THE REPRESENTATION OF SPATIAL KNOWLEDGE IN GIS

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ABSTRACT

Central to the organization of GIS is the representation of spatial knowledge structured on several levels of abstraction, and the control strategy that has to use the knowledge efficiently. The representation of spatial data is of importance because it provides with useful information of world model, is helpful to build up GIS, and aids spatial relationship reasoning and decision making. This paper presents an approach of representation of spatial data knowledge(both spatial relationships and semantic relationships), the representation schema uses frame-like data structure, objects are represented by their frames, by their boundaries, and by the corresponding relation tables. Using this representation schema, different user views of the contents of spatial data and corresponding interpretation are supported. The knowledge of geographic data, spatial relationships and other relevant knowledge can be well represented, organized, and manipulated. Spatial relationship reasoning is possible and can be implemented without much difficulties.

1. INTRODUCTION

The representation of spatial data has been a central theme for the design of geographical information system, the representation scheme of spatial data mean to represent and manage information of image objects and their spatial relationships. Such scheme are of importance because they provide with useful information of world model, and aid decision making[1]. Examples of such systems may include land information systems, world maps for automated vehicle navigation, etc.

Although the exact representation of real objects and their relationships in human mind are still unknown, we are in confidence that some knowledge-based modeling of the system should be explored to represent followings:

- both geometric features and semantic features of objects, such as area, position, population if it represents a city.
- both spatial relationships and semantic relationships, such as near, contained in, surrounded by, effected by if they are two regions of a city.

This paper describes an ongoing research project whose goal is to represent the spatial relationships of geographic data in a knowledge base[2]. The project can be conceived as the combination of two methodologies: expert systems, spatial relationships and online databases.

The knowledge base of the system contains frame[3] subsystem that represents spatial and other relevant knowledge of geographic data, attached to the slots of frame are various procedures and heuristic rules. The knowledge base deals with building and checking user models, appropriateness of various modalities and representations. Some heuristics are domain-independent(learning strategies), but many are domain-specific; Some heuristics generate plausible suggestions, some analyze, evaluate and critique.

The reasoning model implemented in the system is based on formal methods which have been developed from classical logical, non-classical logical, model logical, and fuzzy logics. The control module receives the query from user interface module, selects a candidate frame, and uses the data in geographic base to fill the slots of the frame, then the reasoning engine starts to work. Finally, the reasoning results and corresponding interpretation are presented to users.

