line*, *point-to-region*, *line-to-line*, *line-to-region*, and *region-to-region*.
6. Systematic and classified predicates, such as *is_a*.
7. Others.

For example 1, if a road crosses a river, then it is possible to have a bridge over the river, which can be represented in logic by the predicates mentioned above:

◇ (*is_a*(X,road) ∧ *is_a*(Y,river) ∧ *to-intersect*(X,Y)⇒bridge) = true

For example 2, if a mountain exits along the Yangtze River, then it is not feasible to build up a large dock, which can be represented in logic by the predicates mentioned above:

is_a(X, hill)∧*close_to*(X, Yangtze River)∨*is_a*(Y, mountain) ∧*close_to*(Y, Yangtze River) ⇒ ~*is_a*(Z, large_dock)

4. THE BASIC FRAMEWORK

Mining spatial association rule from GIS database is different from the general relation data mining and is a problem of multi-level and multi-relational spatial data mining. And it deals with computation of spatial relationship, which is tightly concerned with the data structure and storage mode of GIS database. So the basic framework for mining spatial association rules from GIS should fully take into account the characteristics of GIS storage and data processing. We use *Apriori* algorithm for reference to propose an approach framework named by *reference-feature-centric multi-level and multi-relational spatial association rules mining* on the basis of the formers' correlative researches (Agrawal et al. 1993, Dzeroski 1996, Mannila 1997, Dehaspe & De Raedt 1997, Popelinsky 1998, Han & Fu 1999, Malerba & Lisi 2001a, 2001b, Malerba et al. 2002). The procedure can be seen in Figure 2 and described as follows:

- To determine the mining task and build up *GIS database* according with the corresponding requirements and requests in data structure, etc.
- To extract the correlative layers from the *GIS database* to develop a *temporal database* directly servicing the task
- to store the spatial relations denoted by spatial predicates into the *deductive database*, which can be acquired by the spatial searching and computation but should be linked with the standard *predicate database*
- to develop the *multi-level database* by a multi-level decision tree searching algorithm based on the *prior knowledge database* to store the multi-level spatial decision tree serving for spatial association rules mining at different level
- to link the spatial predicates to object attributes by key words and store the linkage into the *multi-relational database*
- to use some algorithm such as *Apriori* to mine some frequent spatial association rules based on the *prior knowledge database*, which may be stored into the *rule database*
- to filter out to leave some creditable and useful spatial association rules

One of the important advances mentioned above is able to add the spatial predicates into the *Spatial Join Index* (SJI) proposed by Valduriez (1987) and Zeitouni et al. (2000), which can be named by *Spatial Join Index for Predicates* (SJI-P) in this papaer. And the computation and storage of the spatial predicates make the spatial relationships of different objects be represented in non-spatial formal. Then they can be stored in the general relation database. So the framework transforms the problem about spatial association rule mining from GIS database into the problem about general association rules mining from the general relation database, which is in the field of data mining from multi-relational tables. Consequently, the complex problem is simplified and then can be dealt with integrating the general and existing methods. And the key of this framework is to construct the spatial predicates mentioned in the section 3 and table 1.

