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Improved base state with amendments model based spatio-temporal 4d information modeling of open pits

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Abstract. The conventional base state with amendments model is defective due to their low efficiency in historical data retrieval and poor performance in processing the space relations of spatio-temporal objects and the relations of patio-temporal objects. In order to reduce data redundancy of Temporal Grographic Information System(TGIS) and improve its operation efficiency, a composite spatio-temporal database model of the base state with amendments is presented after comparison and analysis of various spatio-temporal data models based on the base state with amendments. Multi-level indexing is operated as the first step according to the time attribute of TGIS while improving the historical data retrieval efficiency of data by the base state distance which is generated by integrating the various granularity base state distance factor and critical index of objective changes. These steps are followed by introducing a hypergraph model of space relation theory. Finally, the model propose is tested by using the geographical data of a mine. In its application, the model, aide by 3Dmine and Visual C++6.0, presents the changes of open pits in GIS by 3D dynamic results, so that a 3D spatio-temporl visualization representation of the changes of open pits is realized.

Key words. Base state with amendments, open pits, 4d model, tgis.

1. Introduction

The spatial distributive state of mines changes over time, and this happens by no means in 2D but in 3D; therefore, time dimension is required to incorporated into a 3D space, in which 3D modeling and TGIS are indispensable to serve as the theoretical and technological support to reflect the timely changes of open pits.

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3D modeling, mainly built for geographical bodies and the spatial information of mining engineering, is widely used in mining engineering designs such as mineral deposit modeling and mining aided designs. Despite that mine construction and mining are dynamic in nature, the modeling is static due to little or less description of the data and time attribute, so that it merely presents the real-time state of mining spatial entities, rather than the historical state and the multi-source heterogeneous spatio-temporal information, and thus fails to foresee the future trend.

2. The defects of the conventional base state with amendments model

TGIS refers to geographical information system with time dimension, focusing on the spatial features, attribute features and time features of geographical entities. The spatio-temporal data model is the core of TGIS as the hierarchical data model has been introduced to deal with the problem that area boundaries change over time in the late 1970s. Research on TGIS data modeling unveils officially as Lorenizos(1988) and Langran(1989) pioneered to present their study findings on TGIS in the doctoral dissertations and that Langran [1] published doctoral dissertation " Time in Geography Information System" in 1992 marks the milestone. Spatio-temporal data modeling remains the focus in academic community with an emergence of massive spatio-temporal data models representing and managing spatio-temporal semantics. The representatives include but not limit to:

Four temporal data models under file system were proposed Langran from the time varying data storage perspective, including spatial temporal cube model, snapshot sequence model, the base state with amendments model, and space-time composite model; Extended research on 4DGIS theories made by Hazelton[2]; A distinctive temporal model was built by Sugam[3] when they introduced the concept of temporal element and the concept of temporal assignment and transformed the 1NF relations attribute into temporal attribute when time is set as a reference; A database technique based spatio-temporal data models was introduced by Aziz[4]. as they interpreted temporal semantics as a sequence of events from the perspective of spatio-temporal semantics;Interpretationsa were made by Batsakis[5]. onspatio-temporal representation, spatio-temporal reasoning and spatio-temporal query based on spatio-temporal semantics; The description of spatio-temporal objects relations by utilizing 4D dynamic graphs from cartography prespective was made by Resch[6];TUDM, a new spatio-temporal data model based on 4DGIS spatio-temporal model was proposed by Anh[7]. It can record the span of spatio-temporal objectives, explicitly represent and store their historical evolutionary process; ESTDM, proposed by Silva[8], regards the change in state in a space as an event, which is represented by the event sequence in a time line. The model do not work when spatio-temporal changes happen among multiple spatio-temporal objectives; ESTDM was improved as spatio-temporal query mode of moving objectives proposed by Sakr[9] who introduced the reasons of spatio-temporal changes. However, it is defective in generosity as it only aims at set objective; The spatio-temporal data model of moving objects was proposed by Bittner[10], and it only applicable to the spatio-temporal database whose position changes over time rather than the general ones; STUP was introduced by Liu and Schneider[11] to visit the moving objectives in spatio-temporal database given the space topology relations and uncertainties of moving objectives.

