Article

Topology Conflict Detection Considering Incremental Updating of Multi-Scale Road Networks

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Abstract: Incremental updating is an important technical method used to maintain the data of road networks. Topology conflict detection of multiscale road networks in incremental updating is an important link. Most of the previous algorithms focus on a single scale road network, which cannot be applied to topology conflict detection for different scale road networks during incremental updating. Therefore, this study proposes a topology conflict detection algorithm that considers the incremental updating of multiscale networks. The algorithm designs a K -order topological neighborhood to judge incremental neighborhood links and builds a topology refinement model based on geometric measurement. Furthermore, we propose a network topology conflict detection rule considering the influence of cartographic generalization operator and use the improved topological distance to detect topology conflicts. The experimental results show that (1) the overall accuracy and recall rate of the proposed method are more than 90%; (2) after considering the topology conflict caused by cartography generalization, the accuracy was increased by 29.2%; and (3) the value of average path length of a network can be used as the basis for setting the best K value.

Keywords: incremental update; topology conflict; multiscale road networks; topology refinement model; K -order topological proximity; cartographic generalization operator

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1. Introduction

In recent years, location-based service (LBS) has become one of the most popular geographic information applications for the government and the public. As the basis of these applications, the road network data largely determine the quality of application services. Incremental updating is one of the important techniques to keep spatial data consistent with the real world, and its advantages have been widely studied and recognized [1–5]. However, there are a series of cartographic generalization operations, such as selection and simplification, which cause some problems in larger updated road network data. These problems are that the road network data of different scales before and after updating do not conform to the mapping rules or spatial cognition and can be defined as spatial conflicts. These spatial conflicts seriously affect the availability of road network data. Therefore, identifying the spatial conflict and correcting the error in the spatial relationships are key steps that must be faced after the incremental update of the road network database. Spatial conflicts include geometric structure conflict, topological conflict, and direction conflict. Among them, topological conflict is one of the earliest and the most studied conflicts. As the most important element of road networks in navigation using electronic maps, the accuracy of road network topology directly affects the function of road network navigation

and path planning. Therefore, this study aims to identify topology conflicts considering the incremental updating method applied in road networks.

Incremental data refers to the difference between old and new road data sets. Incremental updating mainly includes incremental extraction, incremental fusion, and incremental coordination. Topology conflicts come from the last two phases. Topology conflict of type I is generated in the process of incremental fusion, such as existing overhead lines and disjointed road segments at intersections (Figure 1a). The detection of this type of topology conflict only considers a single road database. Topology conflict of type II is produced in the process of incremental coordination. This type of topology conflict is mainly caused by cartographic generalization operations, and the detection of such a topology conflict requires a comparison of different road databases at different scales [6,7]. For example, owing to the displacement or simplification operation operators, the intersection relationship of two roads becomes a disjointed relationship from large-scale to small-scale, or when two roads before and after updating are both intersection relationships, the relative positions of the two roads have changed greatly after updating, which will affect the practical application of the updated road network (Figure 1b).

Figure 1. Different types of topology conflict: (a) topology conflict of type I and (b) topology conflict of type II.

Most of the previous studies focused on a single scale to detect whether topology conflicts of type I [8–14] exist. However, there are few studies on detecting type II topology conflicts in different scales caused by incremental update, thus leading to the topology inconsistency and hindering the application of road path query and planning in the updated road data. The performance of roundabouts and intersections can affect urban transport systems in terms of environmental and operational impacts, safety and efficiency [15,16]. The existence of the topology conflict of type II may confuse the driver and bring about traffic safety problems when unreasonable distance of two road intersections is caused by the displacement generalization operator in the updated small-scale road map. Therefore, this study aims to detect the type II topology conflict.

During the incremental update method, the spatial location of topology conflicts is predictable. In other words, the conflict only occurs in the adjacent area where the updated road segments are located [11]. Therefore, the definition and identification of the adjacent area of increment road segments is the premise of the proposed detection method. Spatial neighborhood relationships can be measured using the distance indicator or the topology indicator. The methods used to calculate the neighborhood mainly include grid method, buffer method, and Voronoi diagram method [10,11,17]. However, it is difficult to determine the size of the grid and the radius of the buffer in the grid method and buffer method. As for the Voronoi diagram method, it is suitable to express the proximity of discrete objects, but it is difficult to express the proximity of consecutive spatial objects. In addition, there is a high time cost when constructing the Voronoi diagram.