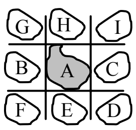
	Predicate operators	For instance	Explanation	Meaning	Value-range
Epistemic modal predicates	*Certain* (□)	□ ϕ ⇒ ψ	ϕ : an event	If it is *certain* that ϕ happens, then ψ happens	
	Possible (◇)	◇□ ϕ ⇒ ψ	ψ :another event	If it is *possible* ϕ certainly happens, ψ happens	
General tense predicates	*Always in the future* (*G*)	*G*q	q denotes the event "there exits a bridge over the Yangtze River"	There will exit a bridge *always in the future*	{T, F}
	Always in the past (*H*)	*H*q		There exited a bridge *always in the past*	{T, F}
	Possible in the future (*F*)	*F*q		There will *possibly* exit a bridge *in the futre*	{T, F}
	Ever (*P*)	*P*q		There *ever* exited a bridge	{T, F}
GIS temporal predicates	*ti-before*	*ti-before*(ϕ , ψ)		ϕ happened before ψ	{T, F}
	ti-after	*ti-after*(ϕ , ψ)		ϕ happened after ψ	{T, F}
	ti-equal	*ti-equal*(ϕ , ψ)		The durative time is equal between ϕ and ψ	{T, F}
	ti-start	*ti-start* (ϕ , ψ)		Φ and ψ starts at the same time	{T, F}
	ti-meet	*ti-meet* (ϕ , ψ)		ψ happened as soon as ϕ finished	{T, F}
	ti-overlap	*ti-overlap* (ϕ , ψ)		Ψ happened but ϕ didn't finish	{T, F}
	ti-end	*ti-end* (ϕ , ψ)		Φ and ψ finished at the same time	{T, F}
	ti-during	*ti-during* (ϕ , ψ)		Ψ has finished in one life period when ϕ is being	{T, F}
GIS topology predicates	*to-disjoint*	*to-disjoint* (A,B)		Object A is disjoined with object B	{T, F}
	to-intersect	*to-overlap* (A,B)		Object A overlaps object B	{T, F}
	to-contain	*to-contain* (B,A)		Object B entirely contains object A	{T, F}
	to-inside	*to-inside* (A,B)		Object A is entirely contained by object B	{T, F}
	to-meet	*to-meet* (A,B)		Object A borders upon object B	{T, F}
	to-equal	*to-equal* (A,B)		Object A is the entire same as object B	{T, F}
	to-cover	*to-cover* (B,A)		Object B covers object A	{T, F}
	to-cover-by	*to-cover-by* (A,B)		Object A is covered by object B	{T, F}
GIS direction predicates	*direct*	*direct* (P,A)		Object P is in some direction of object A	{E, W, S, N, SE, NE, SW, NW}
	east-of	*east-of* (C,A)		Object C is in the east of object A	{T, F}
	west-of	*west-of* (B,A)		Object B is in the west of object A	{T, F}
	south-of	*south-of* (H,A)		Object H is in the north of object A	{T, F}
	north-of	*north-of* (E,A)		Object E is in the south of object A	{T, F}
	southeast-of	*southeast-of* (I,A)		Object I is in the northeast of object A	{T, F}
	northeast-of	*northeast-of* (D,A)		Object D is in the southeast of object A	{T, F}
	southwest-of	*southwest-of* (G,A)		Object G is in the northwest of object A	{T, F}
	southeast-of	*southeast-of* (F,A)		Object F is in the southwest of object A	{T, F}
GIS distance predicates	*dist*	*dist*(A,B)		The distance form object A to object B	[0…max. distance]
	close_to /near_to	*close_to* (A,B)		Object A is near object B	{T, F}
	far_away	*far_away* (A,B)		Object A is far away from object B	{T, F}
Correlation predicates between point, line and region	*point-to-line*	*point-to-line*(P, A)		Spatial relation between point P and line A	{on_line, besides}
	point-to-region	*point-to-region* (P,W)		Spatial relation between point P and region W	{inside, outside, on_ boundary, on_vertex}
	line-to-line	*line-to-line*(A, B)		Spatial relation between line B and line A	{intersect, parallel, perpendicular }
	line-to-region	line-to-region (A, W)		Spatial relation between line A and region W	{along_edge, intersect}
	region-to-region	*region-to-region* (Y, Z)		Spatial relation between region Y and region Z	{disjoint, meet, overlap, cover, covered_by, contains, equal, inside}

