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The construction and application of knowledge graph for the conflicts between birds and power lines

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Abstract Addressing the challenges posed by the extensive background knowledge of the conflicts between birds and power lines and the intricate association among them, accurate management of this problem is difficult. To tackle this issue, a knowledge graph construction method that incorporates fact association modeling while considering temporal and spatial aspects was proposed. Firstly, a knowledge representation model is proposed based on the dynamic changes in power line space, vegetation dynamics, and bird migration paths over time and space. Secondly, a knowledge graph representation learning method based on event correlation is proposed to construct entity, attribute and relation knowledge models. Finally, a knowledge map for bird-line conflict is constructed by using the literature data of CNKI and the effectiveness of the proposed method is proved by experiments.

Index Terms power line, bird hazard of transmission line, knowledge graph, knowledge representation model, knowledge graph embedding

I. Introduction

Wild birds as an important indicator species of the ecological environment, along with the continuous improvement of the ecological environment, the number of birds appeared to rise sharply, and with the expansion of the activities of birds in the transmission and distribution lines as well as the increase in the number of nesting, the frequency of faults in overhead transmission and distribution lines induced by birds significantly increased [1]. With the birds and transmission and distribution lines between the "bird line conflict" is more and more prominent, bird line conflict caused by line faults involving birds has become in addition to lightning damage and external damage, triggered by line tripping the third major cause [2].

From the 1950s and 1960s researchers have observed the transmission and distribution lines bird line conflict [3], bird line conflict more inclined to prevent and cure. Measures are mostly centered around a specific season, a line area, a voltage level or a single tower pole to carry out governance work, with the development of ecological concepts and environmental protection concepts, it has been difficult to meet the current social and technological development. Therefore, the comprehensive ecological protection strategy combining bird ecology, population ecology, community ecology, conservation biology theory, animal protection law and other related disciplines "combining blocking and sparing" is of great significance for the protection of bird ecology and guaranteeing the continuity of electric power supply, and has become a hot spot of current research.

However, from the point of view of the source of knowledge of bird line conflict, the knowledge field is very rich, including bird ecology, electric power design and operation, plant and animal community science, animal protection theory and so on. Knowledge from different fields and sources is scattered and rich, and the knowledge in each field is isolated, making it difficult to form a unified knowledge system. From the perspective of engineering application, decision-making on bird pest control needs to be based on comprehensive, accurate and timely information, and the existing complicated research results do not form a comprehensive knowledge network, which cannot help decision-makers to better understand the relationship and influence of various factors, and make correct decisions.

The most promising solution at present is Knowledge Graph [4]. As an important component of artificial intelligence, Knowledge Graph adopts the form of graph structure to represent the entities, concepts and associated relationships in the objective world, with the characteristics of open interconnection and powerful semantic reasoning and computing ability, which can be used as an external knowledge base for intelligent dialog, intelligent search, troubleshooting and other scenarios, generating significant application value [5]-[7].

Based on the above analysis, this paper analyzes the research status quo and knowledge structure characteristics of the bird line conflict at home and abroad, and proposes a knowledge expression model that takes into account spatial and temporal granularity as well as an expression learning method in view of the transmission and distribution lines as well as the actual situation of the dynamic change of topography and geomorphology, dynamic characteristics of the vegetation, classification of birds, and bird roosting and migratory paths, etc. In the light of the obvious cross-domain nature of the knowledge map of bird line conflict, the connection between entities is relatively small, and the knowledge base of the bird line conflict is not as clear as it should be. In view of the obvious cross-domain nature of the knowledge graph of bird line conflict and less connection between entities, a knowledge graph representation learning method integrating event information is proposed on the basis of the above expression model, which improves the performance of the knowledge graph completion model; finally, the knowledge graph of bird line conflict is constructed with the help of the literature data of Zhiwei.com, and the validity of the proposed method is confirmed through experiments.

II. Related work

II. A. Current status of domestic bird line conflict research

With the requirement of environmental and ecological construction, the vegetation and landforms damaged by the construction of overhead lines have been restored. However, the presence of overhead lines and towers has changed the migration and roosting habitats of bird populations in the study area to a certain extent, affecting the living habits of birds. Jiangxi, Inner Mongolia, Shandong and other provinces have conducted very distinctive studies under the leadership of power grid-related enterprises or research institutes.

