DATABASE STRUCTURE FOR THE INTEGRATION OF RS WITH GIS BASED ON SEMANTIC NETWORK

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ABSTRACT The integration of remote sensing (RS) with geographical information system (GIS) is a hotspot in geographical information science. A good database structure is important to the integration of RS with GIS, which should be beneficial to the complete integration of RS with GIS, able to deal with the disagreement between the resolution of remote sensing images and the precision of GIS data, and also helpful to the knowledge discovery and exploitation. In this paper, the database structure storing the spatial data based on semantic network is presented. This database structure has several advantages. Firstly, the spatial data is stored as raster data with space index, so the image processing can be done directly on the GIS data that is stored hierarchically according to the distinguishing precision. Secondly, the simple objects are aggregated into complex ones. Thirdly, because we use the indexing tree to depict the relationship of aggregation and the indexing pictures expressed by 2-D strings to describe the topology structure of the objects, the concepts of surrounding and region are expressed clearly and the semantic content of the landscape can be illustrated well. All the factors that affect the recognition of the objects are depicted in the factor space, which provides a uniform mathematical frame for the fusion of the semantic and non-semantic information. Lastly, the object node, knowledge node and the indexing node are integrated into one node. This feature enhances the ability of system in knowledge expressing, intelligent inference and association. The application shows that this database structure can benefit the interpretation of remote sensing image with the information of GIS.

1 The concept of the integration of RS with GIS

The integration of remote sensing (RS) with geographical information system (GIS) is a hotspot in geographical information science. The concept of the integration of RS with GIS, in the view of Prof. Li Deren, is that RS is the way to obtain the information about the objects and the surroundings, to discover the changes on the surface of the earth, and to update the data of GIS, while GIS, the base of the new integrated system, manages the spatial data and provides the geographical information for the interpretation of remote sensing images[1]. This view correctly explains the goal of the integration of RS with GIS. According to this, GIS should satisfy two requirements:

1) It should help the system based on it to develop the function.
2) It should be conducive to obtain the interpretation of the remote sensing image with geographical information.

The traditional techniques to classify the remote sensing image are usually based only on the spectral features of the objects. Because the resolution of the remote sensing image is limited, one pixel in the image may consist of different objects. In the image, different kinds of objects may have identical spectral feature and the same object probably has different spectral features in different conditions. All these make it difficult to classify the objects in a high precision using the traditional techniques based on the spectral features.

Updating the GIS by the traditional method is to input the data by hand and needs practical surveying to get the geographical information. This approach consumes too much time and produces little effect, so GIS can not be updated in time.

The integration of RS with GIS provides a new way to solve these problems. GIS can provide a large amount of prior knowledge about the landscape scenes, including the positions of the objects, the geometric properties, the spectral feature, the textural feature, the altitude, the information about the surroundings, and the disciplinarian about the objects' distribution, etc. These kinds of information can help us to interpret the remote sensing image based on multiple rules, so that the interpretation can be automatic and the precision can be improved.

In fact, the abundant geographical information in GIS has not been exploited sufficiently for the interpretation of the remote sensing image yet, and the available GIS software has not realized the goal of complete integration of RS with GIS. There are two main difficulties. 1) The data in GIS is object-oriented and controllable, while the remote sensing data is space-oriented and uncontrollable. This difference makes it difficult to combine them for processing. Usually there is need for some transformation or extra processing if these two kinds of data need to be processed together. 2) Because of the large amount of data in GIS and the complex relation between them, it is difficult to discover and exploit the knowledge in GIS.

In order to resolve these problems, we should do as follows. 1) Enrich the methods to discover and to exploit knowledge in GIS;2) Enhance the function of spatial analysis of GIS;3) Improve the spatial database structure of GIS. In this paper, the database structure for the integration of RS with GIS is discussed, and a new spatial data structure is presented.

2 The requirements for the database structure

In order to realize the integration of RS with GIS, the data structure of GIS should satisfy three requirements.

