GENERAL ANALYZING AND RESEARCH ON UNCERTAINTY OF MULTI-SCALE REPRESENTATION FOR STREET-BLOCK SETTLEMENT

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ABSTRACT:

Analyzing and evaluating the reliability of multi-scale representation of spatial data are already becoming an important issue of the current digital cartography and GIS. Settlement place is the main content of maps. For this reason, studying on the uncertainty of multi-scale representation of settlement place is one of important contents of the uncertainty of multi-scale representation of spatial data. In this paper, uncertainty of multi-scale representation of street-block settlement was get comprehensive analysis and system research. This paper holds that map generalization is the essential cause leading to uncertainty of multi-scale representation of street-block settlement. First, it is explored of essence and types of uncertainty on multi-scale representation of street-block settlement, and it divides these uncertainties into four large classes and seven subclasses. Second, among all kinds of uncertainties of multi-scale representation of street-block settlement, this paper mainly studies the uncertainty of settlement of street-block symbolic representation, and establishes the evaluation content and evaluation indexes and computing method of uncertainty of street-block and street network generalization and building generalization. The result can use for evaluating the good and bad of scale transfer methods and the uncertainty of products of multi-scale representation of street-block settlement.

1. INTRODUCTION

The uncertainty of spatial data exists in the entire data life cycle（J.C. Cheng, H.D. Guo, W.Z. Shi, 2004）. The multi-scale representation of spatial data, especially the uncertainty introduced during the course of scale transformation, that can be cumulated at multiple scale transferring, and finally influences the quality of spatial data. Therefore, how to analyze and evaluate the reliability of multi-scale representation of spatial data are already becoming an important issue of the current digital cartography and GIS (F. Xu, J.Q. Niu, 2007). Correctly understanding the uncertainty of multi-scale representation of spatial data is also the necessary condition for optimizing algorithms and improving product quality of multi-scale representation of spatial data. Settlement is grouping residences formed in the social production and living, it is the main content of maps, and occupies the maximum proportion of map loading, sometimes can reach 70%～80% of total map loading (G.R. Zhu, L.Z. Guo, G.B. Yin, etc., 2010). For this reason, studying on the uncertainty about multi-scale representation of settlement is one of important contents of uncertainty research on multi-scale representation of spatial data.

In the case of individual resident, its internal structure and external shape can be clear display on large scale map, its external contour can be only displayed on medium scale map, however it can only be used ring-shaped symbol on small scale map. Judging by figure 1, spatial information of settlement decreases following the scale reducing, that is the existence information of settlement continues decreasing and information entropy continues increasing. Multi-scale representation of settlement is realized by automatic generalization, there have already many automatic generalization algorithms on city-building and city plane figure or street-block settlement, such as automatic generalization experiment of urban settlement (R.Z. Guo, 1993), layer-based generalization model of street-block settlement (X.Y. Shi, 1993), automatic generalization problems in the GIS environment (H.H. Wu, 2000)， generalization method of street-block and quality assessment method of city-building geometry generalization on dimension-reducing technique (H.Z. Qian, F. Wu, K.P. Zhu,etc., 2007; H.Z. Qian, F. Wu, L. Ge, etc., 2007)，but rarely studies on the quality of generalization result and the good and bad of generalization algorithm. Therefore, it is necessary to carry out the comprehensive analysis and system research on the uncertain problems of Multi-scale representation of street-block settlement. According to the building types and distribution condition, settlements can be divided into four kinds, namely street-block settlement, hash settlement, cave dwelling settlement and other kinds of settlements.

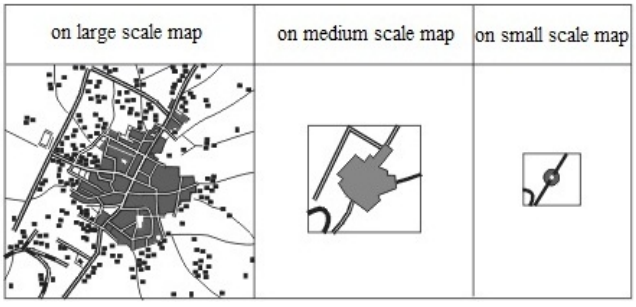

Figure 1. Graphic symbol of multi-scale representation of street-block settlement(G.R. Zhu, L.Z. Guo, etc., 2010)

This paper studied on the uncertainty problems of street-block settlement by the scale as the main line. By means of investigating the express status of street-block settlement in different scale, these questions including generalization angle and method of settlement, essential characteristic, manifestation of uncertainty had been carried on the thorough analysis and system analysis, the evaluation index of all kinds of uncertainties were established.