Jiangxi is a region where bird-line conflicts are more prominent. Literature [8], [9] statistics 2009 ~ 2016 bird-related faults, line tripping due to short-circuiting of bird nesting material has 185 times, bird droppings flashover led to tripping 40 times, bird body shorting category 6 times, and shows a trend of increasing year by year. Some waters along the Yellow River Basin in Inner Mongolia Autonomous Region are important habitats for migratory birds and are one of the important stopping places on the East Asia-Australia migratory corridor. Literature [10], [11] statistics show that the number of transmission faults ranked in the top three are lightning damage, bird damage and external damage, of which bird damage faults amounted to 38 times, accounting for 25% of the total number of faults. The months of transmission line bird damage faults are mainly concentrated in April and August, which are the peak times of major bird migrations. In summary, it is also found that bird damage has been called one of the main factors of high-voltage overhead lines. Shandong is also a major power transmission province, rich in bird resources, literature [12] through the time analysis of bird damage analysis found that the number of bird failure was “double hump” curve. At the same time, the distribution pattern of birds also exists in time and space of multiple hotspots.

From the above statistical study of bird-related faults in many places, it is found that the bird-related faults of power lines caused by bird line conflicts are mainly: bird droppings faults, bird nest faults, bird body shorting faults and bird pecking faults.

In the early stage of bird damage management, usually used to “block + drive” as the main prevention and control methods. With the deepening of ecological protection, the problems of “blocking + driving” prevention and control methods have been gradually exposed: first, a single way, blindly driving birds, easy to cause harm to birds. Secondly, birds have strong adaptability, and the effect of bird prevention will become worse and worse. At the same time, after the activities and living environment of birds are destroyed by human beings, they will fight with human beings for a long time, which will not achieve the effect of long-term peace and security. Thirdly, the lack of protection for rare birds does not meet the requirements of maintaining ecological balance and protecting biodiversity.

In recent years, the management of “bird damage” has been upgraded to the ecological management of bird line conflict. The main idea is to combine population ecology, community ecology, conservation biology theory, animal law for thematic research. Literature [13] used vision algorithms to identify birds on transmission lines. Research literature [14]-[16] also do thematic studies on the impact on specific birds, bird droppings on insulators, bird nests on lines, etc.

The current scientific research on bird-line conflicts is not only deeply intertwined with different disciplines, but also highly relevant to a variety of scenarios: e.g., bird-proofing of orchards, bird-proofing of airports, ecological containment of wind farms, etc. [17]. It will be a very urgent and important research direction to effectively integrate these fragmented information scattered in different knowledge systems and professional fields to serve the related industries and provide new paths for knowledge discovery and knowledge innovation of birdline conflicts.

II. B.Characteristics of the Birdline Conflict Knowledge Map

With the continuous exploration of technology at all stages, knowledge graphs contain more and more rich research content, literature [18], [19] summarizes the progress of knowledge graphs in recent years. Including algorithms that add dimensions such as time, space, and hierarchy on the basis of the expression of the triad of entities, relationships, and attributes to improve the accuracy and effectiveness of the knowledge expression of multimodal knowledge, dynamic knowledge, and so on. Literature [20] Deep Learning-based Knowledge Representation Learning: utilizes the powerful feature learning capabilities of deep learning to automatically learn low-dimensional vector representations of knowledge to capture the implicit semantics and complex relationships of knowledge. Studies such as [21] design knowledge representation model structures with intrinsic interpretability to facilitate understanding and analysis. In terms of knowledge extraction and knowledge complementation, the traditional process of entity extraction, relationship extraction, and attribute extraction is more integrated with the development of current technological elements such as multimodal information fusion, deep neural networks, and deep learning in order to improve the efficiency of knowledge acquisition [22]. At the same time the application of knowledge graphs within specialized fields has also received great attention. Among them, finance, education, law, and healthcare are the fields with the most active applications and practices [6], [7]. Knowledge graph in real time has become the foundation of knowledge-based intelligent services such as accurate search, intelligent Q&A, and recommendation systems. No research results related to knowledge graph of birdline conflict have been seen yet, therefore, there is an urgent need to carry out research on knowledge graph in the field of birdline conflict to provide new ideas for knowledge discovery and knowledge innovation in this field.