1) It should be profitable to the complete integration of RS with GIS. The data structure should be able to carry out the spatial analysis function of GIS, and at the same time, image processing can be done on it directly. In this way, the transformation of data between GIS and the image is avoided, and the modules of image processing and GIS can be merged into one.

2) It should be able to deal with the contradiction between the resolution of the remote sensing images and the precision of the data of GIS. Sometimes the size of the smallest object that can be distinguished by the data of remote sensing is inconsistent with that of GIS, and different kinds of remote sensing images also have different resolutions. The data of GIS may become disordered, if the data of remote sensing is used to update it. In order to resolve the problem, the data structure should be able to process and fuse all kinds of data in different layers according to their resolutions.

3) The data structure of GIS should be beneficial to the knowledge discovery and exploitation. An object has many features and there is strong spatial correlation between different objects. An object is affected greatly by its surroundings. The data structure should be able to describe complex objects and express the semantic or non-semantic information. The information should be able to be propagated freely in the data structure by association.
3 Several typical database structures

Several typical spatial database structures, such as the raster-to-vector compound data structure, the vector-based data structure with spatial index raster, the raster-based data structure, the object-oriented data structure and the feature-based data structure, are discussed in this section. We compare several different kinds of data structures with each other according to the requirements by the integration of GIS with RS. The result is shown in Table 1.

| Data structure                                      | Data type              | Index mechanism | Support to the image processing | Support to the spatial analysis | Support to the system integration |
|-----------------------------------------------------|------------------------|-----------------|---------------------------------|---------------------------------|----------------------------------|
| Raster-to-vector compound data structure             | Vector                 | Index file      | Support by raster-vector conversion | Weak in spatial index          | Seamless integration of RS & GIS |
| Vector based data structure with spatial index raster | Vector                 | Index raster    | Support by raster-vector conversion | Better on spatial index        | Seamless integration of RS & GIS |
| The raster based data structure                      | Raster                | Index grid and quad tree | Support direct image processing | Better on boolean calculation, integral operation and spatial index | Complete integration of RS & GIS |

Some kinds of GIS software are based on the vector data structure (e.g. Arc/Info). The system provides an interface to transform vector data into raster data. When the data in GIS is required, vector data is transformed into raster data and thus can participate in the remote sensing image processing. The mechanism provides an interface between the GIS module and the image processing module, so the two modules can be united on the same platform seamlessly. But they are not completely integrated. Frequent transformations between raster data and vector data reduce the efficiency of the system.

In order to locate the objects efficiently in space, Randal C. Nelson in Maryland University represented a data structure based on the vector data with raster index\(^{[3]}\). Using raster index, it is easy to find the objects that pass through a particular region, but GIS data also needs to be transformed when it is used to interpret the remote sensing image.

The complete integration of RS with GIS requires the data structure to support both the spatial analysis and the image processing. The vector data and raster data are different. The vector data is object-oriented and the raster is space-oriented. With the data structure based on the latter it is easier to realize the complete integration. Tan Guoxin has presented a data structure based on the raster data with grids of three levels\(^{[4,5]}\).

On the basis of the RDBS, the data of most GIS is stored in the tables and the data storage is separated from the data processing. This kind of data structure is not beneficial for the discovery and exploitation of knowledge. Some other kinds of data structures have been represented, such as object-oriented data structure, feature-based data structure, etc.\(^{[6,7]}\) But these models are too simple to describe the complex semantic relations among spatial objects.

4 The database structure based on semantic network

In this section, a new database structure based on semantic network is presented. Different data structures reflect different viewpoints on the structure of the information space. In most spatial data structures, objects are the units for organizing spatial data and property data, and the semantic relationship among different objects can not be described well. In fact, the landscape should be understood as a whole, not several separated parts. The recognition of an object is affected greatly by its surroundings. The geographical information space can be seen as a system carrying out some tasks of interpretation of
remote sensing image, and in this system every part is a factor affecting the final result. So a good data structure should be able to depict the relation of the objects and semantic concepts such as “surrounding” and “region”.