2. NATURE OF UNCERTAINTY ON MULTI-SCALE REPRESENTATION OF STREET-BLOCK SETTLEMENT

2.1 Scaling Transfer Process of Multi-scale Representation of Street-block Settlement

According to the actual standards of surveying and mapping, the representing methods of street-block settlement have five forms on topographic maps. The five forms as follows: ① the reduced expression according to the true form, usually derived from actual measurement, as the settlement on topographic maps whose scales are 1:500, 1:1000, 1:2000, 1:5000, 1:10000; ②street-block symbol where buildings, street-blocks and streets are generalized with different generalization degrees, settlement on measurement topographic map is its compiled original; ③ rough sketch symbol; ④ ring-shaped symbol; ⑤ the disappearance of street-block settlement. This reflects the polymorphism of representation of street-block settlement in its data life cycle. In addition, according to the rules in standards of surveying and mapping, a single settlement should properly represent its spatial character which includes position, basic configuration feature of plane figure, traffic condition, name and administrative rand and deal with the relationship between settlement and other elements. With the reducing of scale, space feature of street-block settlement have become more and more fuzzy.

During the data life cycle of street-block settlement, cartographic generalization is the main method of scaling transfer. It have been some cartographic generalization thoughts and algorithms, which can be used in the generalization of street-block settlement, specific cartographic generalization process occurs on three levels: ①the continuous change of basic composition unit including housing (true , building material, building storey), roadway, patio, courtyard, temporality buildings, streets, safety islands, green belt, street crossing center garden, which occurred mainly in measurement scale, generally it does not belong to the scope of cartographic generalization. ②the continuous change of internal structure characteristic on plane figure of street-block settlement which is represented by street-block, street network. This generalization divides into two steps, first step is the generalization of street-block and street network, the second step is the generalization of internal landmark in street-block, including the shift processing of streets and buildings and building generalization. ③ the continuous change of external characteristic. The important point of generalization is its outline characteristic and relationship with other elements. The change in every generalization level is data quantity, the three generalization levels can also be understood as three variation ranges of scale. The change of settlement is qualitative leap (mutation) when it is from the first scaling variation range transiting to the second one, the second one to the third one, the third one to the ring-shape symbol, the ring-shaped symbol to dying out (non-showing). These transition points can also be referred to scaling transfer point. Figure 2 shows the scaling transfer range of street-block settlement, scaling transfer point and the varying contents of each variation range.

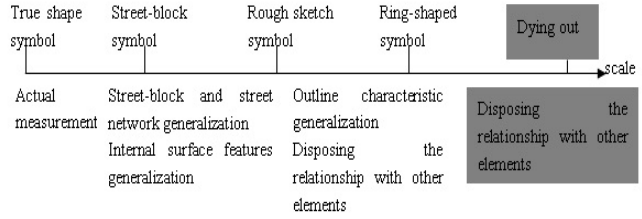

Figure 2. Scaling transfer process of street-block settlement in data life cycle

2.2 Nature of Uncertainty on Multi-scale Representation of Street-block Settlement

Generalization aim becomes more and more macroscopic with the changing of representing form of street-block settlement, which fundamentally determines that the spatial character of settlement becomes more and more roughly in the process of Multi-scale representation for street-block settlement, its uncertainty increases constantly. Which the essential cause of this change being excavated from figure 2 is cartographic generalization.

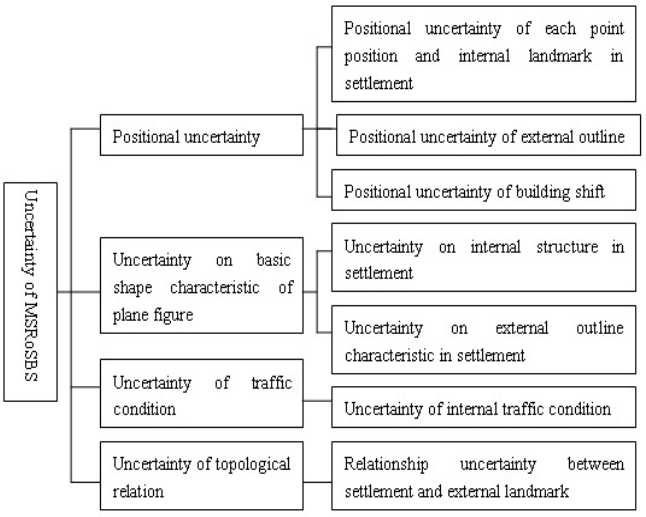

Figure 3. Types of uncertainty of multi-scale representation of street-block settlement

