A MULTI-SCALE ROAD VISUALIZATION METHOD IN NAVIGABLE DATABASE

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ABSTRACT:

In order to provide users with the function of navigating across different details of level, ranging from overview screen to detailed views, it is necessary to display these representations with different detail levels at a successive and smoothly transformation order, the existing methods for multi-scale visualization are integrated and extended in the paper, and a new method, named as 'object interpolation' is proposed, which describes the method and process that deriving the object at a middle scale from the representation objects at the larger and smaller scales. In the context, and the interpolation principle, overall framework and technical flow are put forward. Then, the object interpolation function is defined and described, which reflects the inheritable and transferable characterizes of quantitative, structural, geometrical, semantic, topological and attribute related information among multi-scale representation objects. At last, a case in point is given to indicate that the new method is a guarantee for multi-scale visualization to objective selection of the road objects at middle scale.

1. INTRODUCTION

As an important component of embedded spatial application system (such as LBS, ITS), multi-scale geographical navigable database plays a critical role in route planning and road guiding operation. Compared with other traditional databases, geographical navigable database is characterized by multi-scale geographical features, which means that several representations at different levels of detail and scales representing the same feature in the real world are stored in the database. In order to provide users with the function of navigating across different details of level, ranging from overview screen to detailed views, it is necessary to display these representations with different detail levels at a successive and smoothly transformation order, which is also the core question of multi-scale visualization.

However, the multi-scale geovisualization switching among different scales indicates the possible change of representations a geographical feature undergoes when moving from one representation to the next, and these transformations are manifold: objects may keep their representation, they may change their geometry, type or attributes, merge with other objects, or disappear completely. Obviously, these changes are influenced by objects themselves, their semantics, their geometric properties, and the given application.

Specially, at present, in many countries, e.g, China, there have initially established multiple road databases at from 1:500 to 1:4,000,000 scales , which corresponds to the region range from national level, province level, to city level, however, in these databases, there only consist of several key scales of datasets, just confined by the technological and equipment conditions restriction during the process of database building, usually the selected scales is the nationally basic scale series consist of such as 1:500,1:2000,1:10,000,and so on. at the same time, when people travel among a bigger activity district scope, they usually need to use and accommodate several scales of road maps , linking corresponding representations from different scale, and to design and optimize the travel route, to search for the interesting road target and then to calculate their locations and visualizations. However, in digital computer environment, when different analogue maps are digitized and stored separately, the functions of successive display and matching among objects at different scales have not been developed in existing GIS spatial database. It is impossible to find the corresponding objects, promulgate update information, so as to show absonant and discrete zoom at different scales, which will cause to ill result.

For the purpose, this paper will focus on the multi-scale visualization, the structure is organized as follows, in section 2, the related work on visualization and multi-scale visualization is reviewed. Section 3 and 4 will reveal the essential problem of multi-scale visualization and introduces a new method, namely object interpolation, and will discuss in details the object interpolation model and its application strategies. in section 5, a case in point is given to show the feasibility and effectivity. At last, the conclusion and perspectives are drawn about the study.

2. RELATED WORK

Visualization is the exploration of data graphically in order to understand it. Scientific visualization which is applied to scientific data, often physically based (the human body, the earth, molecules, ...) is commonly distinguished from information visualization which is applied to non-physical data (financial data, abstract conceptions, ...). Geovisualization integrates approaches from different fields (scientific visualization, information visualization, GIS, ...) "to provide theory, methods and tools for the visual exploration, analysis, synthesis and presentation of geospatial data"[1]. Situational visualization, introduced by [2], is different from information visualization and scientific visualization because the user is "experiencing the situation firsthand and in realtime". Visualization in an embedded context is the exploration of data graphically in order to enhance the user's experience and understanding of the surrounding world by using mobile computing resources.

There exist two main solutions for providing a user with multi-resolution data [3] (Figure 1): the *on-the-fly generalization* (A) where different LoD representations are computed in real-time from a detailed map (*G*) and transmitted (*T*) to client upon a query *q*, and *LoD approach* (B) where different LoD representations are pre-computed and stored on the server side and the appropriate LoD is sent to client.

These two approaches present drawbacks and advantages [4, 5]. They are resumed in table 1. The + correspond to advantages: for example for multi-representation, time of access to data is reduced for client, on the server side less calculation power is needed and produced maps are of better quality for user (because "complex and computational expensive methods and algorithms can be used in the generalization"). For on-the-fly generalization, data can be provided to user with more flexibility because LoDs are not defined at fixed levels. The ¡ correspond to limitations: for example for multi-representation the need for existing data (and so on for more storage capacity and for updates of data).