In order to exploit the geographical knowledge, the expert system is used in some software to help interpretation, but the knowledge needs to be input by hand and it is difficult to be discovered. A good GIS should be able to learn by itself from the data. Because of the large amount of data, it is important for a good structure to find the factors easily, which affect an object’s recognition. Therefore the spatial data structure must be developed from the object-oriented structure to the semantic-oriented structure.

The database structure storing spatial data based on the semantic network has the features as follows.

1) The object node, knowledge node and the indexing node are integrated into one node. This feature enhances the system’s ability of expressing knowledge, intelligent inference and association.

2) The data is stored hierarchically according to the distinguishing precision. Simple objects are aggregated into complex objects. This feature resolves the disagreement between the resolution of remote sensing data and the precision of GIS data. At the same time the concept of region is formed.

3) The strong mechanism of space index has been built to depict the relative positions of the objects and express the spatial semantic information. The indexing tree depicts the relationship of aggregation, and the indexing pictures represented by 2-D strings depict the topology structure of the objects. The database structure can depict the concepts of region and surrounding. The feature is very important for interpreting the remote sensing image with the information about surroundings and evaluating the condition of a region synthetically.

The database structure will be represented in several aspects.

4.1 The aggregation and hierarchical storage of objects

Complex objects consist of simple objects. Higher the precision of the data of GIS, smaller the size of the objects that can be distinguished. The data of GIS with high precision can depict the objects in detail. In the hierarchical structure, the small objects are aggregated into complex objects with big size, so different layers are formed. A minimal size is defined in every layer and there is no object smaller than the minimal size in this layer. The remote sensing data can update the GIS in different layers according to the resolution of the remote sensing image.

The objects are aggregated according to their spatial semantic information. A group of objects that have close relationships and notable semantic features should be aggregated into a new node. This node is the base for the aggregation in a higher layer. The super nodes contain the indexing information about their sub-objects. The indexing information is represented by the indexing grids and quadtree codes. The nodes are divided into secondary nodes continually and then an indexing tree is formed.

Aggregation forms the concept of region. A region consists of a group of objects that have close semantic relationship. In the region, the geographical objects can be viewed in a high level, and superior information can be obtained. The data of a complex object can be derived from the data of its sub-objects. The data of the sub-objects is synthesized to get the property data and the factor space of the complex objects. During this process, the new useful information, which reflects the integral feature and the regularity of the objects’ distribution, is generated. This kinds of information is very important for the interpretation of the remote sensing images. For example, in the region where ditches and the paddy fields distribute in commixture, the textural feature and the relationship of these two kinds of objects can be found by the aggregation.

During the interpretation of a remote sensing image, a complex problem can be decomposed into several simple problems to be resolved in sub-regions. If an object can not be identified in a layer, it can be prompted into a higher layer where more information can be obtained. The information translation between different layers greatly benefits the interpretation.
The authors realized the model for the hierarchical structure. The class for region can be described in DELPHI language as follows.

```
Tregion {
Region-ID: LongInt /* the ID for the region */
Layer-ID: LongInt /* the layer the region belonging to */
Sup-Region-ID: LongInt /* the ID of the super-region */
QuadTree-Code: Ttree /* the quad-tree code in the super-region */
/* Ttree is the data type defined for the quad-tree structure */
MinSize: LongInt /* the minimum size that can be distinguished */
TopLeft: Tpoint /* the top-left point of this region */
ButtomRight: Tpoint /* the down-right point of this region */
/* TopLeft and ButtomRight limits the scope of the square region */
Sub-Object-Num: Integer /* the number of the sub-objects */
Sub-Objects: array of LongInt /* the array for the sub-objects */
Index-Tree: TTree /* the indexing quad-tree for sub-objects */
Index-Stings: Strings /* the 2-D strings describing the topology of the sub-objects */
}
```

In the hierarchical structure, "MinSize" defines the size of the raster and the minimum size that can be distinguished in this layer, so different layers have different solutions. "TopLeft" and "ButtomRight" limits the scope of the square region (square of 2" * 2" usually). The sub-objects in this region can be coded in the form of quadtree in this scope based on the two parameters, building multiple indexing quadtree. Thus the length of the code can be reduced greatly. If the objects are not stored in respective regions but indexed in the whole scope, various sizes of objects will make it difficult to control the precision of the data and the great number of objects will make the quadtree too complex to be built. We have studied the Quanjiao county in Anhui province. There are more than 1 600 objects in this area, but if the data is stored by hierarchical aggregation, there are less than 100 objects in each region to be indexed. “Index-strings” is the 2-D strings used to describe the topology of the sub-objects in the region. The 2-D strings will be described in detail in 4.2.