Uncertainty is the extent which is related to spatial process and character can't be accurately determined, it is the inherent property of all kinds of space phenomenon in nature (S.W. Hu, 2006). Thus, uncertainty of multi-scale representation of street-block settlement is the extent that its spatial character can' t be accurately determined, that is the extent of its position, basic shape characteristic of plane figure, traffic condition and relationship with other elements can' t be accurately determined following the change of scale. These can also be called positional uncertainty, uncertainty of basic shape characteristic of plane figure, uncertainty of traffic condition and uncertainty of relationship with other elements. This is the nature of uncertainty on multi-scale representation of street-block settlement. Here positional uncertainty includes positional uncertainty of each point position and internal landmark in settlement, external outline, the buildings shift; uncertainty on

basic shape characteristic of plane figures includes the uncertainty of internal structure and external characteristic; uncertainty of traffic condition mainly discusses the uncertainty of internal traffic condition in street-block; relationship uncertainty with other elements refers to the uncertainty between settlement and rivers, railways, highways, etc., which can also be understood as the uncertainty of topological relation between settlement and external landmark. Types on uncertainty of multi-scale representation of street-block settlement can be expressed using Figure 3.

Comprehensive analyzing Figure 2 and Figure 3, uncertainty classes of multi-scale representation of street-block settlement on each scale stage can be refined using Figure 4.

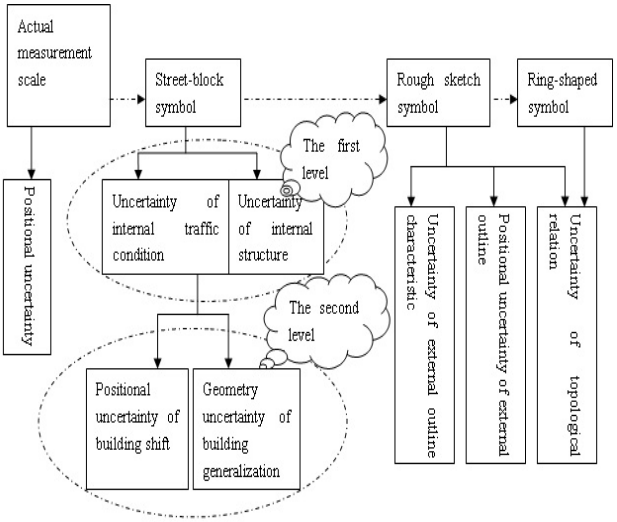

Figure 4. Uncertainty types of multi-scale representation of settlement on each scale stage

3. EVALUATION METHODS OF UNCERTAINTY OF MULTI-SCALE REPRESENTATION OF STREET-BLOCK SETTLEMENT

At the stage of actual measurement scale, it generally considers positional uncertainty of each important point position and landmark in settlement (measurement error). At the stage of rough sketch symbol, generalization of external outline is mainly to simplify contour line and dispose the relation with other elements. The uncertainty causing by simplifying contour line includes positional uncertainty of external outline and uncertainty of external outline characteristic, the uncertainty causing by disposing with other elements is uncertainty of topological relation. The three kinds of uncertainties can be evaluated making use of the existing relative research results(C.K. Cheng, W.Z. Shi, 2004; Y.H. Zhang, Y.D. Cheng, H.W. Yan, etc., 2008; M. Deng, Z.L. Li, T. Cheng,2006).

In the stage of street-block and street network generalization, street-block settlement is represented by Street-block symbol, characteristic of plane figure occurs continues change, this generalization divides into two steps, first step is the generalization of street-block and street network, its uncertainty corresponding to the first level in figure 4; the second step is the generalization on internal landmark in street-block, its uncertainty corresponding to the second level in figure 4.

3.1 Evaluation Methods of Uncertainty of Street-block and Street Network Generalization

At the stage of street-block and street network generalization, it is mainly to generalize internal structural feature of settlement. Street network graph is skeleton element of internal structure of settlement. Merging street-blocks is mainly through generalizing street network (giving up small streets), or through merging small street-blocks (giving up small streets) to realizing the generalization of street-block and street network (H.H. Wu, 2000), then generalizing concave-convex corner by means of removing. The simplifying of street network graph triggers the change of internal structure and traffic condition of street-block settlement, this process triggered some uncertainties which are the uncertainty of internal structure and traffic condition of settlement.