From the birdline conflict knowledge collection, organization and research, it is found that birdline conflict has some characteristics as follows.

Birdline conflict knowledge has a strong problem orientation, following the engineering and social hotspot changes. With the development of natural environmental protection and ecological environmental protection, the conflict between birds and transmission and distribution facilities and equipment is gradually recognized by many parties, and the research theme is constantly expanding. The content of bird line conflict has also developed from the consideration of bird removal, facility protection and related policies and regulations after the construction of the project to the coordination of ecological environment protection and the formulation of related policies and regulations before the construction of the project. At the same time, the research method of bird line conflict has also begun to show diversification, and case study, big data and artificial intelligence and other analysis methods have become mainstream.

Bird activities and ecological environment in the knowledge of bird line conflict have obvious spatial and temporal correlation.

On the one hand bird activities have spatio-temporal characteristics. Bird roosting has a typical diurnal activity pattern, most birds in the morning and evening activity pattern; bird migration has a typical seasonal; at the same time, bird roosting also has a typical spatial characteristics. Birds will choose different geographic areas and ecological environments to live in according to their own habits. Forests are the habitat of many birds; shrubs and grasslands have large bird species that are good at flying; wetlands attract a large number of waterfowl, etc. The habitat of birds is also characterized by vertical distribution. For example, the canopy, middle branches and the ground in the forest may be inhabited by specific birds.

On the other hand, the ecological environment also has obvious spatial and temporal characteristics. Seasonal patterns of habitats; climatic conditions vary markedly from season to season, which has a significant impact on the ecosystem. Changes in seasons cause changes in vegetation and landforms. Ecosystems also undergo evolutionary processes over long time scales. The earth's climate, topography, and biomes are constantly changing, and these changes have far-reaching effects on the ecological environment. Biomes, vegetation types, animal species, etc. vary from region to region due to differences in climate, topography, soil and other natural factors. For the Aba region, a large number of statistical studies surface large birds and raptors, etc. perching activities at transmission and distribution towers as a general factor in bird-line conflict events. These large birds in turn are closely associated with specific habitats.

Another distinctive feature of the bird line conflict knowledge map is that it involves multi-disciplinary knowledge including bird habitats, bird roosting habits, vegetation, landforms, climate, transmission and distribution facilities, etc.

II. C.Description of the problem

Taking the transmission and distribution lines as the modeling unit, the spatio-temporal knowledge of bird line conflict is expressed after matching the geomorphology, climate, vegetation, and bird activities to the lines, in order to discover the causal and evolutionary processes in fact, and ultimately to achieve the purpose of bird line conflict event prevention.

The role of transmission lines and bird populations in the bird line conflict as a typical spatio-temporal activity, its knowledge necessarily needs to express the characteristics of the multiple entities in the knowledge in different granularity spatio-temporal dimensions and the associated relationships, the literature [22], [23] used the knowledge graph to complement the above problem. However, the design of knowledge expression model to design such spatio-temporal characteristics of birdline conflict in simple words will also be a challenge to establish the knowledge graph of birdline conflict.

III. Knowledge representation model for birdline conflicts considering spatio-temporal granularity

Given a knowledge graph represented by the directed graph $G=(E,R,T)$, where the triples are, in order, the set of entities, the set of relations and the set of triples, i.e.

$T=\{(h,r,t)\mid h,t\in E, r\in R\}\subseteq E\times R\times E$

In a knowledge graph, the vertices of the graph consist of entities that are used to characterize things in the objective world and that have multiple attributes. And edges consist of relations to represent interconnections between entities. Each triple (h,r,t) in T describes a fact, which is the head entity, the relationship and the tail entity, respectively.

For the bird line conflict knowledge in the entity is always in a certain space, such as the tower is in a certain geographic location, its entity belongs to a certain line; the tower is located in the environment of the vegetation changes dynamically over time; birds with the seasons to convert the spatial location of their habitats; the growth of plants change over time, the activities of birds is always and a specific environment, the environment changes with the time of the season.

New spatial and temporal attributes are added to the original attribute set in the entity description. At the same time, in order to represent the spatio-temporal dynamics of the entity at the point in time of the changes in the attributes, the introduction of “state” entity to describe, multiple states can be described at different levels of granularity of the temporal and spatial attributes.