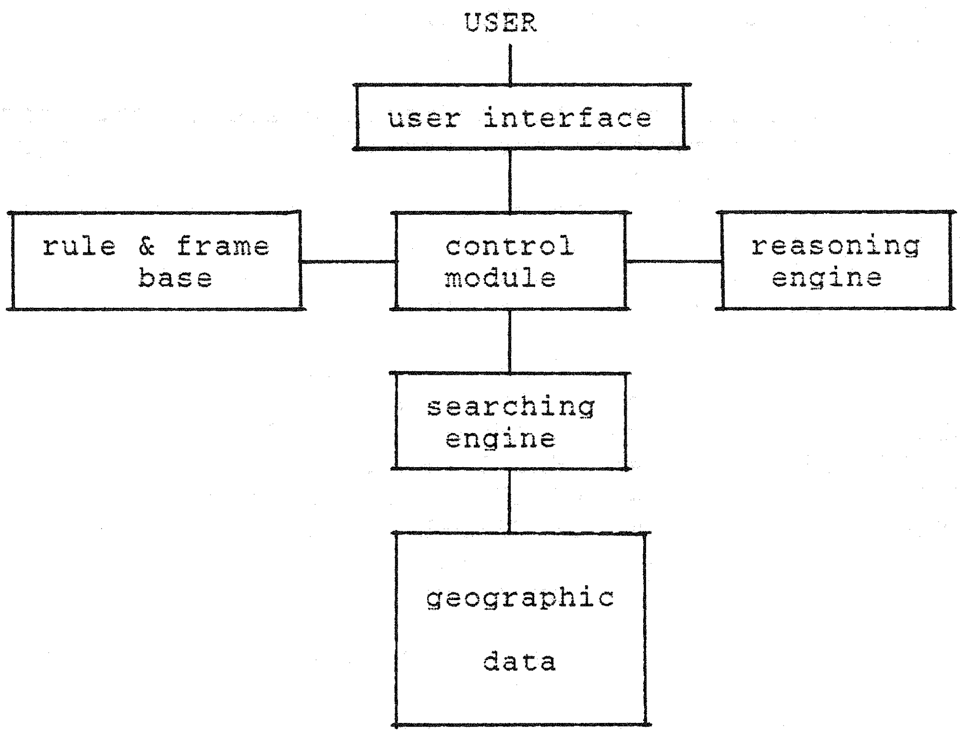


Fig. 1 The diagram of query processing

2. IMAGE CODING

The object-oriented geographic data are represented by vector coding. The basic geographic primitives in GIS are points, lines, and regions. All the three primitives can be represented by one or several vectors. A vector is a 4-tuple $\langle x,y,u,v \rangle$ where x and y are, respectly, the x-coordinate and y-coordinate of the starting point, called the tail of the vector, and u and v are, respectly, the x-coordinate and y-coordinate of the ending point, called the head of the vector. In vector-code representation, a straight line segment is represented as one vector whose coordinates for two end points are stored. With the original information about line segments stored in a relation table, the conventional attribute manipulation can be applied to these pictorial attributes in the same manner as applied to the conventional attributes. Since the original information for line segments are stored, all the descriptions such as relative position, absolute position, shape, length, and slope can be derived from the coordinates of vectors. The relational tables of geographic data are stored in geographic base.

By using pattern recognition and image processing techniques, structures and features of the original raster image are extracted as picture sketchgs, the set operator converts picture sketchg into the pictorial attributes of a relational table. Some examples of relational tables are given as follows:

ROADS(PID,RONAME,ROID,X1,Y1,X2,Y2)
RIVERS(PID,RINAME,RIID,X1,Y1,X2,Y2)
CITIES(PID,CNAME,CID,X1,Y1,X2,Y2)
BRIDGES(PID,BNAME,BID,WIDTH,X1,Y1,X2,Y2)

We use these relational tables(basic elements are straight line segments) to represent the geometric parts of geographic data, and employ frames to represent the spatial and other relevant knowledge of the data, the procedure attached to the frame can take tuples of relational tables as inputs, and fill the slots with output values. Rewriting rules of the frame-structure grammer is defined below:

```
FRAME          :== <FNAME><SLOT-LIST>
SLOT-LIST      :== <SLOT>(<SLOT>)
SLOT           :== <SNAME><FACET-LIST>
FACET-LIST     :== <FACET><FACET>
FACET          :== <FACET-NAME><information-about FACET><PROC>
PROC           :== IF-NEEDED procedure
               :== IF-ADDED procedure
               :== domain-specific RULE
```

Many objects do not have straight line borders, therefore, the above vector-code representations are only approximations. It is important to define how they are approximation, and to be able to state how inaccurate a given approximation is. The measure of the inaccurate of a region is its grain-size, which is an upper bound on the distance from any point in the region to a point in the object. The smaller the grain-size, the better the approximation.

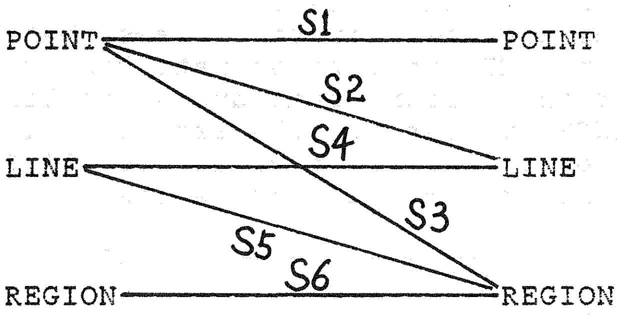
Following is an example of frame CITY:

```
|------------------------------------------------------------------|
| CITY                                                             |
|  IS-A:    RANGE ( basic entity )                                 |
|  NAME:    RANGE ( c10 )                                          |
|           IF-ADDED ( print the name on the terminal )            |
|           IF-NEEDED ( find the value from the                    |
|                      field NAME of relational tables )           |
|  EXAMPLES: ( city1,... )                                         |
|  PARENT: RANGE ( c10 )                                           |
|  CENTER: DEFAULT ( integer-range 40 1000 )                       |
|           IF-NEEDED ( find the coordinate of the center          |
|                       point using procedure CENT-R )             |
|  AREA:    DEFAULT ( i4 )                                         |
|           IF-NEEDED ( call procedure AREA-R )                    |
|  PERIMETER:DEFAULT ( integer-range 15 600 )                      |
|           IF-NEEDED ( get the value by calling                   |
|                      procedure LENGTH )                          |
|  THROUGH:RANGE ( river, road, rail )                             |
|           IF-NEEDED ( find the name list of rivers,              |
|                       roads and rails which pass through         |
|                       the region )                               |
|           IF-ADDED ( print the list, display the                 |
|                       entities on display screen )               |
|------------------------------------------------------------------|
```