Evaluation Content of Uncertainty	Evaluation index	Computing method
Total length changes of street lane	Decrement of total length of street ΔL	D-value of street length of new map L_B and street length of original map L_A, $\Delta L = L_B - L_A$
Density changes of street network	Density changes of street network K_η	the ratio of street network density of new map η_B and street nttwork density of original map η_A, $K_\eta = \eta_B / \eta_A$
Number change of street-block	Number change of street-block K_M	Ratio of number of street-block of new map M_B and number of street-block of original map M_A $K_M = M_B / M_A$
Maximum area change of street-block unit	Maximum area difference of street-block unit $\Delta A_{\max}$	D-value of maximum area of street-block on new map $A_{\max B}$ and maximum area of street-block on original map $A_{\max A}$, $\Delta A_{\max} = A_{\max B} - A_{\max A}$
Minimum area change of street-block unit	Minimum area difference of street-block unit $\Delta A_{\min}$	D-value of minimum area of street-block on new map $A_{\min B}$ and minimum area of street-block on original map A_{mainA}, $\Delta A_{\min} = A_{\min B} - A_{\min A}$
Shape characteristic change of street network	Similarity degree	Similarity degree of shape characteristic of street network on new map and shape characteristic of street network on original map
Changes of density zoning of street network and its contrast relation		Use the clustering method to zoning, use the above-mentioned computing method to calculating every zone density

Table 1. Evaluation Methods Of Uncertainty Of Internal Structure Of Street-Block Settlement

Street-block and street network are generalized under the guidance of whole conception and science principle, the purpose of generalization is to maintain the similarity of street network under ensuring internal traffic condition of settlement. The component unit of street network is street lane, and we can describe the structure of street network graph using total length of street lanes, density of street network, density contrast of each street network district, shape characteristic of street network, etc. From the point of street-block, settlement can be described using number of street-block, the largest and least area of street-block unit, etc. Therefore, changes of these indexes before and after generalizing are the specific contents of uncertainty evaluation of internal structure of street-block settlement, specific index seeing in Table 1.

In table 1, total length of street (L_A 、 L_B), number of street-block (M_A 、 M_B), maximum area of street-block unit ($A_{\max A}$ 、 $A_{\max B}$) and minimum area of street-block unit ($A_{\min A}$ 、 $A_{\min B}$) can be directly statistic or measured on map or data base. Density of street network（ η_A 、 η_B ） can be quantized using the ratio of total length of street (L_A 、 L_B) and area of settlement S, that is,

$$\eta_A = L_A / S$$
$$\eta_B = L_B / S \quad (1)$$

The purpose of street network generalization is to maintain similarity of street network under ensuring internal traffic condition of settlement, therefore, geometry similarity degree of street network can be used to measure the change of shape characteristic of street network before and after generalizing, however, researches on similarity relational model and computing method of multi-scale spatial data are still at the starting stage in worldwide (H.W. Yan, Y.D. Chu, 2009), how to calculate the geometric similarity degree of street network also needs further study. About density zoning of street network, street network can be divided into a few subareas by using cluster methods before and after generalization, then contrast relation of density can be gained by calculating street network density of every subarea; thus comparing subarea and its density contrast relation before and after generalizing, the change characteristic of density zoning of street network and its density contrast before and after generalizing can be gained.

On uncertainty of traffic condition, that can be calculated and estimated using relevant methods on road capacity calculation (W.S. Gao, H.Z. Tu, C.Y. Du, 2005).

3.2 Evaluation Methods of Uncertainty of Building Generalization

At the stage of building generalization, generalizing methods include buildings merging, buildings removing and outline graph simplifying of buildings. At this stage the key point of generalization is buildings, generalizing process does not basically affect the position of settlement, traffic condition and the relationship with other elements, it can only cause little change of basic shape characteristic of plane figure and changes of shape and area of building, etc., corresponding to the uncertainty is uncertainty of internal structure of settlement. In addition, because the width of road symbol is greater than the width of ground level road at real scale, consequently results is overlay of roads or roads and buildings, that can be solved through affine transformation (shifting, simplifying, merging, etc.) when generalizing, there are many vector shifting models about the conflict of street and building in existing studies, which brings positional uncertainty because of shift of buildings and street, these uncertainties can be evaluated by using number of target displacement, maximum, median, standard deviation of displacement and so on.