	Data	flexibility	Computational cost	Access to data	Good quality maps
on-the-fly generalization	+	+	–	–	–
LoD approach	–	–	+	+	+

Table 1: Drawbacks and advantages of the two approaches

A third alternative has been chosen by reference [3]: a *combined approach* where "some feature classes are stored as LoD in a multi-scale database, while others are generated in real-time from the base dataset".

From the view of the mobile map application, there are three possible solutions to provide mobile user with different scale maps on a single screen [7]:*Adapted presentation* where different scale maps are viewed in the full window and the user switches between them; *Key-map* approach where different scale maps are simultaneously shown: large-scale map is presented in main window and small-scale one is shown in a little window; *Context + zoom* or *Focus* approach where different scale data are integrated and presented in a same map : peripheral (i.e. contextual) information is displayed with less detail than information in the vicinity of the user's position (i.e. in the focus) . Selective reduction of information can be obtained by filtering and/ or distortion techniques. Distortion oriented technique adopted in reference [7] is a variable-scale mapping function. This provides a map with "a circular cap where the scale is homogeneous and beyond which the radial scale constantly decreases to a threshold value".

This study is devoted to the first solution. Adapted presentation appears more interesting to visualize data on a small screen than second one and it needs less calculation power than the third one. Furthermore it seems more suited to our data *management* strategy because increments are only used during transitions between different levels of detail.

3. THE INTERPOLATION METHOD FOR MULTI-SCALE ROAD VISUALIZATION

3.1. Basic principle

As the problem of multi-scale representation objects selection is concerned, it can be considered indeed as a problem that obtaining the unknown objects making most of the relative information among multiple representations from different scales. So, if the representation objects from the both the larger and smaller scales, then, taking the relative information as information resource, it is possible, also is reasonable to derive the objects at a middle scale, which is also the basic idea of the spatial object interpolation method that combining the existing two types of methods.

Essentially, the multi-scale representation objects have strong corresponding relations in quantitative, attributive, structural, and qualitative properties. On one hand, when considering the relations from the view of the information theory, it is comprehensible that map is a carrier transferring spatial information, and there exist the transferable and inheritable properties, specially the geometrical, structural, attributable and semantic related information among multi-scale spatial representation objects. Similarly, there also exist the transferable and inheritable properties between the known objects, coming from larger and smaller scale data sources, and the unknown objects coming from the middle scale data source. So when solving the problem of deriving the unknown objects at a certain scale, *it* is helpful to take into account of the related information among the certain middle scale, the larger scale, and the smaller scales.

On the other hand, in the view of mathematic theory, it is a so-called "interpolation" that calculating the unknown middle data by uses of the beginning data and the end data. In the similar view, it may be also called an "object interpolation" describing the process of deriving the unknown middle –scale object by use of the larger-scale object information and the smaller-scale object information. In this way, the problem of object objective selection can be solved by the use of "object interpolation" method.

The "object interpolation", interpolating a representation object O（S_2） at S_2 scale whose value locates between S_1 and S_3 scale, can be explained as showed in the figure 1(c): Firstly, to design a *object* interpolation function *f(x)* based on the objects $O(S_1)$ at S_1 scale and the objects $O(S_3)$ at S_3 scale, and then, based on the object interpolation function to calculation the geometrical location and shape of the objects $O(S_2)$ at S_2 scale ($S_1 > S_2 > S_3$).

3.2. Object interpolation method

All the interpolation function (or called model) is usually proposed based on a certain hypothesis. Similarly, as the multi-scale road object interpolation is concerned, it conforms to the following hypothesis: if a representation object is retained at a smaller scale, then it is more important and its weight value is bigger; otherwise, if a representation object is discarded at a smaller scale, then it is less important and its weight value is smaller. So when deciding which object should be retained from a larger -scale dataset to make up of the dataset at a middle -level scale, it seems natural to prefer to retain those objects represented at a smaller scale dataset. In other words, if a object has been represented at a smaller scale, then it should also be represented at a larger scales， which means that a precondition is made to find the corresponding matching objects at larger and smaller scales. In this paper, the hypothesis is that the matching relation of corresponding objects has been established by the proposed aggregation-based semantic hierarchical matching rules [11].