All the above research findings enrich the TGIS theory and expand its application. However, in most cases, the objectives investigated are 2D with little of them concerning 3D geographical space.

The existed theoretical studies on mining spatio-temporal 4D information modeling can be summarized into two categories: One refers to the study related to the integrated representation of the spatio-temporal 4D information and visual modeling theory in the field of spatio-temporal GIS data modeling with fruitful results being yielded. However, the study with regard to the data integrated representation and modeling based on the spatio-temporal objectives of the geographical bodies in geographical and mining engineering under a unified spatio-temporal framework is rarely. The other involves the applied research on mining spatio-temporal 4D information visualization model mainly focusing on the open pits 3D spatial information visualization. 4D information modeling and applied research on visualization are burgeoning. However, the study on open pits spatio-temporal 4D information visualization model which represents, stores and manages the static spatio-temporal data and the dynamic data of a mining falls into shortage.

3. Composite Spatio-temporal Database Model of the Base State with Amendments

3.1. Evolution of the Base State with Amendments Model

In the open pits model, the changes in geographical space only happen in some areas. However, large storage space is used to store unnecessary redundant information as the the conventional sequent snapshot model stores the overall new model in the database after the changes of geographical space. The base state with amendments model only records the changes relative to the base state while keeping the geographical date in a certain moment as the base state. As is shown in Figure 1, various base state with amendments models are presented, as the data storage and retrieval efficiency will be affected when the base state, number of the base states and calculating methods of different files change given that the base state with amendments model is capable in reducing data redundancy.

Model a and model b are the improved solutions of the model proposed by Gail Langran[12]. These two are defective in restoring temporal-spatial snapshots if they read in distant historical conditions. Besides, their inefficiency in reading surplus difference files is another drawback. Model (c)and model (d), the improved versions of model (a) and model (b), are distinctive in designing a more advanced difference file indexing which leads to a higher efficiency in historical status retrospect and less different files to be inquired contributes to imperfect the models themselves. Nevertheless, massive data redundancy in distance historical conditions and ineffectiveness in restoring temporal-spatial snapshots remains problems. In model (e), a

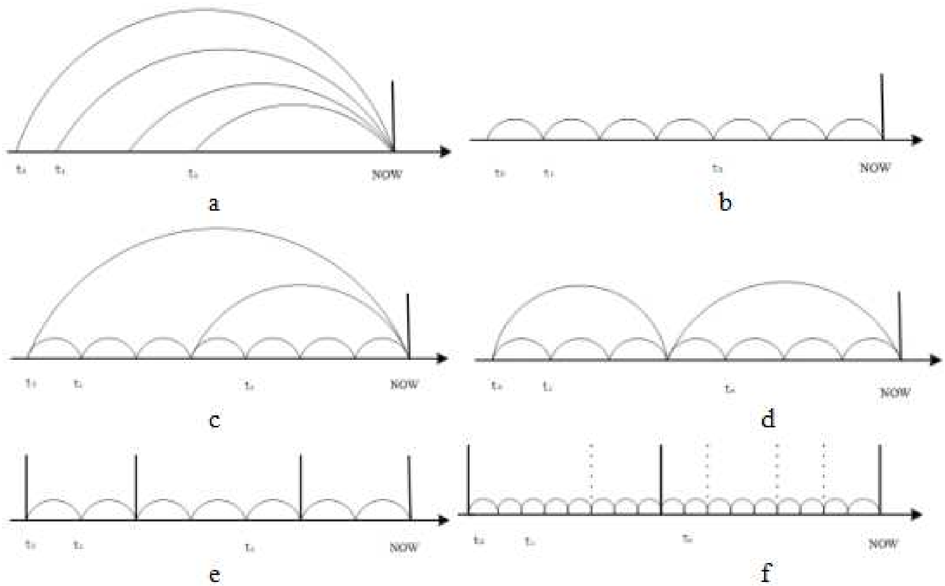

Fig. 1. Six spatio-temporal data models

dynamic multi-level index retrieval is introduced throughout the whole system and specific historical objectives with a higher storage efficiency and lower data redundancy. However, the base states increase as the number of difference files grows, resulting in a high memory cost. The method to confirm the threshold value of base statedistance in this solution should be improved.