Fig. 2 The structure of frame REGION

Where, PARENT slots in frames point to their immediate containers and contents, an image can be divided into sub-images hierarchically arranged by containment, frame representation is complex but complete.

3. SPATIAL RELATIONSHIPS[4]



As it is well known, there are three element entities in GIS, said points, lines, and regions. Therefore, there exist six basic spatial relationships. For each of these six basic relationships, several sub-relationships exist. For instance, point to region relationship can be divided into 4 sub-relations: near, beside, in side of, surounded by, and contained in. As the same way, we can divided the other basic spatial relationships into their sub-relations. The spatial relationships of geographic data can be classified as the combination of the following relations.

They are:

S1: near, beside, to the south(east, northwest, ...) of.
S2: near, on the line, to the right(left) of.
S3: near, beside, contained in, surrounded by, in south(east,...) side of
S4: cross, closed to, near, intersection, paralell.
S5: pass through, near, beside, in side of, contained in.
S6: near, beside, intersection, in side of, contained in, surrounded by.

The spatial reasoning module of the knowledge base derived the spatial relationships listed above directly from geographic data stored in relational tables.

4. INEXACT FRAME MATCHING

In general, the geographic data in GIS are very large and complex, we can not think that the knowledge base of GIS give precise and complete description of the application domain. This fact is important to the reasoning strategy, frame matching and other operators, we should use approximate reasoning[6] to obtain satisfying results.

The knowledge base consists of a hiererachy frame subsystem F. Suppose there are N frames in F, $F = [F_1, F_2, \ldots, F_N]$, our goal is to find the frame appropriate to the current situation and query. The criterion of frame selection is the matching degree CF derived from slots maching degree.

we associate certainty factors with the conclusions of inference rules and procedures attached to each facet of the slots, the number associated with conclusion could be in [0, 1], that represents certainty in the system. If the head parts are themselves uncertain, the number associated with conclusion is modified to account for the uncertainty of its premises. We refer to them as degree of belief.

Two functions are used for the frame matching: a slot matching function SMD and a facet matching function FMD. All facet values obtained from procedures calling are matched against the RANGE values for the same slots. The larger the number FMD, the nearer the facet value to RANGE. The facet matching degree FMD is defined mathematically as follow:

$$FMD(facet) = \frac{1}{Max(VALUE,\ RANGE)} \left| VALUE - RANGE \right| \qquad \langle 1 \rangle$$

Where, RANGE is the expected value of facet, and VALUE is the computing result of attached procedure.

We can see that:

$$0 <= FMD(facet) <= 1 \qquad \langle 2 \rangle$$

Suppose there are Kj facets in the slot $S_j \in F_i$, the matching degree of slot S_j is defined below:

$$SMD[S_j] = \sum_{k=1}^{K_j} WF(f_k) * FMD(f_k) \qquad \langle 3 \rangle$$

Where $WF(f_k)$ $(k=1,2,\ldots,K_j)$ is the discrete weight for facet f_k, and $\sum_{k=1}^{K_j} WF(f_k) = 1$

