A STUDY ON INCREMENTAL OBJECT-ORIENTED MODEL AND ITS SUPPORTING ENVIRONMENT FOR CARTOGRAPHIC GENERALIZATION IN MULTI-SCALE SPATIAL DATABASE

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Abstract: The multiple representation of spatial data has become one of the keys for constructing and maintaining Spatial Data Infrastructures (NSDI, GSDI and SDI) and visualization of spatial data. This paper analyzes the status and requirements about automatic generalization of spatial data for constructing multi-scale spatial databases, represents a new object-oriented data model for automatic generalization, where scale is regarded as one dimension like space position and time. A new spatial object can be reconstructed or produced by supplementing or decreasing information incrementally at any scales, and then stored into a new coverage in databases. The relative generalization operators are composed of a set of scale-dependent automatic generalization algorithms, which can control spatial objects in object detail levels incrementally with scale changing so as to acquire any detail spatial objects dynamically and continuously. The model has been implemented partly and demonstrated in our experimental software system – InMapping Soft.

1 INTRODUCTION

There are two problems obviously in current multi-scale spatial databases, the one is that the multiple representations of the same geographical entity are in the same database simultaneously so as to incur a large amount of data redundancies and inconsistencies; the other is that the maintenance of multi-scale spatial databases, especially updating, is very difficult because there no relations and interlinkages among the multiple representations of the same geographical entity at different scales so that the propagating update cannot be implemented. Automatic generalization of spatial data is an effective method for building multi-scale spatial databases to avoid the problems mentioned above. However, automatic generalization about geographic information has not been regarded as thinking means for recognizing and modeling the geographical world for a long time, so that automatic generalization has been only as an algorithm to derive different representations in digital mapping, and then it cannot control spatial objects in object detail levels in database, which are the counterparts of the geographic entities, but only change their appearances. That is to say, scale has not been regarded as a fundamental dimension like space and time in presentation for spatial data model in geographical database so that existing GIS has no ability at scale dimension. Moreover, most of existing automatic generalization algorithms do not relate to scale directly or accurately, not forecast and control effectively the details to be generalized with scale changing, and so the scaleless and on-the-fly representations of spatial data cannot be obtained.

The best data model in a multiple representation database (MRDB) should be: objects could hold different representations, which are related to each other so as to propagate updating from one database to the others; the best structure for multiple representation database management should satisfy with coherence, updating, derivation (Anne Ruas, 2002). This paper suggests a new data model for MRDB, which can decompose geographic information space scale-dependently, describe the scale behavior of spatial object, construct and maintain spatial objects at different scales dynamically and incrementally, and build the logical links among the objects at multiple scales so as to transform one representation of spatial data to the others and propagate updating from one database to the others completely. The increments in the model are the key issues, which describes the detail changes of spatial objects between scales.

2 INCREMENTAL OBJECT-ORIENTED MODEL FOR MULTI-SCALE SPATIAL DATABASE AND ITS COHERENT DERIVATION

2.1 Incremental object-oriented model for multi-scale spatial database
The main idea of incremental object-oriented model for multi-scale spatial database is that every spatial object in database is regarded as a multi-scale spatial object, and every multi-scale spatial object is composed of the approximate and the detail components. The detail indicates the changes of the same object between scales when roll-down or roll-up with scaling, and the approximate is the primary component of spatial object at a scale, which is the skeleton and is unchangeable relatively. This structure is demonstrated in figure 1.

The incremental object-oriented mode may be defined as tuple:

\[ \text{MGeoObjects}=<\text{OID},\ A_j,\ D_j> \ (1) \]

Where: MGeoObjects is a multi-scale spatial object, OID is its identifier, A_j is the subspace composed of approximate component of the relevant spatial object, and D_j is the sequence of subspaces composed of detail component of the object, which describe the change increments between scales; j is scale.

Every MGeoObjects is composed of an approximate subspace A_j and sequence of detail subspaces D_j. A_j and D_j can be gained by using some special mathematic algorithms such as decomposition of wavelet analysis. The combination of A_j and D_j is a full spatial entity, and this process can be implemented completely by using reconstructing algorithm of wavelet transformation. The whole geographic information space is composed of many MGeoObjects, i.e., the whole space is decomposed by MGeoObjects.

This decomposition structure is demonstrated in figure 1.

\[ S = A_1 + D_1 \]
\[ = A_2 + D_2 + D_1 \]
\[ = A_3 + D_3 + D_2 + D_1 \]

Figure 1. The decomposition structure of a multi-scale spatial object

2.2 Coherent Derivation Through Automatic Generalization Based on the Model

The key for constructing the incremental object-oriented mode mentioned above is how to found and maintain the subspaces nested at multiple scales for geographic information space, and the characters of these subspaces accord with the general principles about abstract and generalization of geographic information in cartography.

It is important that spatial objects at multiple scales preserve consistency in order to avoid incorrect answers for queries performed at different levels of detail (LOD), i.e., coherence can ensure the result of querying at a coarser scale is the same or alike at least as at a finer scale.

Coherence is based on preserving the common spatial structures and characteristics of the same object at different scales in our model. The spatial structures at the finer scale should be still preserved at coarser scale, and the spatial structures at the coarser scale must be contained in those at finer scale when generalizing and transforming.

