CATEGORICAL DATABASE GENERALIZATION AIDED BY DATA MODEL

Liu, Y[1]., Molenaar, M[2]., Ai, T[1]. and Liu, Y[1].

[1]School of Resource and Environment, Wuhan University,
Wuhan, 430072, P.R. China. E-mail : yaolin@itc.nl
[2]Department of Geo-Informatics, International Institute for Geo-Infomation and Earth Observation
7500 AA, Enschede, The Netherlands. E-mail: molenaar@itc.nl

ABSTRACT

This paper focuses on the issues of categorical database generalization and emphasizes the roles of supporting data model, integrated data model, spatial analysis and semantic analysis in database generalization. The framework contents of categorical database generalization transformation are defined. The paper presents an integrated spatial supporting data structure, a semantic supporting model and similarity model for categorical database generalization. The concept of transformation unit is proposed in generalization. The paper concludes with an application of categorical database generalization.

Keywords: Categorical Database Generalization, Data Model, Hierarchy, Semantic Evaluation Model, Transformation, Transformation Unit.

1. INTRODUCTION

The main objective of database generalization is to derive a new database with different (coarser) spatial/thematic/temporal resolutions from existing more detail database(s), for a particular application.

To a large database, efficiency in storage and access to multi-scale and multiple representation data as well as complex generalization operators need to be supported by powerful data model and data structure. Although existing data models such as Delaunay triangulation networks (Delaunay 1934) and Formal data structure (Molenaar 1989, 1991,1995) are applied to support automated generalization , The development in this area (Peng 1997) is still early stage and requires the investment of much more effort. Categorical database generalization relies on the exploitation of hierarchies which are inherent to spatial data (Molenaar 1996; Richardson 1994; Martinez Casanovas 1994, 1996; Smaalen 1996). For categorical database research, several people have done some works. Molenaar (1996) proposes four strategies of database generalization. Robin Fuller and Nigel Brown (1999) discuss automation generalization the land cover map of Great Britain. Wang (2001) elaborates area geometric aggregation. Yet, these past studies emphasize on the geometric and visualization aspects only. For example, an area with a size smaller than 25 x 25 m^2 will be eliminated; the gap between two area features smaller than 5 pixels will be bridged. But there is lack of method research of supporting data model, statistics analysis, semantic analysis and spatial analysis in categorical database generalization. Supporting data model, statistics analysis, semantic analysis and spatial analysis play a key role in the operations in generalization.

The following part of the paper is organized as following, the semantic supporting data model for database generalization transformation are defined, followed by transformation model and semantic similarity analysis model are elaborated. Then the concept of transformation unit for transformation process is proposed. Finally the examples are demonstrated.

2. SEMANTIC SUPPORTING MODEL FOR DATABASE GENERALIZATION

The contents of categorical database are always closely related with a taxonomic system. i.e., soil database with soil taxonomy system and landuse database with landuse taxonomic system etc. The taxonomic system is used in the real world to establish hierarchies of classes that permit us to understand, as fully as possible, the relationships among entities and between entities and properties which are responsible for their character in the real world. Some concepts must be defined before discussing semantic model.

2.1 Class, Object type and Object

In this paper, the class and object type have the same meaning. A class or object type is defined by the attributes shared. A class or object type determines a set of attributes to form its attribute structure. An object is an instance of an object type or class.

The attribute structure of objects is determined by the class to which they belong, so that each object has an attribute structure list containing one value for every attribute of its class. An object inherits the attribute structure of a class to which it belong to. The thematic description of an object can now be specified by its class (which specifies the attributes for the object) together with the list of attribute values.

2. 2 Classification Hierarchy and Aggregation Hierarchy

Classification and aggregation hierarchy play a key role in defining conceptual data model of categorical database since the object types in the conceptual data model are meaningful within a certain classification and aggregation hierarchy. Before a categorical database can be built, the classification structure must be chosen (Molenaar 1998) and aggregation structure must be specified.

The classification hierarchy is used in the context of database. A classification hierarchy is expressed as an object type hierarchy that represents levels of object specificity. Furthermore, a classification hierarchy as an abstraction type organizes levels of both objects and object type definition and reflects the abstract level of objects in the database. For categorical database which is always related to a taxonomic system in a certain application filed, a classification hierarchy is derived from the taxonomic system. In this sense, we can say that the object types in the classification hierarchy correspond to the classes in the taxonomic system. The super object types and sub object types in the classification hierarchy correspond to the super classes and sub classes respectively. The objects of the object type correspond to the entities of the class. This system can be easily transformed into classification hierarchy in the database (see Figure 1).