In summary, topology conflicts are mainly caused by cartographic generalization, and they often appear in the incremental neighborhood in incremental updating road networks. The precondition of this study is that the basic topological relationships have

been established, and the unreasonable topological conflicts, such as line self-intersection and hanging roads, have been corrected. This study focuses on the detection of topology conflicts caused by cartographic generalization. The main objective of the study is to propose an algorithm to detect a topology conflict for updating multiscale networks. In order to achieve such objective, the main tasks are as follows: (1) propose a K -order neighborhood judgment method to identify adjacent regions of an updated road segment; (2) build a topology refinement model based on geometric measurement; and (3) construct a rule set of topology conflict detection by classifying the generalization operators and analyzing the influence of each single operator and the combination of operators on the topological change.

2. Topology Conflict Detection Based on Topology Consistency

To improve the efficiency and accuracy of topology conflict detection in the process of road network updating, this study proposes a topology conflict detection method considering the incremental updating of road networks. According to the characteristics of the incremental updating of road networks, the K -order topology proximity method is designed to identify the neighborhood of incremental road networks. Then a refined topological relationship model based on geometric measurement is designed to calculate the topological relationship between incremental road segments and their corresponding neighborhood segments. The topological conflict rules are then built from the perspective of cartographic generalization operators. Finally, the topology conflict is detected using the improved topology consistency measurement method.

There are mainly two kinds of topological conflicts from cartographic generalization (Table 1). One is that the basic topological type does not change, but the change of measurement index between them has exceeded the threshold; the other is that the basic topology type changes, but it does not meet the requirements of road navigation or cartographic generalization.

Table 1. Types of topology conflicts in cartographic generalization.

Type of Topology Conflict	Topological Relations at Large Scale	Topological Relations at Small Scale
The basic topological relationship does not change
The basic topology type changes

2.1. Identification of Incremental Neighborhood Road Segments Based on K -Order Topological Proximity Method

One feature of incremental updating is that only the partially changed targets are updated, and not the unchanged ones. Therefore, topology conflicts often occur in the local areas adjacent to the spatial targets. The detection of topology conflicts should also be focused on the areas adjacent instead of only considering the data to the updated targets. The detection of the adjacent regions of updated targets is the key to improve the speed of conflict detection.

Owing to the limitations of the Voronoi diagram method, grid method, and buffer method for neighborhood judgment in incremental updating of road networks, topological adjacency of K -order refers to the fact that there are at least K edges starting from one vertex and passing through at least K edges to another vertex in the dual graph of road networks. In fact, the proposed method is based on the actual topology view of the road network, while the Voronoi diagram method or grid method defines the neighborhood

range from the geometric view. The dual topological graph of road networks is established to represent the adjacency relationship between road edges, which can directly query the adjacency relationship between road edges and improve the efficiency of topology conflict detection [18]. The key to judging the neighborhood is to calculate the value of K . Literature [18] shows that a certain road segment is affected by the road network within a certain range. When it exceeds this range, the updated road segment is no longer affecting other road segments. This range is defined as the average path length of a road network. Since an updated road segment only occurs in a small area, it has a certain area of impact on other road segments. Therefore, the average path length of a network can be used as the basis for the calculation of the K value. The calculation formula is as follows [19]:

$$K = \frac{1}{N(N-1)} \sum_{i,j,i \neq j} d_{ij}, \quad (1)$$

where N is the number of nodes in the network and d_{ij} is the number of edges for the shortest path between nodes i and j .

As shown in Figure 2, the first order adjacent road segments of R_0 is R_1 , R_2 , R_3 , and R_4 , and the second order of that is R_1 , R_2 , R_3 , R_4 , R_5 , R_6 , R_7 , and R_8 .

Figure 2. K -order neighborhood road segments.