In the model (f) based on dynamic base state, the fact that it is difficult to retrieve the historical temporal data is fully considered. In this version, temporal data falls into two categories: static base state data and dynamic base state data. Retrieval results will be automatically stored into the dynamic base state category when the number of difference files read in retrieval exceeds a certain amount, and the old base state will be deleted as the new emerges. However, the model still awaits further improvements so as to adapt to the retrospect of mining model since it seems complicate to retrieve a more distant historical time point or time section, added by open pits modeling retrospect is frequent and the memory space of dynamic base state data is limited.

3.2. Spatio temporal data organization of the Base state with Amendments Model

The traditional geographic information system is a digital management system constructed by computer technology. Its focus is on the geographical data in space and the processing and analysis of geological data. However, the data in the real world is not only space-related but also time-related. Especially in the mining area, the data will change over time. In order to make mine information system represent spatio-temporal process, we need to introduce spatio-temporal data model. In the visualization of space-time information of 3D GIS, in order to reduce the complexity of 3D data model storage, the change of 3D model can be abstracted as an increase process, which can be divided into three kinds of situations: increase, decrease and change. If the space objective of the geographical phenomenon of a point in time is increased relative to the previous point in time, it is defined as positive increase, if the decrease is defined as a negative increase, and if the space objective changes, it can be divided into 2 Phases as first disappear, then appear, that is, negative increase, then increase. The three kinds of changes of the space objective from the previous time using the three-dimensional model are shown in Figure 2, in which Figure 2 (a) shows the increase of the space objective, Figure 2 (b) shows the decrease of the space objective , and Figure 2 (c) indicates that the space objective has changed.

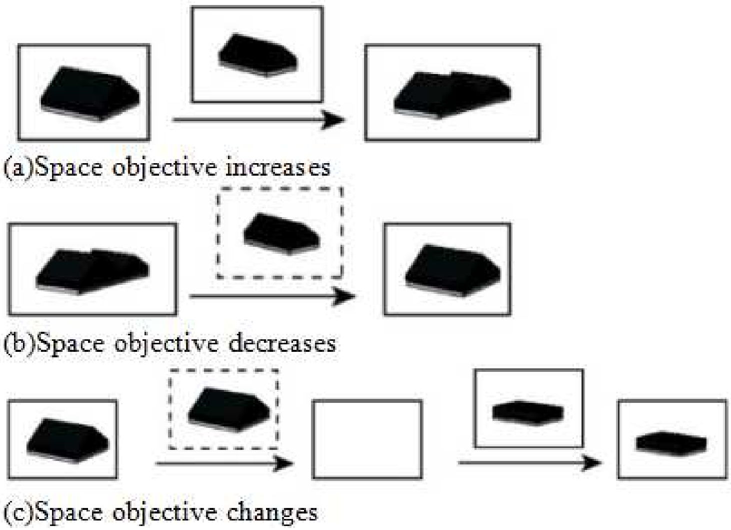

Fig. 2. Three-dimensional expression of three kinds of changes in space objective

3.3. Various Granularity Composite Model of Base State with Amendments

The various granularity base state distance factor (Ki) means that farther away from the current time, the larger the base state distance between the base states, the closer to the current time, the smaller the base state distance between the base states. This will reduce the query time and improve query efficiency. However, to achieve the dynamic update of the base state, the correlation between Ki and Ki and Q, the total number of difference files must be considered. Thus the geometric ratio a $(a<1)$ is introduced, and the relationship between Ki is $k=k1/k1=k3/k2=k4/k3......=a$, then the correlation between Q, a *andKi* is $Q=k1/(1-a)$. The total number of difference files Q is known and a can be determined by taking a small sample for investigation. The value of the various granularity base state distance factor is: $k1=Q\times(1-a)$??$k2=Q\times(1-a)\times a,k3=Q\times(1-a)\times a,....$ The introduction of the ratio coefficient a automatically updates the base state. The improved dynamic multi-level indexing is advantageous for its high storage efficiency, small data redundancy and great improvements in historical data retrieval efficiency.