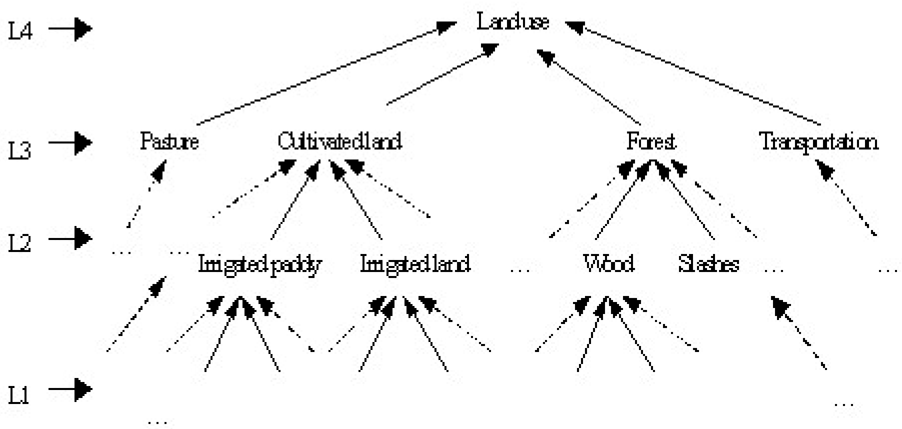

Figure 1. Classification hierarchy.

Aggregation hierarchy is expressed as how a higher-order object is organized by lower-order object types that belong to different classification hierarchy in the sense that the aggregation hierarchy can be derived from the classification hierarchy with a certain application purpose.

Even though we can specify the relations between higher-order object type and lower order object types to build an aggregation hierarchy, the specifying relations are normally based on the classification hierarchies. In function, the classification hierarchy will help us to find the objects we need, because it has sorted and categorized them in the categorical database. Once we have found them, the aggregation hierarchy tells us what to do to put them together meaningfully, such as an aggregation of river and road object types into a transportation network develops a significantly different definition from the individual definitions of river classification and road classification (see Figure 2)

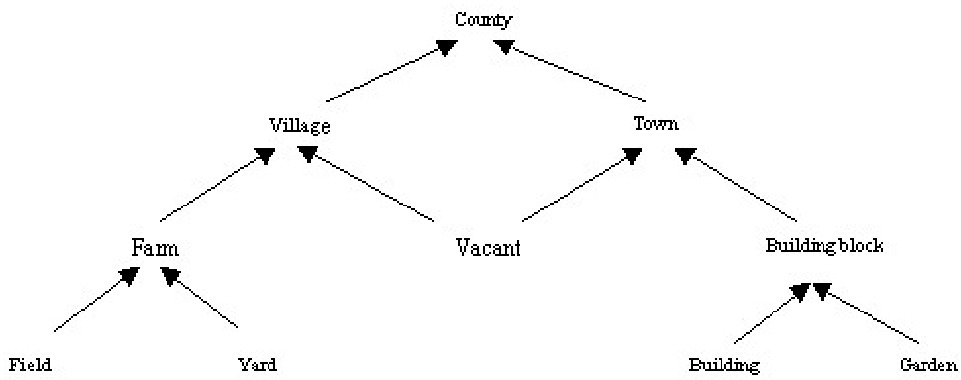

Figure 2. Aggregation hierarchy.

For the categories database, object types, attribute structure of each object type and relationships among object types in the conceptual data model are normally decided by the object types at the lowest level in the classification hierarchy or aggregation hierarchy in categorical database. As shown in Figure3.2, the object type rice, maize and so on at the level 1 in classification hierarchy consist of the object types of conceptual data model in landuse database.

3. TRANSFORMATION MODEL OF DATABASE

The database generalization can be considered as the transformation of the content of a spatial database from high resolution to a lower resolution terrain representation (Molenaar 1996). In fact, database generalization is a transformation from one existing state of a database at certain detail level to a new state at less detail on the basis of the application and useer's requirements (see Fig.3).