At the same time, from the view of cartography theory, the quantitative relation between objects at two different scale follows the advanced "radical Law", or called "Principle of Selection", which states that the number of objects to be retained on a derived smaller scale map is proportional to the "*x*" root of the objects on the original larger scale map [3, 12]. The variable "*x*" is also called selection grade. In a word, the object interpolation proposed in this paper follows the hypothesis: the objects represented at a smaller scale should be retained at a larger scale; the unknown derived object and the known source objects have a relation of "x root"; all the factors affecting the derived objects could be processed based on a dimensionless approach and be assigned to different weight coefficients reflecting their own importance; the importance of the object at a certain scale could be measured by use of weight values, the bigger weight values at a larger scale, the more possibility represented at a middle scale, otherwise, the trend turns to the opposite direction.

Accordingly, the object interpolation function, according to which the representation object at a certain scale is retained or discarded, can be described formally its rules as follows: the quantitative selection index is subjected to X root principle; the structural qualitative selection index is subjected to the effect of corresponding relations and attributive relations among multi-scale representations; then all factors in the object selection problems are calculated based on the synthetical weight of each object at the larger scale, in this way, the object selection problem at a middle scale can be switched to the problem on the calculation of synthetical weight of each involved object by use of synthetical weight function.

Further, dominating the weight values(importance) of each involved object, the synthetical weight function f_p has close relation to the scale factor (S), the road network structural factor (A) , and multi-scale corresponding factor (C). specially, the larger scale, the bigger weight value; the more important structure, the bigger weight value; represented at the smaller scale, the bigger weight value; those objects that have been represented at a smaller scale has the preferential right to be selected at the interpolation scale.

If the variable N_d is used to represent the quantitative numbers of the objects at the interpolation scale S_2 selected from a larger scale S_1, then when deriving the objects set $\{O_2\}$ at an interpolation scale S_2 from both object sets $\{O_1\}$ at a larger scale S_1 and objects set $\{O_3\}$ at smaller scale S_3, the interpolation function can be expressed as showed in formula (1).

$$\begin{cases} \{O_2\} = \left\{ O_i \,\middle|\, P_{O_i} \ge P_{O_{i+1}},\ O_i \in \{O_1\},\ 1 \le i \le N_d \right\} \\ P_{O_i} = f_p(A, C, S) \\ N_d = N_1 \left(\dfrac{S_1}{S_2}\right)^x \\ x = \dfrac{\lg \dfrac{N_1}{N_3}}{\lg \dfrac{S_3}{S_1}} \end{cases}$$

Formula (1)

It can be observed from formula (1), that the interpolation objects set $\{O_2\}$ representing the features in real world is a subset of $\{O_1\}$ representing the features in real world. In this set $\{O_2\}$, there are N_d objects, the weight value of each of which is bigger than other objects that have been ignored. N_d can be calculated by use of X-Root rule, of which the coefficient x can be calculated by the help of known *variables* N_1 and N_3 in reverse; the weight value P_{O_i} *of* each object can be calculated by use of the synthetical weight function f_p, and the synthetical weight function f_p can be defined by use of three kinds of variable factors, namely the scale factor (S), the road network structural factor (A), and the multi-scale corresponding factor (C).

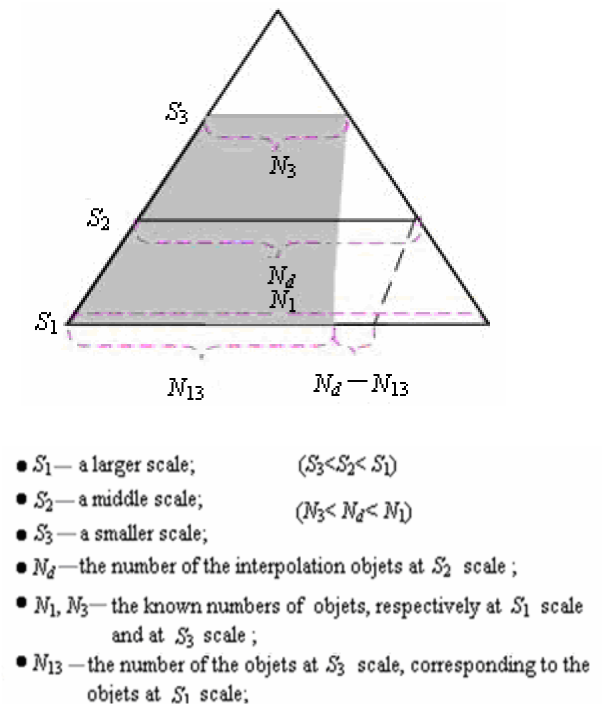

Figure 1. Illustrations of relation between known representations and unknown representations