2.2. Refinement Model of Topological Relationship Based on Geometric Measurement

The expression and calculation of topological relationships is the basis of topological conflict detection. The selection of the topological model is related to the recall and accuracy of conflict detection and also affects the efficiency of conflict detection. Two conditions should be satisfied for the topological relationship expression model to be used for conflict detection. First, the topological model should be able to correctly distinguish topology conflict from all topological relationships; second, on the basis of meeting the first condition, the simpler the model, the better. This can reduce the complexity of topological relationship calculation and improve the efficiency of detection [6]. In addition to the classical 4-intersection, 9-intersection, and Voronoi diagram models, the existing topological representation models [20,21] have proposed many refined representation models in recent years, which have higher discrimination and more complex calculations [22,23]. In the qualitative description of topological relationships, the topological relationship of road networks is relatively simple because the topological detection only focuses on line elements that are all road networks. Therefore, considering the computational efficiency, we can infer the basic topological relationships between roads by using the 4-intersection model,

namely, disjointed, boundary connection, interior connection, and interior intersection. It should be noted that overlap or partial overlap is not allowed, which has been dealt with in advance. As the end-point connection and internal connection are two different forms of line tangency, the basic topological relationship between roads can be further summarized as three types, namely, disjoint, tangency, and intersection.

However, these classical topological models do not consider the measurement characteristics of targets, such as distance, area, and perimeter. Therefore, the topological spatial relationship described by these models is only a qualitative description and rough classification. This makes it difficult to detect the topology conflict of type II and to meet the requirements of quantitative analysis of road networks. In Figure 3, the road network under scale S_2 is obtained by scale S_1 after updating. Road segments A_1 , B_1 , C_1 , and D_1 in S_1 scale correspond to road segments A_2 , B_2 , C_2 , and D_2 , respectively. Road segments A_1 and B_1 , as well as A_2 and B_2 are disjointed from each other. Although the generalization operators such as displacement will consider different constraints, when there are many constraints that cannot be fully met, the distance between A_2 and B_2 may be changed greatly. In addition, the results of the buffer query at different scales may be inconsistent, which will create some obstacles to the practical application. For example, if the same buffer distance is used for query, the road segment A_1 is not within the buffer range of B_1 at S_1 scale, but under, the road segment B_1 may be in the buffer zone of A_2 at scale S_2 . Similarly, although road C_1 and D_1 , as well as C_2 and D_2 , are an intersection, the displacement or other generation operators result in the problem that the position of the road intersection changes so much that it cannot be practically applied. For example, road intersection O_1 moves to O_2 after updating, which may cause confusion and lead to deviation from the planned navigation route. Therefore, geometric measurement parameters need to be used to realize the quantitative analysis of topological relations.

Figure 3. Road topological relations at different scales: (a) the disjoint relationship and (b) intersection relationship.

There are many indicators of geometric indices [23,24]. The line element has only 0-dimensional boundary and 1-dimensional interior. It can only measure the common length of the interior but cannot measure the external length. Therefore, according to the features of the line element, we introduce the segmentation indices to measure the degree of separation between lines in the intersection type, and the closeness indices to measure the degree of separation between lines in the disjoint type. Internal splitting (*IS*) and external splitting (*ES*) were used to evaluate the segmentation index. Boundary closeness (*BS*), internal closeness (*IS*), and internal boundary closeness (*IBC*) were used to evaluate the closeness index. The calculation method of these indices is shown in [25].

For a certain topological relationship, geometric metric indices can be calculated to get the corresponding values. The basic topological relationship and values of geometric metrics are the basic tuples to describe the refined topological relationship. In other words, the binary tuples R express the refined road segments of topological relationships, which is given by

$$R = (T, v(n)) \quad (2)$$

where T is the basic topological relationship, and $v(n)$ are values of geometric metrics, which is determined by n and T . As shown in Figure 3, the refined topological relationship between A_1 and B_1 can be described as $R(A_1, B_1) = (\text{disjoint}, v(BS), v(IS), v(IBC))$, and that of C_1 and D_1 can be described as $R(C_1, D_1) = (\text{intersection}, v(IS), v(ES))$.

The refined topological relation model considers the qualitative description and quantitative description of topological relationships in a unified ordered binary. It can describe topological relationships in detail and it can not only distinguish the differences between different basic topological relationships but also distinguish the differences between the same basic topological relations.

2.3. Network Topology Conflict Rules Based on Generalization Operators

For the detection of topology conflicts caused by cartographic generalization, the research usually summarizes the map of all elements or infers the spatial relationship of elements from a single generalization operator [26,27]. As for specific road network, research concerning the influence of various generalization operators on the topological relationship and the topological conflict rules is still lacking. There are many classification methods for map generalization operators, and previous literature [28] has proposed a set of map generalization operators with completeness based on the analysis of existing map generalization operators. The set of map generalization operators contains a total of 12 map operators, namely, simplification, smooth, aggregation, mixture, merge, contraction, selection, typification, exaggeration, enhancement, displacement, and classification. Considering the specific application scenarios of each operator and the practical application background, this study discusses the topological changes of road network for four operators, namely, selection, simplification, merge, and displacement, and then obtains the topological conflict rules.