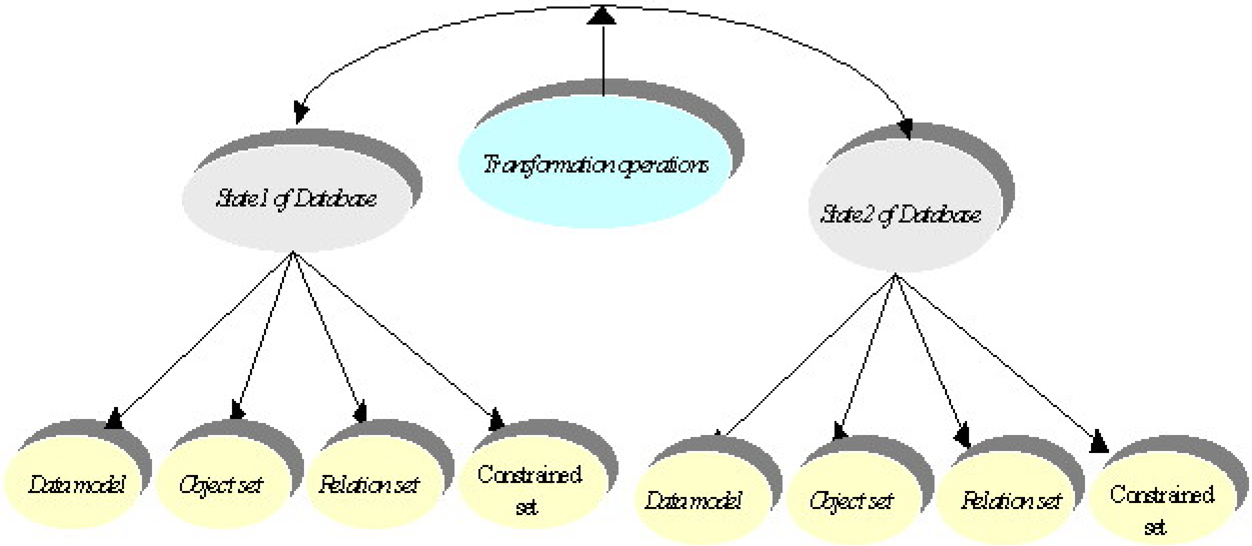

Figure 3. Transformation Model.

The state of database (SDB) can be specified by a five Tuple:

$$SDB=\{ M, O, R , C ,P\}$$

Where:

SDB is the state of database at a certain detail level;
M is the set of conceptual data model, $M=\{m_i\}$;
O is the set of objects, $O=\{o_1,o_2, o_3,\ldots,o_i\}$;
R is the set of relationships among the objects, $R=\{r \mid r\in O\times O\}$;
C is a set of conditions or constraints for transformation.
P is a set of operators
In categorical database transformation, several aspects must be taken into account.

3.1 Conceptual data model transformation

Conceptual data model is an abstraction of real world of interest field. It consists of object types and relationships among the object types in the context of database. It plays an important role in database transformation. It determines what object types and which instances of these object types, should be contained in the database. It determines the degree of detail of the target database and the contents of database as well. Database is the instance of conceptual data model. In a sense, we can say that database generalization is the transformation from one data model of an existing database to another data model of a generalized database based on the application purpose and requirements. This means that if the user introduces a new conceptual data model, it will lead to a database transformation from high resolution to lower resolution. For the categorical database, the conceptual data model of a database has a close relationship with the classification and aggregation hierarchy and taxonomic system in application filed . The classification and aggregation hierarchies play an important role in linking the definition of spatial objects at several scale levels (Molenaar 1996, Peng 1997, Peng and Tempfli 1997, Richardson 1993 and Smaalen 1996) and definition of spatial object types at several scale levels.

These hierarchies play an essential role in defining the conceptual data model of the categorical database. Before transforming an existing database to a new database, a new data model associated the new database must be defined.

