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MODELING AND VISUALIZATION OF SPACE OBJECTS SPATIO-TEMPORAL DATA

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ABSTRACT:

In future, 3 Dimensions Geographic information System (3D GIS) should support the temporal dimensions modeling and manage all three components efficiently. It is difficult for current 3D Visualization software to deal with temporal phenomenon. An spatio-temporal data model is proposed in this paper, this data model take geometry-data, space moving data and inside action data of the object into account comprehensively. And accomplish holistic modeling of geometry, action, and moving data of the object..

With the increasing of applications need to dispose moving objects, the conventional DBMS can not fit the continuous changing data, moving objects Spatio-temporal Data Model is the key technique of moving objects Spatio-temporal DBMS, thus, moving objects Spatio-temporal data modeling became a popular issue these years.

1. RELATIONAL RESEARCH

Sistla (Sistla, 1997) had advanced the conception of moving object in 1997, and accomplish the MOST(Moving Objects Spatio-temporal Data Model). This model dose not contains the whole history of moving object and only support query of its' current state, so, query at different time receive different result, base on got knowledge of moving object, we can query future state of the object, but can not receive the history data.

Guting(Guting 1998, Guting 2000),Erwig(Erwig 1998, Erwig 1999) and Forlizzi(Forlizzi 2000), etc research on space moving object modeling, and Sliced Representation conception is proposed, namely, use a set of Spatio-temporal units represent the evolvement of a space moving object.

Hong Yong Wang analyzed space Moving Objects Spatio-temporal Data Model created by Guting, etc , combined with spatio-temporal knowledge and spatio-temporal extended query experiment, worked over part of basic method, accomplished history evolvement of moving object's in 2D space, query of space moving object's state at any time, and so on.

Yan Sheng Lu, etc(Lu 2006)analyzed the problem of MOST model and discrete model, and a moving object Spatio-temporal Data Model, HCFMOST, is given. This model adopts cubic Hermite polynomial interpolation to simulate trace of moving object's history unit, adopts linear function simulate trace of moving object's current unit, and disposed the error of current unit. This model can query history trace accurately, query current and future trace with error.

Yong Gao(Gao 2007)etc aim at planar moving objects in 2D Euclidean space, establish Spatio-temporal Data Model based on time slice. Defined model of moving objects Spatio-temporal topology relationship based on points set theory, expressed by compound of 9 model description, temporal and spatial topology relationship. At the same time, advanced Spatio-temporal topology validity, calculable restrict and calculate rule, further more, given expression method of moving objects' dynamic Spatio-temporal character. This model proposed a expression and calculation method of moving objects' Spatio-temporal topology relationship, express the dynamic character effectively, provide theory basic for moving objects database and Spatio-temporal query of it.

Ping Zhan (Zhan 2007) etc, concentrate on query technique of moving objects' index method, a integrated tree, used for restricted moving objects' index structure, then, used index smoothness achieve query of future moment.

Spatio-temporal Data of moving objects is multidimensional, the information changed with time is 3+1dimensional (3D space and time), if take pose and other information into account, the dimension increase. The correlative researches mentioned above aim at moving objects, namely, the space position of objects changed with time, but not consider change of pose and inner attributes. With the change of positions of space moving object, it's pose data and inner attributes changed too, so, design of Spatio-temporal Data Model of space moving object is complex.

2 DATA TYPE OF SPACE MOVING OBJECT

Data types chiefly include basic type, temporal and special type. Before definition of data type, we will prove it is preciseness and clear by type domain, so, we define a type domain to define a data type. This paper defines an abstract data type frame for moving object. This frame based on basic data type, special data type, and temporal data type, then, use type structure act on these three types, and generate new data type.

Moving, intime, and range are all type structure. For example, moving act on point, generate moving point type "mpoint"; intime act on point generate intime(point) type, binary unit; range act on instant generate interval type, collection of time. The formalize definition of all data type are given as follows:

(1) Basic data type

Basic data type includes integer, real, string, and Boolean, the meanings are same as in programme language, manage by extended DBMS, no more explication. For more attention, add $\{\perp\}$, means "no definition", into the value domain.

(2) Temporal type

Time is linear and continuous, same format as real number. Whether moment or temporal zone, need to define a temporal type to describe a time point: instant.

$$Instant ::= < real > \qquad (1)$$

(3)Spatial data type

In field of GIS, already confirmed and used spatial data types chiefly include point, line, and region.