The selection operator is the premise of other generalization operators, and it may result in disconnected road networks. Generally, the minimum extension tree method can be selected to correct this problem [29]. Therefore, topology conflicts of type II do not occur at this stage.

As for the simplification operation, the topology conflict, such as self-intersection and topology inconsistency, will occur due to an improper threshold setting. This study analyzes and summarizes the possible topology conflicts of type II after road simplification and gives the result of topology conflict judgment. The possible relationships before and after the update of topological relations caused by simplification are shown in Table 2 (serial numbers 1–8).

The road merge operation refers to the combination of multiple road segments into a new road segment. As shown in Figure 4, large-scale road segments S_1 and S_2 are deleted in the process of the road update, while road segments S_3 , S_4 , and S_5 are merged into road segment NS in the small scale. In the large scale, road segments S_4 , S_5 , and S_6 are disjoint, and S_3 and S_6 are connected. At a small scale, road segments NS and S_6 are connected. Therefore, the road segments S_3 , S_4 , and S_5 are regarded as a whole to detect topology conflicts by matching road segment NS on the large scale. From this point of view, the merge operation will not cause topology conflicts of type II.

Figure 4. Influence of merging on topological relationships.

The first purpose of the displacement operation is to solve visual problems, such as keeping the minimum visual distance between objects that can be distinguished by human eyes. The second purpose is to keep the topological relationship consistent before and after cartographic generalization. However, if the displacement is large or the displacement error exceeds a certain threshold, the topological relationship will be destroyed. For the road network, the possible topological changes caused by displacement can be seen in Table 2 (serial numbers 1–9). Compared with the simplification operation, the possible topological changes caused by displacement operation adds a new case, namely serial number 9.

Table 2. Possible topological relationship changes before and after generalization.

Serial Number	Graphic Representation	Does the Basic Topological Relationship Change?	Basic Topological Relations before Generalization	Basic Topological Relations after Generalization	Is There a Topology Conflict?
1		No	Disjoint	Disjoint	Undetermined
2		Yes	Disjoint	Tangency	Yes
3		Yes	Disjoint	Intersection	Yes
4		No	Intersection	Intersection	Undetermined
5		Yes	Intersection	Tangency	Undetermined
6		Yes	Intersection	Disjoint	Yes
7		No	Tangency	Tangency	Undetermined
8		Yes	Tangency	Disjoint	Yes
9		Yes	Tangency	Intersection	Yes

It can be concluded that topology conflict of type II mainly comes from the simplification and displacement operations from the impact of a single operator on the topological relationship of the road network. In the cartographic generalization of road networks, there are some relations between different operators. Different operators have cooperated to achieve the generalization and updating of the road network. No matter how the operators are combined, the changes to the road network topology can be summarized into nine cases as shown in Table 2. Generally speaking, nine cases can be divided into two types. One is that the basic type of topology relationship remains unchanged. For example, the disjointed relationship is still the disjointed relationship after the update. The other one is that the basic relationship of topology has changed. For example, the intersection relationship changed into the disjointed relationship.

2.4. The Method of Topology Conflict Detection Based on Topology Consistency

If the changes of topological relationships under different scales of road networks conform to the mapping rules or spatial cognition, it meets topological consistency. Otherwise, there is a topology conflict. Topological consistency can be measured by topological similarity [30–33]. Supposing two topological relations r_1 and r_2 , their topological similarity S_{r_1,r_2} can be defined based on the improved topological distance T_{r_1,r_2} . The specific calculation formula is as follows [34]:

$$S_{r_1,r_2} = 1 - \frac{T_{r_1,r_2}}{n} \quad (3)$$

$$T_{r_1,r_2} = \sum_{i=1}^n |v_{1i} - v_{2i}| + t_{r_1,r_2} \quad (4)$$

where n is the number of geometric metric parameters; v_{1i} and v_{2i} are the value of the i th metric parameter at small scale and large scale, respectively; and t_{r_1,r_2} is the traditional topological distances.