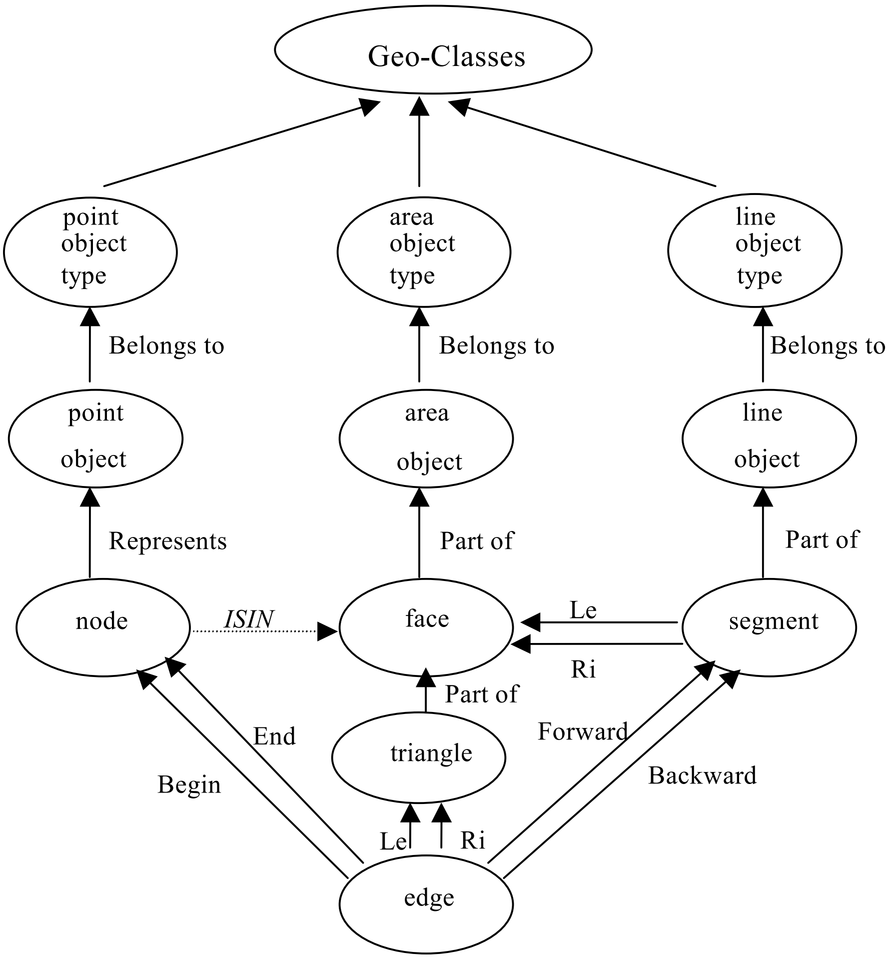

Figure 4 The Data model for database generalization
(modified fromMolenaar 1998)

3.2 Object and relations among objects transformation

In a sense, objects and relations among objects consist of concrete content of a database. An object is an instance of an object type. When an existing data model is transformed into a new data model, a set of object types which consists of an existing data model will be replaced by a set of object types of new data model. When object types are changed, their instances will be changed as well. This replacement will result in the transformation of objects and relations in existing database. This means that when object types are changed, their instances will be changed as well. Some objects in existing database maybe disappear or are merged or form new objects in the new database. The change in objects will induce change in relations among the objects. For example, two spatial adjacent objects with different attribute in existing database will be merged to form an homogeneous object, if their attribute becomes the same. The adjacent relation between the objects will disappear after merged. Transforming the objects and relations among the objects from the existing database to a new database is concrete content of database transformation. The transformations of objects are involved with the geometric and thematic properties of the objects. The transformations of relations include ones of spatial and semantic relations.

Object and relation transformation deal mainly with the preservation of typical shapes (on the object level) or with the preservation of spatial patterns and alignment*s* of objects, whereas Conceptual data model transformations deal with the preservation of the logical context of objects and degree of detail (on the object type level). Data model transformation control objects and relations transformation.

3.3 Transformation conditions or constraints

The transformation of a database is of conditional. Database transformations are controlled by a set of conditions (i.e., application purpose and requirements), called constraints. These constraints govern, or guide the transformation process of database.

Before transformation, the constraints which will influence the transformation must be identified and classified. They are application-dependant. The constraints of the transformation are involved with the aspects of conceptual data model, spatial and semantic properties of objects and relations among objects. The constraints have the properties of multi-level.

3.4 Transformation Operations

To finish transforming database from high resolution to low resolution, some operations are needed to implement these transformations. Some of researchers have discussed operations in the map generalization and database generalization from different point of view (Weibel 1988, Langram 1991, Beard 1991, MaMaster 1989, Molenaar, 1996, Peng 1996, Marc 1999, Mckeness 1994, and Mackness & Purvess 1999) . Operations to the object type level and operations to the object level are quite different. Object types are at higher level than objects in the database in the sense that the former is at decision level and the latter at the operational level in the process of building new database. The operations which will be introduced in the database generalization should reflect this characteristic.