Owing to any spatial entity can described by number of triangles within given precision, this paper improved spatial data type mentioned above with Point, Line, and Triangle. With these three basic spatial data types, construct some basic Meta, as the element of more complex entity. Show as figure 1. Point represents a point in Euclidean planar, Points represent a set of numerable points; Lines represent a set of numerable continuous lines in planar; Triangle represents triangle, Meta represents basic metafile combined by numerable Triangle. Classification of metafile will mention next section.

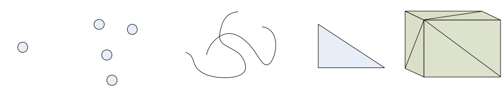

Figure 1. Classification of Spatial data

$$Point ::= < x, y, z >$$

$$Line ::= < (x_1, y_1, z_1), (x_1, y_1, z_1), \ldots, (x_n, y_n, z_n) >$$

$$Triangles ::= < (x_{11}, y_{11}, z_{11}), (x_{12}, y_{12}, z_{12}), (x_{13}, y_{13}, z_{13})$$
$$Meta ::= < Triangle1, Triangle2, \ldots, Trianglen > \qquad (2)$$

(4) Moving data type

Moving type(Guting 2000), is a mapping from time to another type, the value represents the changing function with time of another type. For example, describe a continuous moving point in space, we need position sequence $\{p^k\} \subseteq R^3$ that is corresponded to time sequence $\{t^k\} \subseteq R$. If the trace of the point is a simple curve (a curve has no crossing, and the end is outside the curve, it can be ring), the mapping from 1 D space (time) to 3D space $f:\{t^k\} \rightarrow \{p^k\}$ is existent. Because the time and space are all continuous, the mapping can transform to $f:\overline{DA}_{instant} \rightarrow \overline{DA}_{point}$, this mapping called moving type. For given data type α, use $moving(\alpha)$ represent it's moving type, and domain of $moving(\alpha)$ is:

$$DA_{moving}(\alpha) = \{f \mid f:\overline{DA}_{instant} \rightarrow \overline{DA}_{\alpha}\} \quad (5)$$

Here, α includes all the data type and space type, e.g. $moving(real)$, the value is mapping from time to real, it can represent the distance of two moving points within a while. Every value f of $moving(\alpha)$ is a function of α changing with time, a subsection function. Owing to operate $moving$ to α type, and generate new data type $moving(\alpha)$, we called $moving$ type constructor.

To all the $moving$ type, for convenience mark and consistent to correspond type, we use follow method identify $moving$ type: add a prefixion "M" before parameter type, e.g. Mpoint，Mpoints，Mline，Mtriangle，Mint，Mstring and Mboolean. Take Mpoint for example, explain the data structure.

$$Mpoint ::= < unit\_sum, unit\_cur, Trajectory >$$

$$Trajectory ::= < unit_1, unit_2, \cdots, unit_n >$$

$$unit\_sum ::= < \text{int} >$$

$$unit\_cur ::= < \text{int} >$$

$$unit_k ::= < t\_start, unit\_Mpoint > \quad (1 \le k \le n) \quad (6)$$

$unit\_sum$ is total units of the moving object at current time; $unit\_cur$ is index point to current unit of moving object; $Trajectory$ is the trace of moving object; t_start is the begin moment of unit, $unit\_Mpoint$ express moving rule of moving object, we can adopt linear interpolation function or hermite interpolation function to simulate the trace of moving object.

(5)Range data type

For all moving type, should has correspond operate to mapping, aim at return a range of domain. For moving type correspond to basic type, e.g. $moving(real)$ (the value received from 1D domain) ，mapping can be compactly expressed as set of interval within the 1D domain. In practice, we interest in interval of real number and integer, we can receive $range(\alpha)$ by a type constructor $range$. α is basic type or time type. Take $Interval$ for example:

$$Interval ::= < (T_1, T_2), (T_3, T_4), \cdots, (T_n, T_{n+1}) >$$

（n is a odd number greater than 0）

$$T_i ::= < Instant >$$

$T_{i+1} ::= < Instant > (1 \le i \le n)$ i is odd number

T_i and T_{i+1} are start and end moment respectively.

3 SPACE MOVING OBJECT SPATIO-TEMPORAL DATA MODEL

Literature (Ye 2004)classify describe method of moving object into two kinds:

(1) Describe methods based on moving function

Describe spatial state and moving state of moving object with function, generally, moving function is function of time, giving a time within definition domain, corresponding state data can be calculated.