State = {Temporal Attributes, Spatial Attributes, Attributes}

Spatial dynamic entities can use the “state” entity to express their time-related attributes, resulting in the knowledge expression model shown in Figure 1.

As can be seen from the figure, multiple states with the relationship between time and space can describe the dynamic change process of the entity. In the application of spatio-temporal knowledge graph, it is always hoped that the performance of knowledge graph can be improved through the comparison and analogy of spatio-temporal dimensions. Therefore, the temporal and spatial relationships are introduced here to describe the relationship between entities, which builds an expression model for the traditional “triad” to express spatio-temporal dimension knowledge.

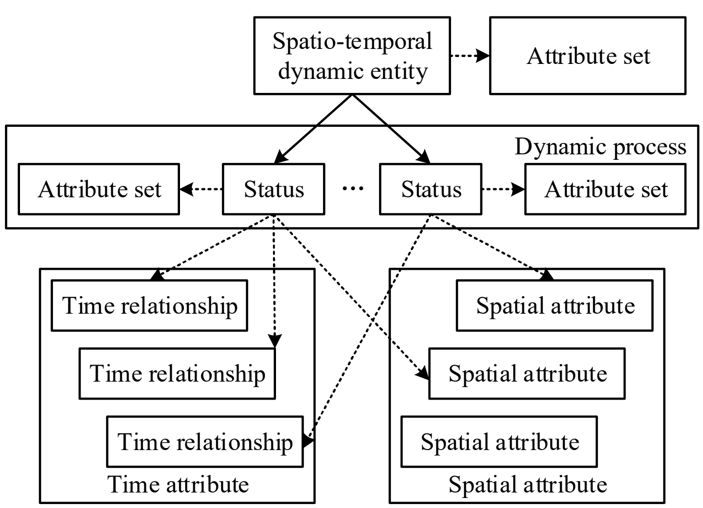

Figure 1: Knowledge representation model considering spatio-temporal structure

In terms of the expression method, a simplified semantic-to-numerical relationship conversion model for spatial and temporal expressions is established, drawing on the literature [24], to meet the need for qualitative and quantitative expression of spatio-temporal relationships. Considering the need for both temporal and spatial dimensions to be semantically expressed at different granularities, all spatial and temporal relations in this computational model can be computationally accessed by establishing discriminant functions for the relations.

IV. Learning Model for Knowledge Graph Representation Combining Multi-Granularity Spatio-Temporal Relational Information

IV. A. Knowledge Graph Representation Learning Model

Knowledge graph representation learning aims at mapping entities and relations separately to a low-dimensional continuous vector space, and thus learning vector representations of entities and relations. The goal is to learn a mapping function $f: E \times R \times E \to \mathbb{R}^{d_r}$, which maps entities and relations to a d_r-dimensional continuous vector space, making it possible to reflect the structural and semantic information in the Knowledge Graph as accurately as possible in the vector space. The reasonableness of the fact triad (e_1, r, e_2) is usually measured by defining a scoring function $g(e_1, r, e_2)$, and then the vector representations of the entities and relations are learned by optimizing the objective function, so that the reasonable triad has a higher score, and the unreasonable triad has a lower ratings.

Currently, there are three main types of learning models, which are translation-based model represented by *TransE*, linear model represented by *DistMult*, and neural network represented by *ConvE*. The distribution of the three methods uses different scoring functions and loss functions.

IV. B. Learning model for knowledge graph representation incorporating state information

As we can see from the above analysis, the knowledge state entity of the bird line conflict has an obvious hierarchical multi-granular structure in terms of geospatial attributes, and the distribution of birds' habitats in the geographic sense from large to small scale is a containment relationship, which maintains a certain degree of continuity in geospatial terms. In terms of bird habitats, specific birds inhabiting geospatially non-adjacent locations may have the same nesting, stopover, and foraging activities due to their similar topography and vegetation, and have similarities in the analysis of bird line conflicts. Bird habitats of similar size also have similar roosting characteristics in similar habitats, thus having similarity in bird line conflict analysis. Similarly, temporal attributes show a hierarchical and multi-granular structure on the time axis, e.g., a yearly cycle contains four seasons, or it can contain multiple months, and so on. Fixed spatial locations are cycled through time to maintain the continuity of bird habitats, with similar climate and vegetation in the same seasons, and a certain continuity of bird activities within a day and night to maintain relative stability. Temporal granularity and bird body size can be expressed as spatial stratification in one dimension. Taken together, the above characteristics can be described as a spatial stratification relationship as shown in Figure 2.