Content of Uncertainty Evaluation	Evaluation index	Computing method
Change of number of building	Ratio of buildings amount K_N	Ratio of building amount on new map N_B and building amount on original map N_A , $K_N = N_B / N_A$
Change of area of structure	Decrement of area of structure ΔS	D-value of area of structure S_B on new map and area of structure S_A on original map, $\Delta S = S_B - S_A$
Change of building density	Change of total building density K_λ	Ratio of building density λ_B on new chart and building density λ_A on original map , $K_\lambda = \lambda_B / \lambda_A$
Change of contour characteristic of building	Diversity of building regularity ΔD	D-value of fractal dimension D_B of building on new map and fractal dimension D_A of building on original map, $\Delta D = D_B - D_A$
Changes of building density and its contrast relation	Use the clustering method to zoning, use the above-mentioned computing method to calculating every zone density	

Table 2. Evaluation methods of uncertainty of building generalizing on street-block settlement

The result of buildings merging is reduction of buildings number, and graph area after merging is greater than the total area of every separation figure before merging; the result of buildings removing is reduction of buildings number and the figure area after removing is less than original figure area; graph simplification of building is mainly to delete concave-convex outline, patio and courtyard, the result is that building becomes regulation, graphic area may increase or reduce. Therefore, uncertainty of this stage generated have three types, first, number change of buildings, clearly reduction of number of buildings; second, change of area of buildings, which is the result of resultant force of building merging and removing and simplifying; third, change of characteristic of building , which become more regular. From the whole point of generalizing results, in addition to the change of number of buildings, area of structure and characteristic of building, there are changes of building density, that results from the change of area of structure, contrast relation of density of every subarea in settlement may change. At this time, the evaluating contents of

uncertainty are changes of number of buildings, area of structure, building density, characteristic of building, building density zoning before and after generalizing. It is very easy to count the number of buildings, area of structure and building density on map or map database, and their corresponding uncertainty evaluation index are for detailed definition in Table 2.

In Table 2, building amount (N_A、 N_B) and area of structure (S_A、 S_B) can be directly statistic or measured on map or data base. Building density (λ_A、 λ_B) can be quantized using ratio of area of structure （ S_A、 S_B ） and area of settlement S, that is,

$$\lambda_A = S_A / S$$
$$\lambda_B = S_B / S \quad (2)$$

It is difficult to assess and quantize directly outline characteristic of building and building density zoning on map or map data base. On outline characteristic of building, the greater degree of generalization, the lower complexity, the more regular outline characteristic. In the field of digital picture, fractal dimension is common quantity index on graph complexity, the larger of fractal dimension, the more complex of graph. Here fractal dimension of graph is cited to describe the regularity of outline characteristic of building, difference of building regularity is conducted as evaluation index of uncertainty on outline characteristic change of building, detailed definition seeing Table 2, how to calculate the fractal dimension of graph can look up relevant material (Q. Wang, H.H. Wu, 1998). On building density zoning, settlement can be divided into some subareas using clustering method before and after generalizing, firstly, calculating building density of every subarea, then contrast relation of density of every subarea is gained; Comparing density zoning and contrast relation before and after generalizing, the change characteristic of building density zoning and its contrast relation before and after generalizing can be get.

4. CONCLUSIONS

Uncertainty of Multi-scale representation of street-block settlement was get comprehensive analysis and system research, it holds that map generalization is essential cause leading to uncertainty of multi-scale representation of street-block settlement, at the same time it is considered that uncertainty on multi-scale representation of street-block settlement is the extent that its spatial character can't be accurately determined, that is the extent of its position, basic shape characteristic of plane figure, traffic condition and relationship with other elements can't be accurately determined following the change of scale, it also divides uncertainty of multi-scale representation of street-block settlement into different types. According to the each kind uncertainty of multi-scale representation of street-block settlement, this paper mainly establishes the type of uncertainty of settlement when it was expressed using street-block symbol, evaluation method and indexes. Products of multi-scale representation of street-block settlement whose uncertainty can be estimated using part or all evaluation index of uncertainty in this paper, which can also be used to assess the good and bad of scaling transfer method. This follow-up study consists of two aspects, the first aspect is quantization of part indexes in this paper, such as calculation of similarity degree; the second aspect is sort order of importance on various evaluation indexes and calculating the comprehensive uncertainty.

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