Table 1. Cognitive logic predicates of GIS for data mining

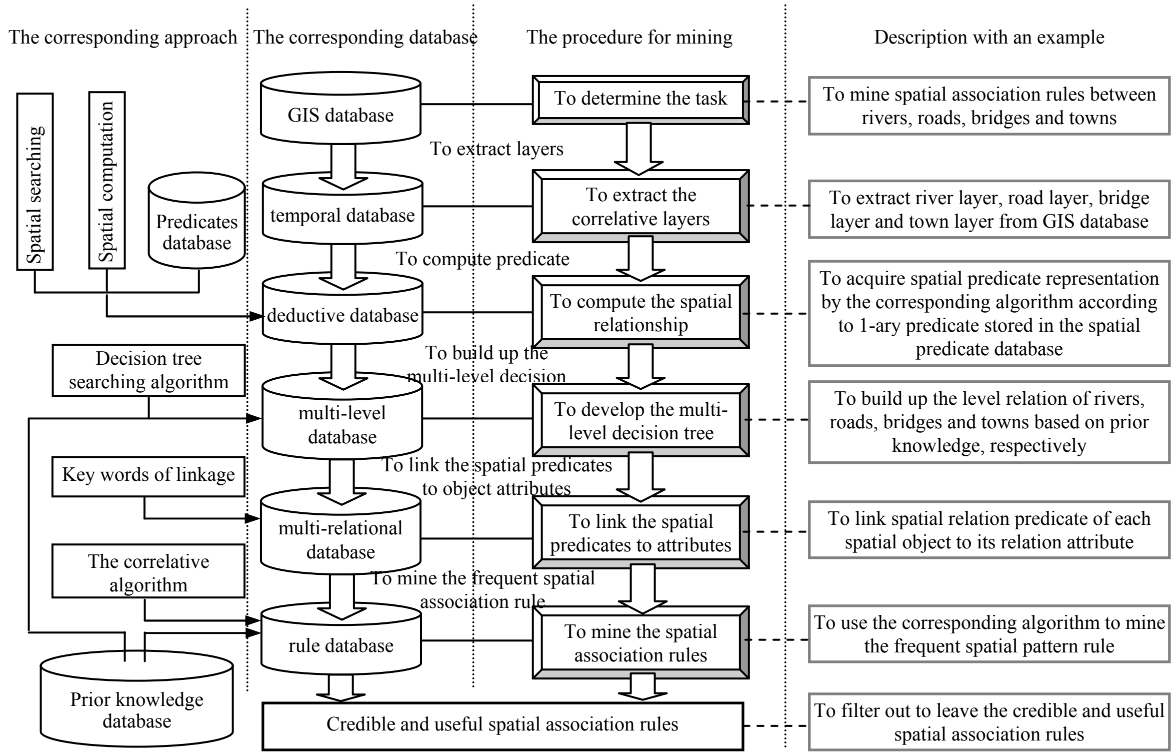


Figure 2. Framework of spatial association rule mining from GIS databases

Now, we are making great efforts to implement the framework under help of several programmers, and the prototype of the programmes to mine the spatial association rules among roads, rivers and bridges from Suzhou topography GIS database has been finished, which interface is illustrated in figure 3. Our strategy is to use the existent software for the second programming. By contrast, the ARC/INFO 9.0 is selected because of its strong second programming capacity with ArcObjects, which can be plugged into another programme such as DELPHI, Visual BASIC, Visual C^{++}, and especially the environment *.net*. Additionally, almost all the function components of ARC/INFO can be founded in the complete object library of ArcObjects, which provide the interface with the exterior. And the programme can be separately run without dependent on ARC/INFO software. So it is very appropriate and feasible for implementing the framework.