In this way, in the object interpolation theory, the distribution information of N_d , describing the quantitative numbers of the objects at the interpolation scale S_2 selected from a larger scale S_1, is showed is showed in figure 1: N_d is composed of two parts of objects, one part of objects, N_{13}, corresponding to N_3

objects derived from the objects set at S_3 scale , the other part of objects are selected from the （N_d －N_{13}） objects at S_1 scale , positive proportional to their weight values calculated by use of the synthetical weight function f_p . In fact, N_3 is uncertain to be equal to N_{13}, there exist two possibilities, one is that all the N_3 objects can find their own corresponding objects from objects set $\{O_1\}$ at scale S_1, the other is that some of N_3 objects can not find their own corresponding objects from objects set $\{O_1\}$ at scale S_1. However, in any case, as stated in the foregoing section, since the multi-scale corresponding factor (C) has been considered when designing the synthetical weight function f_p, according the positive sort order, it is doubtless to select those objects holding bigger weight values.

4. THE SYNTHETICAL WEIGHT FUNCTION FOR OBJECT INTERPOLATION

As the road network objects abstracted at different scale are concerned, although there exist many factors that affect the objects' retained or discarded states, such as scale, road type, length, width, connectivity, and so on, each factor has different influence degree on the whole state. Therefore, it is necessary to synthetically evaluate each factor in a proper way. This paper puts forward a multi-factors weighted linear synthetical evaluation method quantitatively and qualitatively[13], and then to form the evaluation model and its indicator system to assign different weight coefficients to different factor, so as to evaluate weight value of each involved object, which reflect the influence degree to the object selection problem. Here, a road object's weight produced by all kinds of factors (i.e., scale, road type, length, width, lane, connectivity) is called its synthetical weight.

Since each factor in the weight function is independent, this paper puts forward a multi-factors weighted linear method to evaluate weight value of each involved object, which is expressed in formula (2).

$$P_j = F_1 Y_1 + F_2 Y_2 + \cdots + F_i Y_i \qquad \text{Formula (2)}$$

As showed in formula (2), variable F_i denotes the weight coefficients of the factor Y_i, the variable "i" denotes the number of the factors. As road network objects are concerned, there have six kinds of factors, namely in order, multi-scale corresponding, road type, length, lane number, traffic direction, width, and connectivity factor, and the weight coefficients F_i of each of them will be discussed in the next section.

At the same time, since road network shows a network graph made up of each road object, and if each intersection or attribute change point is taken as a node, and each road is taken as a edge, then according to the principle of "graph theory", a road network can be abstracted as a graph adaptive to "graph theory".

Therefore, in this paper, the road object's attribute information (e.g., road type, length, lane number, and so on) is assigned to the abstracted node, and the whole road network is abstracted a graph in "graph theory". Then the synthetical weight estimation function is built, based on which the weight value of each edge can be calculated easily, the weight value of a node is the sum of all weight values of edges connecting to it. This way reflects the object's selection trend as follows: the bigger weight value, the more important role in road network structure, and the bigger selection possibility. the detailed work will be discussed in other documents.

5. CASE TEST

The object selection test taken the multi-scale road dataset as samples shows that the selection grade "x" is smaller if the road network is denser, which indicates that most of the involved road objects will be selected based on the "cartographical natural principle". When the scale changes smaller, the selection grade "x" at the smaller scale series (e.g., 1：1000000~1: 50000) changes bigger, which indicates that number of the discarded is getting larger.

Comparing the test result with the corresponding real cartographical representations, the difference is inconspicuous; it also indicates that to a large extent, the factor of "road type" play an essential role in road object selection. So it is also possible to trace the change from the view of the selection grade. the details will be discussed in other materials.

6. CONCLUSION

In a spatial information visualization system, different resolution data have to be provided to user. In order to adapt these data to requested scale, we have adopted an object interpolation based approach with an "intelligent zoom" respecting the principle of constant information density and structural information and semantic information in multi-scale representation, which describes the method and process that deriving the object at a middle scale from the corresponding representation objects at the larger and smaller scales base on object interpolation function. The object interpolation method integrates the merits of both cartographical generalization method and quantified statistics method, and also overcomes their own deficiencies. It not only incarnates the inheritable and transferable characterizes of related information among multi-scale representation objects, but also takes the attribute effects into account when deriving object from the larger scale according to the road importance, which provides a new research method for the derivation of road representation objects.

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