(2) Describe methods based on state swatch

This method describes the whole process of movement by a series of discrete state swatch, evidently, it is a kind of simulate and approximate method.

Excellent Space Moving Objects model should take various conditions into account, make proper choice as different condition, In other words, it should support function method and swatch method simultaneously, so that it can be used to manage moving objects under control by simulation system and securable object got by moving function, as well as un-securable ones.

Space objects circulate in space include natural planets, automobiles, airplanes, ships, satellites and space scrap, and so on. These moving objects moving within it's own orbit. Not only the position and rate vector, but also include pose and inside state data changing with time. Inside state data include shift, rotate, scale of inside components and change of using state caused by kinds of reasons.

Aimed at the character of space moving object, the paper design a Space Moving Objects Spatio-Temporal model, this data model take geometry-data, space moving data and inside action data of the object comprehensively, space moving data include position, speed and pose data, the compute method of data can choose between orbit kinetic function and interpose function base on practical needed precision, can describe movement state of space object.

As figure 2 shows, structure of Spatio-Temporal data of space moving object make up of geometry model and action model chiefly. ① Geometry model describes the geometry shape of object, can be made up of several basic primitives, every primitives makes up of several Points, Lines, Triangles, and Textures. ②Action model includes inside action model and outside action model. Inside action model describes action between components inside space objects (such as solar board, point of sensor and action of machine arm of detector and so on), so Inside action model acts on components or basic primitives of geometry, which cause the inside action. Outside action model describes space object as whole move state, which can obtain by interpose function and orbit kinetic function.

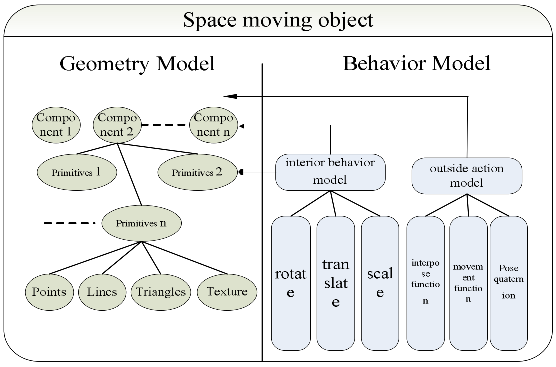

Figure 2. Space moving object Spatio-Temporal data structure

(1) outside action model of Space moving object

Moving trace of Space moving object can be obtained by orbit kinetic function with a series of time interval, these positions called sampling points.To describe moving state of space object within period of time, theoretically, we need infinite points, but is irrealizable and not necessary in discrete model created by computer. For discrete data model, we can only increase sampling points to describe continuous moving attribute more accurately, but due to large amount of space moving objects and complexity of calculate of orbit dynamics function, compute burden of system increasing enormously. In fact, changing of space objects within a period is continuous, that can reduce sampling calculation by appropriate interpolation function.

The position and velocity vector at sampling points of space moving object can calculated through 5 models provided by Space track Report No：3, according to practical requirement of precision. SGP、SGP4 and SGP8 are suit for near-earth satellite, and SDP4 and SDP8 are suit for deep-space satellite.

With these sampling points, the pose, position, and rate vector of Space moving object can obtained by interpolation function. Guting's discrete model adopts linear interpolation function simulate moving trace of moving object between sampling points, but in practice, moving trace of moving object generally is not line, when required precision is high, linear interpolation function is not efficiency. So, against history moving trace, SMOST model adopts cube Hermite polynomial interpolation function to simulate, consequently, make simulation of moving object's historic moving trace more precise，and reduce the error.

Every sampling point of DSMOST model, not only include position, but also velocity (includes value and direction). Suppose that, two neighboring sampling points are (T_i, P_i, V_i) and $(T_{i+1}, P_{i+1}, V_{i+1})$, T means time, P means position(x, y, z) ;V means velocity. Suppose cube Hermite polynomial interpolation function on $[T, T_{i+1}]$ is:

$$P(t) = a_0 + a_1 t + a_2 t^2 + c_3 t^3 \tag{7}$$

Here ： $t = t' - T_i; t' \in [T, T_{i+1}]$. Let $T = T_{i+1} - T_i$, because the function is bound to pass sampling point at the moment T_{i1} , so：

$$P(t=0) = P_i; \quad P'(t=0) = V_i$$

$$P(t=T) = P_{i+1}; \quad P'(t=T) = V_{i+1} \tag{8}$$

Replace element of formula (7)with formula (8), there is:

$$\begin{aligned} &a_0 = P_i; \quad a_1 = V_i \\ &a_0 + a_1 T + a_2 T^2 + a_3 T^3 = P_{i+1} \\ &a_1 + 2a_2 T + 3a_3 T^2 = V_{i+1} \end{aligned} \tag{9}$$