With the passage of time, the value of Q gradually becomes larger. Through the above formula, the position of the difference file where the new base state exists can be obtained. The old base state plus the difference file between the old and the new base state time can be updated to the new base state. In addition, the number of base state could not be set too much, which will greatly increase the storage space, so the number of base state is most suitably controlled in 3 or 4. The various granularity base state distance factor can reduce the retrieval time for most users, however, for a small number of users the retrieval time is prolonged, but from the perspective of total retrieval time, the time is reduced and the efficiency is improved. After the introduction of the various granularity base state distance factor, the renewal process of old and new base state is shown in Figure 3. The total number of difference files is increased from Q to $Q1$, the base state of $q2$ will become the base state of $q'2$, difference file of $q'2$-$q2$ is the process of changing the old base state into a new base state.

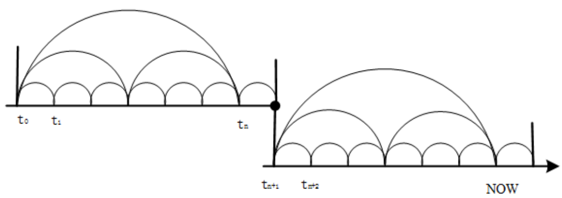

Fig. 3. Composite Model of Base State with Amendments

4. Realization of Open Pit 3D Visualization System

4.1. Database Design

The database design of composite model of base state with amendments is shown in Figure 4. The basic structure of composite model of base state with amendments in database design includes three parts: index part, space object part and change processing part. Among them, the index part includes the base state code, layer name, layer number, Starttime, Endtime, base state distance and so on. The space object part stores all the data in the form of a space object O^s={base state i, object ID-t, spatial property, non-spatial property, time attribute, relation, event}, wherein the critical index of objective changes is determined by the number of changes of the object reaches or exceeds a critical value. The change part of the object includes the change of batch number, attribute ID, change number, object ID, parent object ID (variable length), change date, etc., which are mainly object generation and object disappearance, supplemented by object update. The renewal of an object manifests itself as the emergence of a new object and the demise of an old object.

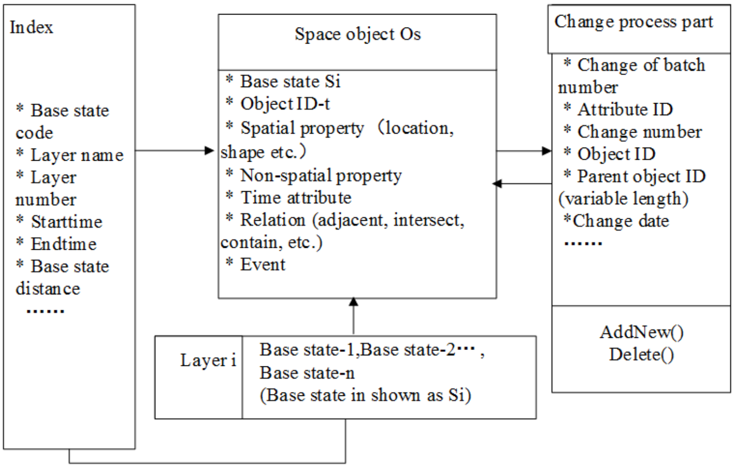

Fig. 4. Database design of composite model of base state with amendments

4.2. System Implementation

The evolution of open pit mines is manifested in many aspects. From the perspective of space, the change of mine surface over time can reflect the development and changes of an open pit mine to a certain extent. In this paper, we designed a three-dimensional visualization system to show the open pit spatio-temporal evolution process, and can quickly retrieve the status quo of space of mines at any time. Using Visual C ++ 6.0 as a platform, 3Dmine software is called by C# language to realize the presetting function. The design of a timeline is mainly used to realize the dynamic display of the spatial change of open pit mine. The temporal information of the 3D scene is shown in Figure 5.