4.2 The depiction of the relationship of topology

The information about the topology of the geographical objects is very important for the interpretation of remote sensing image and GIS’s function of spatially analyzing and decision-making. For this reason, the ability of the database structure to depict the relationship of topology should be enhanced. The traditional database structures have two disadvantages: 1) It lacks enough mathematical tools to depict the topology structure of the objects, so only a few concepts, such as east, west, south, north, can be used to depict the relations in topology, but the actual relationships in topology of the objects are far more complex. 2) Though GIS can depict the topology in some extent, only the adjacent ones of an object can be obtained in the database, and the feature of the integral distribution of the objects in the region can not be obtained. In the database structure based on the semantic network, the topology structure is depicted by the indexing picture, which is represented by the 2-D strings.

The indexing pictures depict the relative position of the objects but the actual position in the remote sensing image, so they do not need much storage space, for example, there are four objects $a$, $b$, $c$ and $d$. The topological relationship among them in topology can be depicted by the following raster picture as shown in Fig. 1.

```
|   |   |
|---|---|
| $d$| $b$|
| $c$|   |
| $a$| $a$|
```

Fig. 1  Indexing picture of the position for $a, b, c, d$

The indexing picture can be depicted by the 2-D
strings: \((a = d < a = b < c, a = a < b = c < d)\).
The two strings represent the orders of the objects aligned in the directions of \(X\) and \(Y\).

The normal strings can be obtained after being simplified.
\((ad < ab < c, aa < bc < d)\) \((1)\)

If there are more than one object in one position, for example, there is another object named \(e\) at the position where \(d\) exits, the strings will change into \((ad : e < ab < c, aa < bc < d)\). The information about partial objects can be extracted from the strings about a group of objects. If only the objects \(a\) and \(c\) are concerned, the strings can be expressed as follows.
\((a < c, a < c)\) \((2)\)

String (2) is the sub-string of string (1). Algorithms can be programmed to test whether the two strings are sub-string-matched and whether the relationships in topology that the two strings depicted are in accordance. It can be proved that an indexing picture can be retrieved according to the 2-D strings in the sense of sub-string-matched\([8]\).

The indexing pictures represented by 2-D strings depict the topology structures of the objects in a concise and accurate way. They can be stored in the super node of a region and then depict the relationship in topology of the objects in the region. When there is need of the information about topology, it can be derived from the 2-D strings and relevant objects can be indexed. The indexing pictures stored in different nodes can be combined to depict the topology structure perfectly.

The indexing pictures depict the surroundings of objects. The concept of surrounding, together with the concept of region formed by aggregation, endows GIS with strong ability to express spatial semantic content and emphasizes the relationships among objects. The spatial data mining and the interpretation using knowledge will not be restricted in single object, and they can be based on the features of the regions and surroundings.

4.3 The factor space in the database structure

In the database structure based on semantic network, semantic information, relationship among the objects can be depicted well, but the information needs to be organized for interpretation of the remote sensing image. In the database structure represented, data storage and data processing are integrated in the nodes. All kinds of information are organized in a uniform mathematical frame. The mathematical frame is termed as factor space\([9]\).

The node contains the raster data that describes the locations of objects, the property data and the knowledge frame for identifying objects from the remote sensing image. The knowledge frame contains the main features for identification of objects.

The node has the ability of intelligently reasoning, utilizing the information in itself and in the relevant nodes to make the final interpretation of the remote sensing image. There are two kinds of restrictions on the interpretation: 1) the restrictions from the object's own property, 2) the restrictions from its adjacent objects. When the interpretation needs the information from adjacent objects, the message can be sent to activate other nodes.