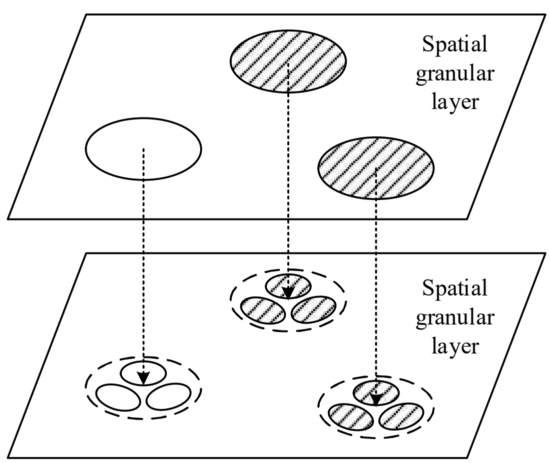

Figure 2: Hierarchical multi-granularity structure of spatial relations

The state entity is spatially modeled as a two-dimensional Gaussian distribution $\mathcal{N}_2(\mu, \Sigma)$, and the KL dispersion of its two-dimensional Gaussian distribution is denoted as:

$$\square_{KL}\left(N(\mu_1,\Sigma_1)\|N(\mu_2,\Sigma_2)\right) = \frac{1}{2}\Big[tr(\Sigma_2^{-1}\Sigma_1)+(\mu_2-\mu_1)^T\Sigma_2^{-1}(\mu_2-\mu_1) -2+\ln\frac{\det(\Sigma_2)}{\det(\Sigma_1)}\Big] \quad (1)$$

where tr(-) denotes the trace of the matrix and det(-) denotes the determinant of the matrix. The state entity is modeled in time as a Gaussian random variable $\square(\mu,\Sigma)$: its KL dispersion can be expressed simply as;

$$\square_{KL}(N(\mu_1,\Sigma_1)\|N(\mu_2,\Sigma_2)) = \ln\frac{\Sigma_2}{\Sigma_1}+\frac{\Sigma_1+(\mu_1-\mu_2)^2}{2\Sigma_2}-\frac{1}{2} \quad (2)$$

In this paper, we propose to generate negative samples for knowledge representation learning training by randomly replacing the head or tail entities of an existing triad. We define the set of negative samples as □ as the concatenation of the set formed by the random replacement of the head entity and the set formed by the random replacement of the tail entity.

To de-train the learning of state vector representations that satisfy the relationship, we use a loss function similar to that used as shown in Equation (3):

$$\square\square = \sum_{(u,v)\in\square} d(u,v) + \sum_{(u',v')\in\square} \max\{0, m-d(u',v')\} \quad (3)$$

where (u,v) is a positive sample that satisfies the containment relationship, and (u',v') is a negative sample that does not satisfy it, where the parameter m is set in order to minimize the difference between positive and negative samples.

In the bird line knowledge graph, the relationships in this paper are one-to-many, for example, the "perched on" relationship is set to have the head entity labeled as a specific kind of bird, and the tail entity is the state entity, for example, the "located on" relationship is set to have the head entity labeled as a specific kind of pole tower.

IV. C. Learning a Knowledge Graph Representation of Birdline Conflicts Considering Spatio-Temporal Granularity

Since all types of spatial granular layer relationships and constraints are known in the birdline conflict analysis, their vector representations are learned by the possibility of combining these loss functions for joint training. This gives the joint loss function as shown in equation (4):

$$\square_{ALL} = \sum_i \alpha_i \square_i \quad (4)$$

where α_i is the weight of each partial constraint. The training procedure for the above fixed loss function is shown in the following algorithm:

Algorithm. Knowledge Graph Embedding Algorithm Considering Multi-Granularity Spatio-Temporal Relationships.

Inputs: training dataset (set of triples *T*), entity set *E*, relation set *R*, weights *α* and learning rate *η*.
Output: Embedding of entities and relations Θ.