Before and after the incremental updating of the road network, the corresponding relationship between road segments at different scales is 1:0, 1:1, m:1, and m:n. The premise of this study is that the corresponding relationship of road segments on different scales has been obtained through the matching method [35]. For the 1:0 type, some road segments are deleted owing to the constraint of cartographic generalization. After the road segment is deleted, the corresponding topological relationship disappears. Therefore, there is no topology conflict of the road segment corresponding to the 1:0 relationship. The m:1 and m:n types can be converted into several 1:1 types by merging the road segments at different scales, and then determine the adjacent road segments. Further analysis shows that if the basic topological relationship before and after the update is the same, topology conflicts can be determined based on the topological similarity. If the topological relationships before and after update are inconsistent, the others can be judged as topological conflicts. It should be noted that the intersection relationship becomes a tangent relationship and needs to take more consideration. For such situation, if the topological similarity is less than the threshold, it is judged as no conflict; otherwise, it is judged as topology conflict. The question is how to calculate the threshold. We select the original map of nonupdated road segments, and calculate the topological similarity $S_{i,j}$ of the corresponding road at different scales. The threshold of topological similarity T_d is as follows:

$$T_d = \text{Average} \left(S_{r_i,r_j} \right) \quad (5)$$

The process of topology conflict detection is shown in Figure 5. The detailed process is as follows:

- (1) Determine the neighborhood range of the incremental road segments at different scales by using K -order neighborhood method;
- (2) Calculate the topological relationship between the incremental road segments and the corresponding neighborhood road segments before and after updating by using refined topological relation;
- (3) Obtain topological conflict rules based on cartographic generalization operators, and then determine whether the basic topological relationship types before and after the update are the same; if so, calculate topological similarity based on improved topological distance and judge whether the topological similarity value is less than the threshold. If so, there is no conflict; otherwise, there is a conflict;
- (4) If the basic relationship types before and after the update are not consistent, determine whether the intersection relationship becomes the tangent relationship. If so, judge whether the conflict is based on the topological similarity threshold; if not, there is a topology conflict.

Figure 5. Topology conflict detection process based on topology consistency.

3. Experimental Verification

This study selected the road data before and after the update in some areas of Neixiang County, Henan Province (Figure 6), in which the incremental road segments were obtained in advance by road matching. We integrated ArcEngine10.1 and C# in Windows 10 operating system to verify the experimental results. The computer was configured with CPU integrated Inter (R) core (TM) 2 Dou E3-1226, 3.30 Ghz, and memory 16G.

Figure 6. Road network data of study area.

3.1. Overall Results and Analysis

Two indicators (precision and recall ratio) were used to evaluate the accuracy of the detection results. The following equation depicts the formula for calculating these two indicators [35]:

$$P = \frac{C_n}{M_n} \times 100\% \quad (6)$$

$$R = \frac{C_n}{A_n} \times 100\% \quad (7)$$

where C_n is the correct number of topology conflicts identified by the algorithm, M_n is the number of topology conflicts identified by the algorithm, and A_n is the number of actual topology conflicts. Additionally, the correct topology conflicts and the actual topology conflicts were counted by artificial visual interpretation from the road datasets.

The experimental results are shown in Figure 7, and the statistics of various types of topology errors are shown in Table 3. It can be seen from Table 3 that the overall accuracy and recall rate were more than 90%. From each topology type, the accuracy and recall rate of the algorithm were more than 80%. In addition, the precision and recall rate of the change of basic topological type could reach 100%, except when the intersection relationship became a tangent relationship. These results show that the proposed algorithm has high accuracy.

Figure 7. Results of topology conflict detection.

Table 3. Statistical results of topology conflict detection.

Type		Number of Actual Topology Conflicts	Number of Topology Conflicts Identified by the Algorithm	Correct Number of Topology Conflicts Identified by the Algorithm	Precision (%)	Recall (%)	F_1 (%)
Basic topology type change	From disjoint to intersection	15	15	15	100	100	100.0
	From disjoint to tangency	9	9	9	100	100	100.0
	From tangency to intersection	12	12	12	100	100	100.0
	From tangency to disjoint	10	10	10	100	100	100.0
	From intersection to disjoint	6	6	6	100	100	100.0
	From intersection to tangency	10	8	8	100	80	88.9
Basic topology type remains unchanged	From intersection to intersection	18	16	15	93.8	83.3	88.2
	From disjoint to disjointed	15	17	14	82.4	93.3	87.5
	From tangency to tangency	11	10	9	90	81.8	85.7
Sum	/	106	103	98	95.1	92.5	94.4