4. SPATIAL SUPPORTING DATA STRUCTURE

Categorical database generalization is a process of analyzing, understanding and decision-making on geographical objects. Not only the information about the object, but also the information about the environment (such as neighbors) that constraints the behavior of the object are all require in the process. On the other hand, the process also requires not only geometric data of the object, but also attribute data of the object. In this case, it needs adequate data structure which can be used to represent the objects and detect the natures of spatial relationships and interaction among geographical object in database to support generalization decision-making and operation implementation.

4.1 Integration of FDS and Delaunay Triangulation Network

Formal data structure for single valued vector maps (Molenaar 1991, 1998) is an object-oriented topological (conceptual) data model, which combines aspects of object-oriented and topologic data model. point, line and area objects are represented with their geometric and thematic aspects. Their geometric representation contains information about topologic object relationships, whereas their thematic description is structured in object classes that may form generalization hierarchies. Such class hierarchies in combination with the topologic object relationships of FDS supports the definition of aggregation hierarchies of objects. These classification and aggregation hierarchies play an important role in linking the definition of spatial objects at several scale levels (Molenaar 1996. Peng 1997, Peng and Tempfli 1996, Richardson 1993 and Smaalen 1996). An important property of Constrained Delaunay Triangulation (CDT) is the adjacent relationship between two points connected by a Delaunay edge. Each Delaunay edge in Delaunay triangle represents topology between two points. The triangulation is equilateral as possible, so that the unexpected effect of long elongated edges can be minimized. Constrained Delaunay Triangulation can be used for defining adjacent relation among connected or disconnected objects, and conflict detection and displace of spatial objects, finding nearest neighboring object to a given object in generalization (Ware et al 1996, Chris B. Jones et al 1998, Wanning Pan 1997 etc). The CDT can also be used to measure the spatial relations such as measuring disjoint relation, distance relation and direction relation. For category database generalization, CDT is very useful to analyze and measure local spatial relationship but not to organize the whole data set since a simple area object will consist of a lot of triangles that will lead to date redundant too much and also lead to the difficulty of semantic analysis among objects. CDT may be generated dynamically and locally at a certain step of a generalization process.

In the real world, the concept of adjacent may also include the adjacency relationship between those area objects that are geometrically disconnected from each other, as well as the adjacency relationship between line objects, between point objects, and moreover, the adjacency relationship between objects of different geometric description types. FDS can not support these kinds of adjacent and inclusion relation. In order to make full use of advantages of FDS and CDT, the advantage of FDS and CDT are combined into developing a data model which is dynamic integration of FDS and CDT in database generalization transformation process (see Fig.4).

5. SEMANTIC SIMILARITY ANALYSIS MODEL

Whether the two adjacent objects or an adjacent group of objects can be merged or aggregated depends on if the attributes of the two objects are same or similar or not. If the attributes of them are same or similar or higher than the threshold, they can be merged or aggregated. Otherwise not. The closeness or similar among objects and object types can be described by the similarity. The similarity is application-dependent. Classification and aggregation hierarchy are an ordered structure as discussed before. These hierarchies can reflect the similarity between object types at the same level and at the different levels. In a sense, the similarity will control and guide database transformation operations.

5.1 Hierarchic Semantic Similarity Matrix

For a hierarchical structure as shown in Figure. A semantic similarity matrix can be defined based on the properties of the hierarchical structure as shown in Figure 5.

The semantic similarity matrix represents the similarity between objects, between object and object type, and between object type and object type.

SIMILARITY	Obj1	Obj2	…	Sub-type1	Sub-type2	…	Sup-type1	Sup-type2	…
Obj1	s_{11}	s_{12}	…	s_{14}	s_{15}	…	s_{17}	s_{18}	…
Obj2		s_{22}	…	s_{24}	s_{25}	…	s_{27}	s_{28}	…
…			…	…	…	…	…	…	…
Sub-type1				s_{44}	s_{45}	…	s_{47}	s_{48}	…
Sub-type2					s_{55}	…	s_{57}	s_{58}	…
…						…	…	…	…
Sup-type1							s_{77}	s_{78}	…
Sup-type2								s_{88}	…
…									…

Figure 5. Matrix of similarity.

Where: obj1, obj2 etc denote different elementary objects; Sub-type1, sub-type2 etc denote different elementary object types; sup-type1, sup-type etc denote composite object type. s_{ij} denotes similarity value between matrix elements.

The larger the value of a element in the matrix is, the closer or more similar the objects or object types that the element links are. The matrix is symmetric and reflexive one, and has the property that s_{ij} is equal to s_{ji} ($s_{ij} = s_{ji}$) and s_{ii} is equal to s_{jj} ($s_{ii} = s_{jj} = 1$) in the matrix. s_{ji} is a value between o and 1.