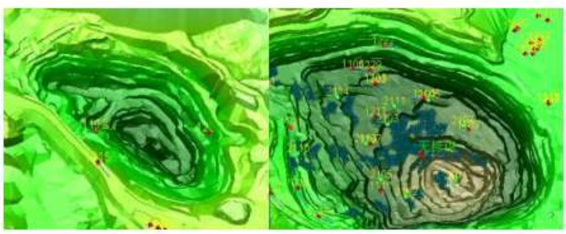

Fig. 5. 3D scene of open pit evolution

The figure shows the 3D scene of the year of 2010 and 2015, limited by the map, 3D scene maps of other years are not listed one by one. By dragging the time bar, the system calls the change of the base state and the corresponding 3D model variation (ie, difference file) to realize the dynamic visualization of the development and changes of the open pit mine. By clicking the time node, the system can search and browse the status quo of the mine at that moment.

4.3. Analysis and Comparison

In order to compare the data size and retrieval efficiency of different models, the data storage and retrieval efficiency of several spatio-temporal data models are calculated respectively based on the 3D model data of mining area. Among them, the dynamic multi-stage model of base state with amendments is not included in the analysis as the algorithm is complex and relatively difficult to implement. For multi model of base state with amendments, the state of initial year is set as the base state. In order to facilitate comparison, the difference file of 2010 data state (ie, the initial state) and the two adjacent times is calculated as a unit of measurement. Table 1 lists the data volume of six data models stored six years of model data and the amount of number of superposition operations when retrieve state of the data of the year of 2015, which is the farthest from the base state, in which the number of superposition operations of the retrieval of time snapshot model and single model of base state with amendments is very small, which means the retrieval efficiency is very high, but the huge amount of data will result in a large amount of data redundancy. The single-base incremental model has the least amount of data and the least retrieval efficiency. The multi-base incremental model and multi-base multi-level difference file model has the same retrieval efficiency, but the multi-base multi-level difference file model has less data storage than the multi-base incremental model, so it further shows that the multi-base and multi-level difference file model balances the relationship between the data volume and retrieval efficiency, and is more suitable for the organization and management of three-dimensional spatio-temporal data.

Table 1 Comparison of Six Data Model Data Storage and Retrieval Efficiency

Year	Model data needed to be stored in year	Incremental stacking results	Whether it is ground state
2010	Data state of 2010	Data state of 2010	Yes
2011	2011 changes relative to 2010	Data state of 2011	No
2012	2012 changes relative to 2011	Data state of 2012	No
2013	2013 changes relative to 2012	Data state of 2013	No
2014	2014 changes relative to 2013	Data state of 2014	No
2015	2015 changes relative to 2014	Data state of 2015	Yes
2016	2016 changes relative to 2015	Data state of 2016	No

5. Conclusion

Spatio-temporal data model is the core of TGIS, which is directly affects the efficiency of system operation. Based on the comparison of various database base states with amendments model and the current status of an open pit, this paper defines a new composite spatio-temporal database model of base state with amendments based on the idea of base state with amendments model, which is compositely made by method of optimizing base state distance, part of the hypergraph model theory, object-based spatio-temporal data model, and base states with amendments model. The three-dimensional model data of mining area is organized, stored and dispatched, and the 3D scene of the open pit mine is dynamically rendered and quickly retrieved. The time elements are successfully integrated into the 3D geographic information system to realize the purpose of not only dynamically displays the urban spatial landscape, but also queries and browses the state of instantaneous space. It plays a significant role in solving the existing problems in the conventional base state with amendments model.

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