① Initialization
for 1:N number of iterations
② Sample the training dataset
③ Generate negative sample sampling
④ Calculate the gradient of the loss function and update the embedded values
end for

IV. D. Algorithm complexity analysis

Taking the *TransE* model as the base knowledge graph embedding model as an example, define n, m to denote the number of entities and relations in the knowledge graph, and the vector dimension is d; the size of the dataset for each iteration is b. In one iteration, the time complexity of computing the loss functions of all the triples and updating the parameters is roughly $O(bnmd)$, and the space complexity is $O((n+m)d)$, considering that the spatio-temporal granularity relation proposed earlier is only computed in at most 2 dimensions, which is much smaller than the vector dimension d. Therefore, the computational complexity of the present algorithm can be approximated to be equal to that of the original algorithm.

V. Experimental results and analysis

V. A. Birdline Conflict Knowledge Mapping Construction

Through the above methods, this experimental platform adopts Python as the processing platform, the system adopts B/S structure, and Neo4j is used as the graph database to realize the knowledge mapping and analysis system of bird line conflict.

Since no publicly available corpus suitable for bird line conflict analysis has been found yet. In this experiment, China Knowledge Network (CNKI) database was chosen as the main data source. Only "bird damage" as the subject field was searched, and 361 journal articles were obtained. Wikipedia retrieved 712 documents.

The frequency of keywords is listed in Table 1.

Table 1: Frequency of keywords

Keywords	Word Frequency	Keywords	Word Frequency
Transmission Line	92	Preventive measures	26
Bird Failure	81	Preventive Measures	22
Bird damage prevention and control	50	Overhead transmission lines	21
Bird damage prevention	33	Insulators	20
Bird Repeller	28	Substation	18

The most common keyword is "transmission line", followed by "bird failure" and "bird control". This suggests that "bird damage control" of "transmission lines" is the more relevant research object at present. It can be seen that the main topics of academic research on related subjects include bird damage control, bird protection measures, bird repellents, insulator failures, trip failures, etc. Some of these are related to transmission line corridors. Some of these are highly relevant to transmission line corridors and neighboring bird populations. However, there are also some that are not highly relevant to the entity we are studying itself and do not help much in the construction of the ontology. Therefore, in this paper, the irrelevant terms are eliminated based on the disciplinary classification.

From the perspective of the whole process of spatio-temporal knowledge graph construction, the factors affecting the construction efficiency of the knowledge graph of transmission line corridors and neighboring bird populations are mainly the extraction and generation of the knowledge of transmission line corridors and neighboring bird populations. The efficiency of knowledge generation depends on the computational complexity and data volume of the algorithms for entity generation, attribute generation and relationship generation.

V. B. Link prediction testing

In order to test the knowledge graph embedding algorithm proposed in this paper considering multi-granularity spatio-temporal relationships. We evaluated our approach by performing a link prediction task on the above dataset. The link prediction task is to predict the missing relationships between pairs of entities in the knowledge graph, and its goal is to infer those relationships between entities that have not yet been discovered or are missing based on the available information. Here two Mean Reverse Ranking (MRR) and Hits@ are used as evaluation metrics, which are compared with the modeling approaches of $TransE$ and $DistMult$ as shown in Table 2:

Table 2: Results of running the link prediction task

Methodology	MRR	Hits@1	Hits@10
TransE	0.205	0.143	0.652
DistMult	0.401	0.305	0.573
The algorithms in this paper	0.441	0.535	0.736

The above table shows that the method proposed in this paper has improved in the above three indicators compared with TransE and DistMult, which reflects that the knowledge graph embedding performance can be further enhanced by combining the information related to the space-time, and also proves the effectiveness of the learning method.

VI. Conclusion

After expressing the knowledge of birdline conflict with the knowledge representation model considering spatio-temporal dimension, the state entities contain rich semantic information, which can be used to guide the learning of entity and relationship vector representations. In this paper, we propose a knowledge graph construction method for birdline conflict, which takes into account the fact of birdline conflict and as a basis for knowledge graph representation learning method considering multi-granularity spatio-temporal relationship information.... Their vector representations are learned by mapping state entities into a vector space. Experimental results also confirm the effectiveness of our approach in this case. In our future work, we will further evaluate the performance of the method and investigate the application of knowledge mapping to the ecological prevention of birdline conflicts.

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