This matrix has the characters of hierarchy and shows the similarity between same level of objects and between different levels of objects. This will provide potential possibility for between same level of objects and between different levels of objects to be merged or aggregated. This also means that different levels of objects can be kept in a spatial database. The similarity matrix will be used as a look-up table for guiding or governing the aggregation process of spatial objects in semantic to a certain application.

The value of element s_{ij} in the matrix can be given by expert knowledge or the calculation based on the aggregation hierarchy and classification hierarchy and requirements and purposes of database generalization.

5.2 Computing Model of Similarity

Using set theory, Tversky (1977) defined a similarity measure in terms of matching process based on the normalization of Tversky's model and set-theory. This measure produces a similarity value that is not only the result of the common, but also the result of the different characteristics between objects, which is in agreement to an information theory definition of similarity (Lin,D 1998).

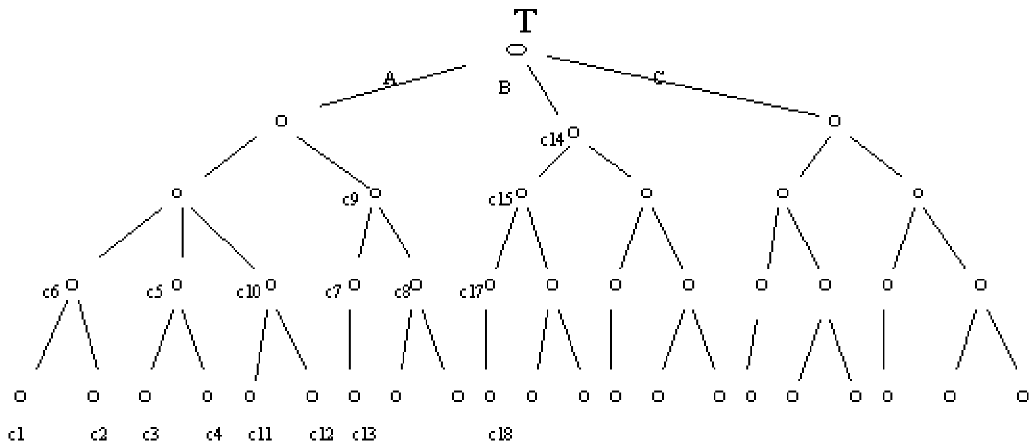

Figure 6. Example of hierarchical structure.

A natural approach to comparing the degree of similarity between object types is to determine the distance from these object types to the immediate super object types that subsumes them, that is, their least upper bound in a partially ordered set (Birkhooff,G, 1967). A computational model that assesses similarity among objects and object types based on some definitions, concepts and hierarchical structure. The similarity model for categorical database is proposed in equation 1. It suits for two cases. One is for two given objects or object types belonging to the same sub tree such as A in Figure 6 and the other is for two given objects or objects belonging to different sub tree as shown A and B in the same Figure. For the first case, the model uses two types of distances to define the common and difference properties between the given objects or object types. One is the distance between given objects or object types and immediate super object types that subsumes them which reflects difference properties between two given objects, or object types and the other is the distance between immediate super object types that subsumes two given objects or object types and the top of hierarchical structure which reflects the common properties of two given object or object types. For second case, the distance between immediate super object types that subsumes two given objects or object types and the top of hierarchical structure will be zero since the two given objects or object types belong to different sub tree. So this distance will be replaced by the correlation value between two sub trees in the equation.

$$S_{ij}(c_i, c_j) = \begin{cases} \dfrac{l}{l + \alpha(c_i, c_j) * d_{ci} + (1 - \alpha(c_i, c_j)) * d_{cj}} & (c_i \text{ and } c_j \in \text{same sub-tree}) \\ \\ \dfrac{\beta}{\beta + \alpha(c_i, c_j) * d_{ci} + (1 - \alpha(c_i, c_j)) * d_{cj}} & (c_i \text{ and } c_j \notin \text{same sub-tree}) \end{cases} \quad (1)$$

Where:

l: the shortest distance (number of the link edge) from immediate super object type that subsumes c_i and c_j to the top of a
hierarchy;

d_{ci}: the shortest distance (number of the link edges) from immediate super object type that subsumes c_i and c_j to c_i ;

d_{cj}: the shortest distance (number of the link edges) from immediate super object type that subsumes c_i and c_j to c_j ;

α : a function of the distance (number of the link edge) between the object types (c_i and c_j) and the top of a hierarchy.