Thus we can get coefficients of cube Hermite polynomial interpolation function:

$$\begin{aligned} &a_0 = P_i; \quad a_1 = V_i; \\ &a_2 = -\frac{3P_i}{T^2} - \frac{2V_i}{T} + \frac{3L_{i+1}}{T^2} - \frac{V_{i+1}}{T}; \\ &a_3 = \frac{2P_i}{T^3} + \frac{V_i}{T^2} - \frac{2P_{i+1}}{T^3} + \frac{V_{i+1}}{T^2}; \end{aligned} \tag{10}$$

Prevenient space moving object Spatio-Temporal Modeling mainly research one dimensional or two dimensional moving object, so most of these do not take pose data into account. But in three dimensional space, for non-linear moving object, especially satellite, pose data is one of significant attribute, generally a important factor to judge whether the state of moving object is normal, thus, pose data is an indispensable factor of expression of moving object. This paper adopts quaternion to describe the outside pose of moving object.

(2) Interior action model of Space moving object

Most of Space moving object have interior action are manual objects, such as remote sensing satellite, automobile, airplane, ship, and so on. They are generally make up of kinds of complicated components, some of the components can act under specific conditions, we called these behavior inside action of space object, such as open of solar board, uncover of the sensor, turning of the cartwheel of moon . In order to describe the complicated interior action data of complicated object, we design a integrated modeling method of geometry and action.

A geometry model can be constitutive of some basic primitives no matter how complicate it is, so we create some basic primitives. Firstly, all of them can describe by parameter, which means the geometry shape, color and transparency can be modified by parameters. This paper define 12 primitives （see table 1）, which include two classes: one is basic primitives; the other is extended primitives, extended primitives allows dynamic supplement which mainly accomplish complicated special effect.

	Name	signification
basic primitives	Cylinder	Cylinder
	Extrusion	Extrusion
	Sphere	Sphere
	Polygon	Space Polygon
	PolygonMesh	Polygon Mesh
	Revolve	Revolve
	Skin	Skin(grid face)
	Helix	Helix
extend primitives	TextureSmoke	Smoke effect
	ParticleSystem	ParticleSystem
	LodMesh	Lod grid
	Billboard	Billboard Primitives
	……	……

Table 1 Class of primitives

Description of geometry Primitives is flexible, we can define different object by set different parameters of same primitives. Take Cylinder for example, it can build Cylinder, taper, prism, pyramid, and so on..

In order to combine these basic primitives into complicated space object, this paper design a tree structure to describe complicated space object, shows as figure 3.

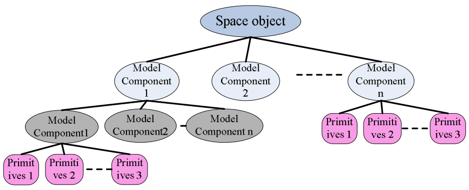

Figure 3 Tree structure of complicated moving object

Node of the tree is called model component, component include action and geometry data, based on different effect domain, action data include local action data and extended action data. Local action data include basic primitives act on this component, extended action data act on son component pointed by this component. Model component include a extended interface message, which used to trigger inside action by outside message. Time tag triggers action by time. Sketch map of model component are as follows.

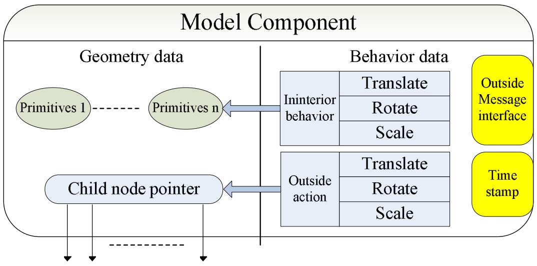

Figure 4. Sketch map of model component

4 TEST RESULT

This paper describe space moving object by MOST Spatio-Temporal data model, these objects include natural planet, manual satellite, moving object on ground, and so on. The visualized result of space moving object Spatio-Temporal data model , is showed as figure 5. And this model has been used in many projects.