3.2. Analysis of Local Detection and Global Detection Results

To compare the results of different incremental neighborhood judgment methods, an F_1 score index is introduced, which is defined as the harmonic average of precision and

recall. The higher the F_1 score is, the higher the overall accuracy of the algorithm is. The formula is as follows [36]:

$$F_1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \quad (8)$$

As the topology conflict detection of incremental updating only works on the incremental neighborhood, its consumption time should be less than the global topology conflict detection. It should be noted that the global detection method means that when dealing with an incremental road segment, its topological relationship with all the other road segments of the road data were taken into account to judge the topology conflict. The global detection time means the time consumptions by using the global detection method. In this experiment, the time of the proposed method was 24 s, while the global detection time was 102 s. The F_1 score of the two methods were 0.938 and 0.921, respectively. Compared with the global detection method, the time efficiency of local topology detection was increased by 76.4%. After considering the topology conflict of type II, the F_1 score of the proposed method was improved from 0.706 to 0.912, and the accuracy was increased by 29.2%. Therefore, the proposed algorithm has obvious advantages in both accuracy and efficiency.

Theoretically, the time complexity of the Voronoi diagram method, grid method, and K -order topological neighborhood judgment method proposed in this study is $O(n^2)$ when preparing candidate neighborhood road segments [35]. However, the proposed method can improve the efficiency of topology conflict detection from the perspective of the partial process. For the Voronoi diagram and grid methods, it takes a certain amount of time to divide the road network space in addition to preparing the candidate road segments. For example, the generation of the Voronoi diagram and grid need a certain amount of time. The proposed method in this study can directly compare the topological relationship between the incrementally updated road network and its neighborhood road segments, so it has high efficiency in theory. The statistical results of the different methods are shown in Table 4. It can be seen from Table 4 that the F_1 score of the three methods was similar due to the consistency of the core algorithms for judging topology conflicts. Compared with the grid method and Voronoi diagram method, the efficiency of the K -order incremental neighborhood method was improved by $(52 - 24)/52 \approx 53.8\%$ and $(207 - 24)/207 \approx 88.4\%$ respectively.

Table 4. Results of different incremental neighborhood judgment methods.

Method	F_1	Time(s)
Gird	0.923	52
Voronoi	0.930	207
K -order neighbor method	0.938	24

In this study, a K -order topological proximity method is proposed to judge incremental neighborhood road segments. Figure 8 shows the F_1 score and time consumption corresponding to different K values. It can be seen from Figure 8 that when the K value increased, the F_1 score increased and tended to be stable after $K = 3$. However, the time consumption also increased. The rate of time increase was fast at first and then it became slow. It can be seen from Figure 8 that $K = 3$ is the best K value to determine the incremental neighborhood road segments, and the experimental results of this paper are also based on $K = 3$. The value of the average path length of the road network in this paper is 2.85, which is about equal to the optimal K value.

Figure 8. Statistical results of different K values.

To verify the reliability of the K_o value, this study selected part of the road data of Beijing, Tianjin, and Shanghai (Table 5). The results showed that the average path length of the road network (K) was consistent with the Optimal K value (K_o). Therefore, this process can be used as a reference for K value calculation.

Table 5. Statistics of optimal K value and average path length of road network in different study areas.

Case Study	Average Path Length of Road Network (K)	Optimal K Value (K_o)
Beijing	2.93	3
Shanghai	4.08	4
Tianjin	2.15	2

4. Conclusions

Traditional topology conflict detection methods are often oriented to a single scale, ignoring the type of network topology conflict caused by cartography generalization in incremental updating. According to the characteristics of incremental updating of road networks, this study proposes a multiscale network topology conflict detection method considering incremental updating. On the basis of K -order incremental neighborhood road segments, the segmentation index and proximity index were used to build the refinement model of topological relationships. In this study, the topological relationship changes between road networks caused by generalization operators were reasoned in detail, the topological conflict rules were constructed, and the topological conflict detection was conducted according to the topological consistency. Experimental results show that the proposed method has high accuracy and efficiency. However, only the average value of the topological similarity of the nonupdated road segments is used as the threshold, and the selection of the threshold samples has uncertainty. Further research should be combined with the mapping specifications to further define the threshold. In addition, this study only considers the topological conflict detection of single line elements, and the geometric and topological conflict detection of double line, multi-line elements, and even line to polygon should also be the focus of future research. Moreover, additional attributes, such as semantics information, could be taken into consideration if they can be acquired.

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