β : correlation degree among different sub-trees (A or B in figure), such as similarity among agriculture land use, forest land
use and building up land use, and its value can be given by experts based on application requirement.

The α (c_i, c_j) can be expressed as a function of the distance of the d_{ci} and d_{cj}. in order to final values of α , the function (equation (2)) is defined as following:

$$\alpha(c_i, c_j) = \begin{cases} \dfrac{d_{ci}}{d_{ci} + d_{cj}} & (d_{ci} \le d_{cj}) \\ \\ 1 - \dfrac{d_{ci}}{d_{ci} + d_{cj}} & (d_{ci} > d_{cj}) \end{cases} \quad (2)$$

where:

d_{ci} : the shortest distance (number of the link edges) from immediate super object type that subsumes c_i and c_j to c_i ;

d_{cj} : the shortest distance (number of the link edges) from immediate super object type that subsumes c_i and c_j to c_j ;

This similarity function yields values between 0and 1. The extreme value 1 represents the case when everything is common between two entity classes, whereas the value 0 occurs when everything is different between two entity classes.

6. TRANSFORMATION UNITS AND THEIR CREATION

Transformation unit is a group of objects or object types, in which there are adjacent relations among these objects or semantic relations among these object types and there exist at least one conflicted object or conflicted object type.

The conflicted object is the seed through it to find a set of objects which have adjacent relationship with it to form a *transformation unit*. Transformation unit proposed in this paper is an important process unit as many generalization problems need to be solved by considering a subset of related objects as a whole, rather than treating them individually. In a sense, it is a basic analysis, processing and decision-making unit and plays an important role in database transformation. Transformation unit that "bring together" a subset of objects can be created by semantic and /or geometric or spatial relation or integrating them constraints in spatial objects. Four types of transformation units are considered in this study, each of which requires a different generalization solution.

6.1 Creating Transformation Unit Based on Thematic Constraints
After data model associated with original database being changed into a new data model with a target database, the first step we should take is that detecting thematic conflict of adjacent objects. Thematic conflict of adjacent objects is the adjacent objects having the same thematic attributes or the similarity value among spatial adjacent objects is higher than the threshold. This group of adjacent objects with thematic conflict will be built as a transformation unit.

6.2 Creating Transformation Unit based on Geometric Constraints
The objects that violate geometric constraints and their spatial adjacent (connected) neighbors will be built as different transformation unit.

6.3 Creating Transformation Unit Based on Spatial Relation Constraints
A set of adjacent (disconnected) objects in which the distance (space) among them is less than the threshold will be built as transformation unit.

6.4 Creating Transformation Unit Based on Geometric and Spatial Relation Constraint
A set of adjacent (connected or disconnected) objects in which there exist geometric and spatial relation conflicts (violated geometric and spatial relation constraints) will be built as transformation unit

Figure shows the relation among data model, transformation operations, constraints, classification and aggregation hierarchy and transformation unit.

7. CASE STUDY

Figure 7 shows a part of subset land use database, in which original land use data are organized following the concept of FDS in thematic and geometric aspects. Then the data are processed to meet the requirement of triangulation network in order to analyze the spatial relations and detect conflicted objects.

After establishing new classification hierarchy, and implementing changing attributes of the objects in a database, transformation unit based on thematic meaning must be formed. Before objects aggregation, the similarity evaluation among objects within a transformation unit must be taken. Figure 7 shows that the thematic conflict objects with dash line. The thematic conflicted objects will be aggregated with the object which has the same object type at next higher level or the semantic similarity value with the conflicted object higher than the threshold.

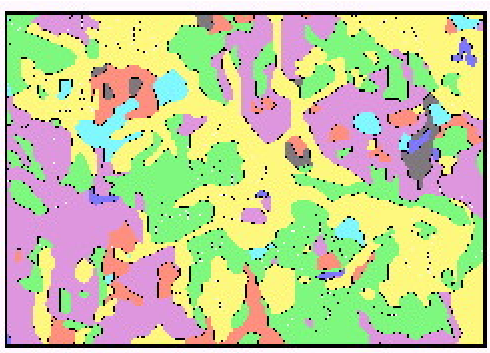

Figure 7. A set of landuse Database.