When SMD[S_j] is greater than a threshold value, said T_j, the slot Sj provides evidence for the triggering of frame F_i, frame selecting is based on function CF[F_i] of frame F_i, the weighted average of SMD[S_j] ($S_j \in F_i$, j=1,2,...,M_i):

$$CF[F_i] = \sum_{j=1}^{M_i} WS(S_j) * T(SMD[S_j]) \quad \langle 4 \rangle$$

where,

$$T_j(\alpha) = \begin{cases} T_j & \alpha >= T_j \\ 0 & \text{other} \end{cases}$$

and

$$\sum_{j=1}^{M_i} WS(S_j) = 1$$

After obtaining CF[Fi] by equation <4>, the system can decide this frame Fi is suitalbe or not, if suitable, the frame Fi is triggered, and the result and interpretation is outputed. If not, the system continue the select processing, until find a suitable frame or create a new frame to describe the current situation.

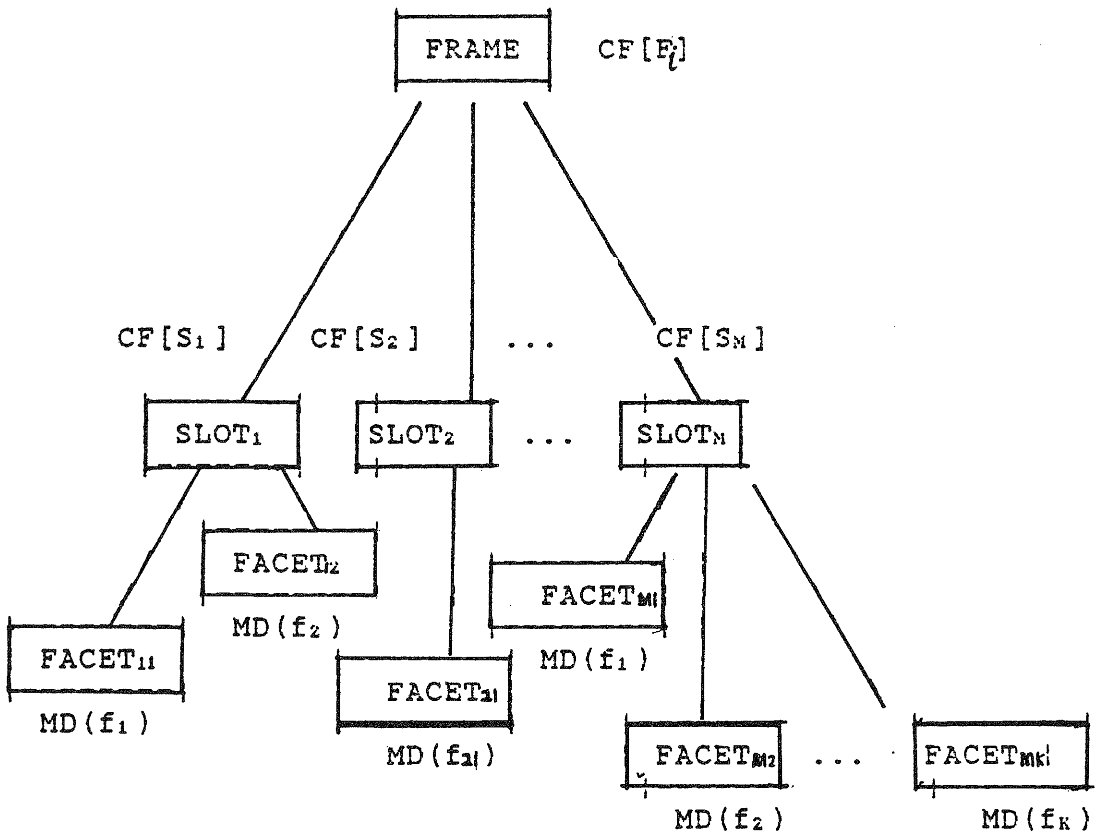


Fig. 3 The control procedure of frame selecting

5. CONCLUSIONS

We have proposed a representation schema of spatial data for GIS. This schema uses frame like structure as its abstract data type, the knowledge of geographic data, their spatial and semantic relationships are represented by frames. The control strategy, using approximate matching and rules, can reason the spatial relationships and give the semantic interpretation of geographic data. The incorporation of techiques from inexact reasoning allow GIS to more closely model realistic situation, thus making them acceptable to GIS practitioners.

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