All kinds of information are organized in a uniform knowledge frame called factor space. All the factors that affect the identification of an object construct the factor space of the object, and each object is the point where different factors intersect. As shown in Fig. 2, in the factor space of the paddy field, the factors are the spectral features, geometric features, altitude, the type of the soil, the objects around it such as ditches, rivers and so on. In different nodes, the factor spaces are different in dimensions. Different kinds of factors should be described by different kinds of variables, for example, the spectral features are described by real vector, the types of soil are described by fuzzy sets, and the other factors can be described by the symbol variables, geometry templates, etc.

All the factors can be divided into two classes. To some factors, their information can be obtained in its own nodes, but to some other factors, if their information is needed, the relevant nodes need to be activated.

Data and its processing are sealed in the same node. The information of some factors can be obtained by the inner functions from the remote sensing image and GIS directly, and the information of some factors have to be obtained by the mechanism of association.
The associating functions can activate another node and transform the reasoning from one factor space into another factor space. For example, a reservoir contains two parts: the water area and the dam. If the reservoir is to be identified, its sub-nodes as the water area and the dam will be activated and the reasoning will enter into the factor space in a secondary layer. The paddy fields are dependent on the rivers in space, so the rivers' factor spaces can be activated to identify the paddy fields. The regularity of the distribution of the rivers and paddy fields must be got in a super factor space.

The associating function can be described as

$$s = S(a, (b_i, F_i), r(a, b_i))$$

where $a$ is the start of the association, $(b_i, F_i)$ is the objects and their factors associated with $a$, and $r(a, b_i)$ is the association intensity between $a$ and $b_i$. The associating function can choose the factors to be activated according to the $r(a, b_i)$. The indexing pictures are important for the associating function, because the relationship among different objects can be got from them, and the objects can be searched in a constrained scope according to the prior knowledge obtained from them.

The final interpretation needs to synthesize all the factors, and some thresholds are needed. The parameters of the factors in the functions, the thresholds, and the association intensity can be adjusted according to the data input into GIS. In this way, GIS can learn by itself.

4.4 Instance

In the key project of the Ninth National Five Years Plan—"building the national dynamic monitoring system for resource and environment (Anhui province)", we have studied the spatial data for Quanjiao county of Anhui province. In Fig. 3, the spatial data structure of the region of Quanjiao is described.

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**Fig. 3 Architecture of spatial data for the region of Quanjiao based on the semantic network**

The region of Quanjiao is divided into several parts: the region of the Sanwan reservoir, the region of Longshan and other regions. The region of Sanwan can be located by the sub-object indexing. In the region of the Sanwan reservoir, sub-objects such as the reservoir, the paddy fields, the glebes, the residence and the dam are relevant. The paddy fields are near the reservoir, and the position of the
residence is dependent on the position of the paddy field, the glebe field and the dam. If the residence is to be identified, first we should obtain the spectral information from the remote sense image and the information of altitude and gradient from GIS. If complete interpretation still cannot be made from these kinds of information, the reasoning has to go up into the super-node. From the index picture in the super-node, the information about the distribution of surrounding objects can be obtained. If the surrounding objects such as the reservoir and the paddy field are not identified, then the residence’s knowledge frame will not be satisfied, so the associating function should activate other nodes.

The texture feature of the fields, the residence and the canals can be obtained by synthesizing the property data and then stored in the super-node, which represents the region of the Sanwan reservoir, for the interpretation.

In this model, the interpretation of remote sensing image is not limited with the single object, but based on the unit of region and surrounding. The information of spectrum, geography and semantic is synthesized for interpretation.

5 Conclusion

A kind of database structure storing the spatial data based on semantic network is presented. In this database structure, the raster-based spatial data is stored hierarchically and supported by an index mechanism. The concepts of surrounding and region are expressed clearly, so the semantic content of the landscape can be depicted well. The factor space provides a uniform mathematical frame for the fusion of the semantic and non-semantic information. The application shows that this database structure can benefit the interpretation of the remote sensing image with the information of GIS.

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