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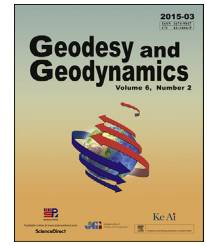

Formula for calculating spatial similarity degrees between point clouds on multi-scale maps taking map scale change as the only independent variable☆

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ABSTRACT

The degree of spatial similarity plays an important role in map generalization, yet there has been no quantitative research into it. To fill this gap, this study first defines map scale change and spatial similarity degree/relation in multi-scale map spaces and then proposes a model for calculating the degree of spatial similarity between a point cloud at one scale and its generalized counterpart at another scale. After validation, the new model features 16 points with map scale change as the *x* coordinate and the degree of spatial similarity as the *y* coordinate. Finally, using an application for curve fitting, the model achieves an empirical formula that can calculate the degree of spatial similarity using map scale change as the sole independent variable, and vice versa. This formula can be used to automate algorithms for point feature generalization and to determine when to terminate them during the generalization.

1. Introduction

Spatial similarity relation refers to similarity among and between objects on maps or in geographic space. For years, it has aroused the interest of researchers in the cartography [1] and geographic information science [2,3] communities. Spatial similarity relation is an important component of the theory of spatial relations, which also includes distance [4], topology [5,6], and directional [7–9] relations. It is an element in spatial retrieval and spatial inference [10,11] and plays a significant role in human spatial cognition [12]. Most

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importantly, spatial similarity relation is one of the crucial factors in intelligent and automatic spatial data processing such as automated map generalization [13,14].

Map generalization is a technique for producing maps at multiple smaller scales from those at a larger scale. It is evident in map generalization that the degree of similarity between a generalized map and the original map and the scale change from the original map to the generalized map are dependent on each other [1]. The more the original map is generalized, the larger the scale changes from the original map to generalized map (Fig. 1). Nevertheless, there have been no achievements in terms of describing such relations quantitatively, which hampers the automation of map generalization for the reasons as follows: (1) the map generalization system/software does not know the extent to which an original map should be generalized to produce a resulting map at a given scale if the degree of similarity between the original map and resulting map is not known beforehand; and (2) the system/software does not know when to terminate a map generalization procedure if its parameters depend on degrees of spatial similarity.

The automation of map generalization relies on automatic algorithms to generalize various types of map attributes, including point, linear, and areal features. This study focuses on point features, aiming to propose a formula that can calculate the degree of spatial similarity by considering map scale change as the only independent variable.

After the introduction, two important concepts are defined: spatial similarity degree and map scale change, and the factors that affect the human judgment of spatial similarity are addressed (Section 2). Next, an approach to calculating spatial similarity degrees among point clouds in multi-scale map spaces is proposed (Section 3) that can calculate the degrees of spatial similarity if the original map and the resulting maps are given at multiple scales. Following this, psychological experiments are designed to validate the model (Section 4). Using the calculated degrees of spatial similarity and their corresponding map scale changes, a formula is constructed that can calculate the degrees of spatial similarity, taking map scale change as the sole independent variable (Section 5). Finally, concluding remarks are made (Section 6).

2. Spatial similarity degrees in multi-scale map spaces

In order to reveal the relations between map scale change and spatial similarity degree in multi-scale map spaces, it is pertinent to define the two concepts and to present the factors that affect human judgments on spatial similarity.

Fig. 1 – Generalization of a settlement: the more the settlement is simplified, the more dissimilar the settlement becomes, and the larger the map scale changes.

2.1. *Map scale change*

Definition 1: There are two maps M_0 and M_1. Their scales are S_0 and S_1, respectively. M_1 is a generalized map of M_0. The ratio $C_{M_0,M_1} = S_0/S_1$ is called the map scale change from map M_0 to map M_1.

Map scale change is an index for evaluating the span of map scale, from the original map to the generalized map.

2.2. *Spatial similarity degree*

Spatial similarity relation refers to the similarity relation in geographic space (including map spaces). It comprises the similarity relations between individual objects and those between object groups (i.e., groups/clusters of objects) in geographic space.

In essence, similarity between two objects (or object groups) means a one-to-one correspondence of the properties of objects [1,15–17]. If the differences in the properties in similarity judgments are evaluated using different weights, spatial similarity relation can be defined as follows:

Definition 2: Suppose that A_1 and A_2 are two objects in the geographic space. Their property sets are $\mathbf{P_1}$ and $\mathbf{P_2}$, respectively, and each has $n(n>0)$ elements $\mathbf{P}=\{p_1, p_2,\ldots,p_n\}$ in it, i.e., $\mathbf{P_1}=\{p_{11}, p_{12},\ldots,p_{1n}\}$, and $\mathbf{P_2}=\{p_{21}, p_{22},\ldots,p_{2n}\}$, and their corresponding weights are $\mathbf{W}=\{w_1, w_2,\ldots,w_n\}$. Let $Sim^{P_i}_{A_1,A_2} = f_i(p_{1i}, p_{2i})$. $Sim^{P_i}_{A_1,A_2}$ is called the spatial similarity relations of object A_1 and object A_2 at property p_i, $i=1, 2,\ldots,n$. It is also named the spatial similarity degree between A_1 and A_2 at property p_i, and $Sim^{P_i}_{A_1,A_2} \in [0,1]$.

Definition 3: Let $Sim(A_l, A_m) = \sum_{i=1}^{n} w_i Sim^{P_i}_{A_1,A_2}$. $Sim(A_l, A_m)$ is called the spatial similarity relations of object A_1 and object A_2, $i=1, 2,\ldots,n$. It is also named the spatial similarity degree between A_1 and A_2, and $Sim(A_l, A_m) \in [0,1]$.

2.3. *Spatial similarity degree in multi-scale map spaces*

Definition 4: Suppose that A is an object in the geographic space. It is symbolized as $A_1, A_2,\ldots,A_n(n>0)$ on the maps at scales $S_1, S_2,\ldots,S_n$. The property sets of $A_1, A_2,\ldots,A_n$ are $P_1, P_2,\ldots,P_n$. If each property set has k $(k>0)$ elements, their corresponding weights are $\mathbf{W}=\{w_1, w_2,\ldots,w_k\}$. The property sets are expressed as follows:

$$P_1 = \{p_{11}, p_{12}, \ldots, p_{1k}\}$$

$$P_2 = \{p_{21}, p_{22}, \ldots, p_{2k}\}$$

$$P_n = \{p_{n1}, p_{n2}, \ldots, p_{nk}\}$$

Let $Sim^{P_j}_{A_l,A_m} = f_i(p_{lj}, p_{mj})$. $Sim^{P_j}_{A_l,A_m}$ is called the spatial similarity relations of object A at scale l and scale m regarding the jth property. Here $i>0$; $j>0$; $l>0$; $m>0$. $Sim^{P_j}_{A_l,A_m}$ is also named the spatial similarity degree of object A at scale l and scale m regarding the jth property, and $Sim^{P_j}_{A_l,A_m} \in [0,1]$.

Definition 5: Let $Sim(A_l, A_m) = \sum_{i=1}^{k} w_i Sim^{P_i}_{A_l,A_m}$. $Sim(A_l, A_m)$ is named the spatial similarity relations of object A at scale l and scale m. Here $l>0$; $m>0$. It is also named the spatial similarity