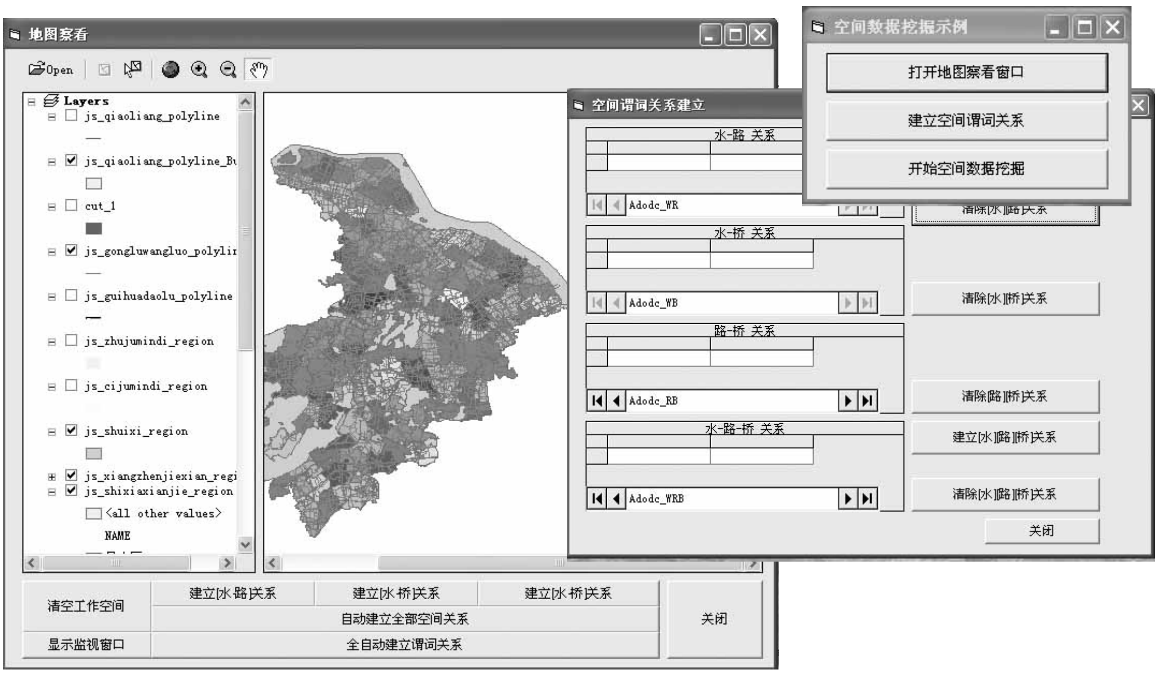


Figure 3. Interface of the prototype of the programmes to mine the spatial association rules among roads, rivers and bridges from Suzhou topography GIS database

5. CONCLUSIONS AND FUTURE WORK

By the detailed analyse mentioned above, on the one hand, we have seen the bright for mining the spatial association rule from GIS database more logical and more sound. But on the other hand, we are also faced with the difficulty in general idea especially cognitive concept, algorithm and efficiency in the course of solving the problem.

Firstly, SDMKD from GIS is a process of abstraction and representation to the geographic phenomena and/or objects of the real world. And it aims to discover some corresponding and implicit rules and/or laws of geographic phenomena from the real world. But it should be founded upon the geographic cognition especially geographic spatial cognition because of its geographic and spatial properties. And the spatial association rule is one of the most important contents of SDMKD from GIS.

Secondly, cognitive image schemata based on the geographic spatial cognition under the three spatial frameworks play important roles in guiding to determine the correlative and corresponding spatial predicates, which should be based on the integrating tightly epistemic logic with ILP. And the epistemic logic and ILP have important complementarities each other to formally describe and define the implicit spatial association rules from GIS database, especially in cognitive rule predicate, which is the key to mine and/or discover the implicit rules.

Thirdly, SDMKD from GIS should take fully into consideration the characteristics of GIS database, especially the storage mode of spatial information and/or objects in database. Finally, the paper proposes almost all the possible spatial predicates for SDMKD from GIS and builds up the basic framework for SDMKD from GIS. But it is a pity that the proposed framework hasn't been entirely implemented up to now, and only a few works have been completed. But we have full reasons to believe that the software or module could be successfully developed and fully accomplished on the basis of the basic framework, which is our next task.

ACKNOWLEDGEMENTS

Funding by the National Natural Science Foundation of China (NSFC) is greatly appreciated. Thanks are also due to Professor Huang Xingyuan from Nanjing University, China for guidance. And the authors also thank all the members participating in the project *Study on the Cognitive Logic Model of GIS Data Mining* funded by NSFC (NO. 40301038).

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