When A_{j+1} is decomposed into A_j and D_j, the coherence can be implemented by preserving A_{j+1} and A_j equal or compatible or approximate in our model because A_j and D_j can be modified respectively at different scale j. This derivation of A_j through generalizing A_{j+1} based on the model is coherent. Any scale-dependent automatic generalization methods can be available in the model as generalization algorithm operators.

Therefore, the process of coherent derivation through automatic generalization corresponding to the model can be defined as:

\[ A_j' = A_{j+1} + D_{j+1}' \ (2) \]

D_{j+1}' is the modification for D_{j+1} in order to change A_j' between A_j and A_{j+1}. Consequently, the coherence can be maintained between the adjacent scales. D_{j+1}' describes the incremental details when generalizing from A_j to A_{j+1} and then resulting in A_j'. The derivation process can be inversely at all, i.e., D_{j+1}' also describes the change details when transforming from A_{j+1} to A_j which can be called combination.

To construct and implement the model, the key is to identify the contents be decomposed and how to decompose. The contents decomposed at multiple scales should be according to spatial, semantic and time attributes of geospatial entity. An example demonstrated in figure 2 is decomposed and generalized based on wavelet analysis.

3 SUPPORTING ENVIRONMENT FOR CARTOGRAPHIC GENERALIZATION

3.1 The Aim and General Structure for the Supporting Environment

The aim for the Supporting Environment is experienced so as to implement the principal derivation and propagate updating incrementally for geographical features in the National Fundamental Geographical Database of China based
on the model mentioned above and automatic generalization algorithm operators. The incremental produce for the fundamental geographical spatial data is to increase or decrease the detail of geographic information step by step so as to approach to the best results.

The Supporting Environment is integrated with a serious of application programs and DLLs or COMs etc, which can be redeveloped farther for some application. The functional structure of the supporting environment is sketched in Figure 3.

Figure 3. The functional structure of the supporting environment

The logic structure of the supporting environment is organized in hierarchy including task or project area (several maps), maps, and feature layers (coverages), objects (geometric and semantic describes) from higher to lower, and its database is redeveloped based on Oracle Spatial. The logic structure of the supporting environment is demonstrated in Figure 4.

Oracle Spatial is a suite of operate COMs for spatial objects in Oracle 9i. It can store and access and analyze spatial data efficiently and quickly because its work is based on the unique object-relation data model, and it supports
3.2 Implement Mode of Generalization Task in the Supporting Environment

To a source map data at a certain scale, the generalization is confirmed from feature coverage to geometric object according to adopted generalization methods and working sequences. A generalization task can be described formally as follows:

Generalization Task: <Source Map Number, Source Map Scale, Accuracy of Source Data, Source Reference; Target Map Number, Target Map Scale, Accuracy of Target Data, Target Reference; Name of Generalization Rule and Parameter Database; Map Specification; Geographical Describe about Mapping Region>

The implement mode of generalization operating for an object need to be generalized can be described formally as follows:

(Object, Operate): < Generalization Task , Feature Coverage, Features, Feature Class, Generalization Methods, Generalization Fields, Field value, Incremental interval>

The generalization implement for an object in a generalization task rests with the coverage where the object locates and which feature and class the object is, and the selected generalization algorithm, generalization fields and their value, incremental interval and threshold.

The implement flow of generalization in the supporting environment is sketched as:

Constructing a new task → Input source data and display → Activate and create generation feature coverage → Extract the Object need to be generalized → Confirm generalizing parameters and suitable rule database (algorithms oriented feature or object) → Selecting generation method → Confirm and analyze generalization fields → Confirm the extent of generalization fields and their incremental interval and threshold → Implement generalizing → Inspect with graphic display → Quality assessment → Store the generalized coverage.
5 CASE DEMONSTRATE IN THE SUPPORTING ENVIRONMENT FOR CARTOGRAPHIC GENERALIZATION

Some examples in the supporting environment for cartographic generalization are demonstrated in the follow figures. The figure 5 is main interface environment for cartographic generalization based on the incremental object-oriented model. The figure 6 is the interface for incremental generalization by using wavelet analysis. The figure 7 is the generalized result contours of terrain overlapped on the contours before generalizing.

Figure 5. The main interface environment in InMapping Sof.

Figure 6. The interface options for incremental generalization by using wavelet analysis.
Figure 7. The generalized result contours of terrain feature by using wavelet incremental generalization overlapped on the contours before generalizing. The left figure is a full map at 1:50000 and the right is a counterpart zoomed in left boxed picture.

8 CONCLUSION

This paper represents an incremental object-oriented model for cartographic generalization in multi-scale spatial database and describes its implemental support environment. This model divides every spatial object into two sections according to the scales or the content details, the one is a principal or core part, and the other is detailed or supplemented parts. Every part can be modified freely according to the needs of applications through the generalization operators. A new spatial object can be reconstructed or produced through assembling the core part and the relative detailed parts by supplementing or decreasing information incrementally at any scales, and then stored into a new coverage in databases. The generalization operators are composed of a set of scale-dependent automatic generalization algorithms, which can control spatial objects in object detail levels incrementally with scale changing so as to acquire any detail spatial objects dynamically and continuously. The updating of spatial databases can be implemented through propagating the details across scales and then modifying the objects needed to be updated. Taking InMapping Soft. as examples, the model has been implemented partly and demonstrated.

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