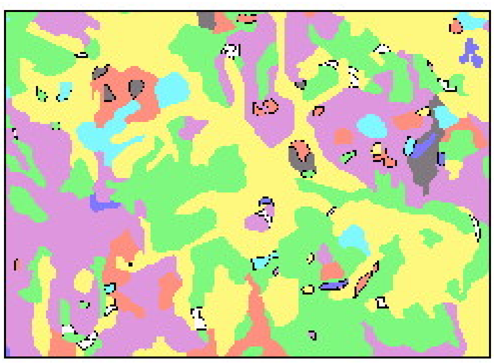

Figure 8. Examples of conflicted objects.

A number of unimportant small objects or their area is less than area threshold will be first detected (see Figure 8) in order to build the transformation. These conflicted objects will be as seeds to form transformation units. For a conflicted object an object (s) will be find using triangulation network which a higher similarity or same object type at next higher level with it. If the distance between these objects is less than the distance threshold, then they form a transformation unit. Later they will be aggregated according to algorithm proposed in chapter 6. If there exist no these object (s), a conflicted object with its adjacent objects will form a transformation unit.

The semantic similarity among the objects will be evaluated based on the model within a transformation unit. The object having the highest semantic similarity with the conflicted object within the transformation unit will be selected and will be aggregated with the conflicted object. Figure 9 gives examples of transformation units. Object Aggregation (objection transformation) Figure 10 shows the result of a subset of land use database generalization.

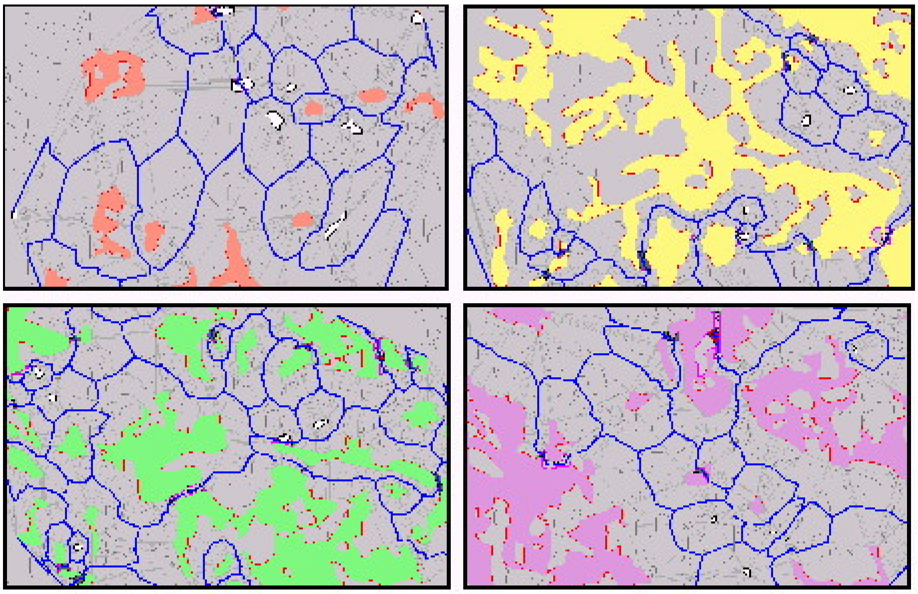

Figure 9. Examples of transformation unit.

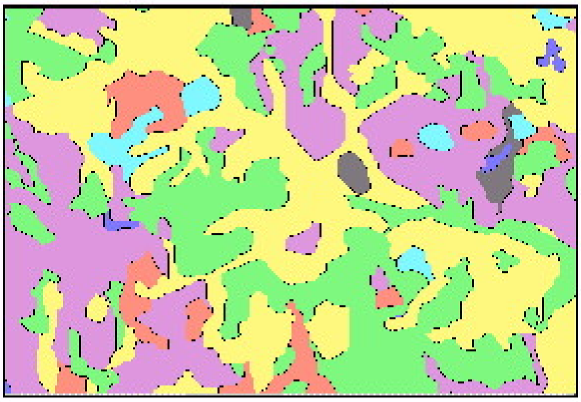

Figure 10. Result of case study.

8. CONCLUSION

This paper introduced contents of categorical database generalization, integrated and enhanced spatial supporting data structure and semantic evaluation model for database generalization. This data model and integrated data structure and the evaluation model in combination with classification and aggregation hierarchy play a very important role in data description, organization, spatial analysis, decision-making and implementation of database generalization transformation. Transformation unit provide the information about processing objects which makes more efficient and effective spatial analysis and process.

This research has been supported by National Natural Scientific Foundation and Research Fund of International Institute of Geo-information Science and Earth Observation.

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