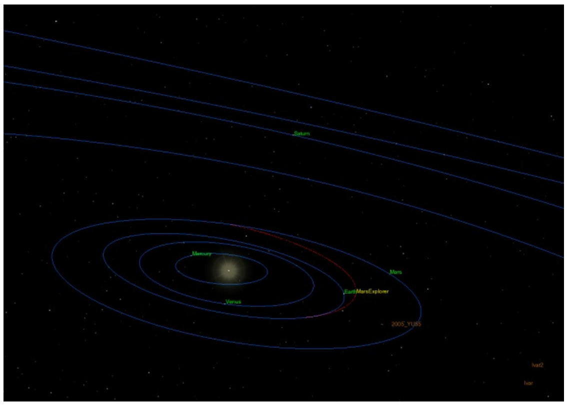

Figure 5a. Modeling and Visualization of planets of solar system

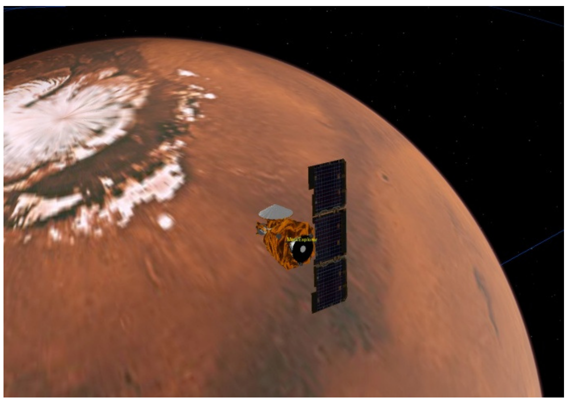

Figure 5b. Modeling and Visualization of deep space detector

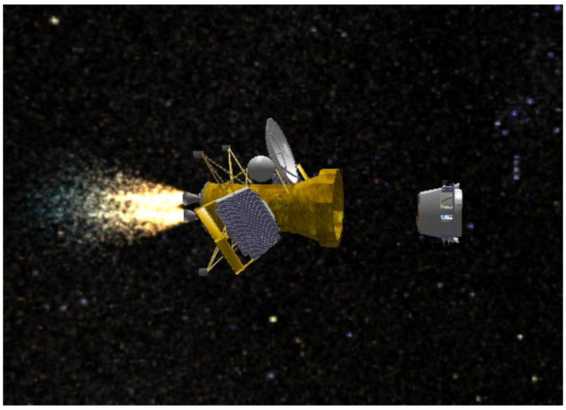

Figure 5c. Modeling and Visualization of geometry and interior action of deep space detector

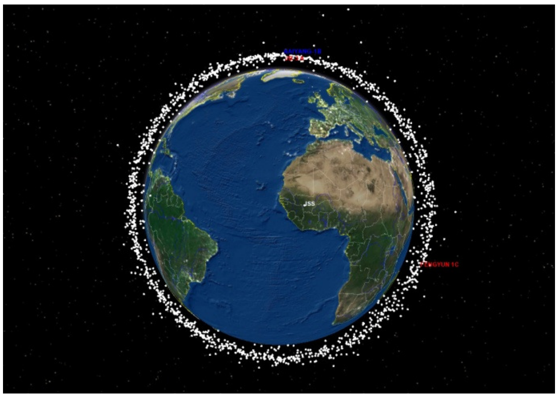

Figure 5d. Modeling and Visualization of space scrap running within orbit

Figure 5. Modeling and Visualization of space moving objects

Because this data model take both the describe methods base on moving function and state swatch into account, so it can extend conveniently to suit the describe of object near-earth, even on the ground. (Figure 6)

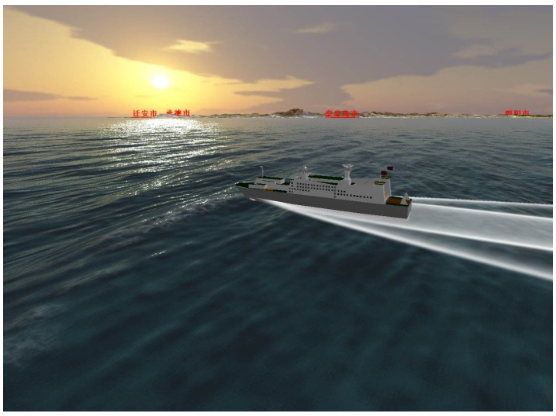

Figure 6a. moving object on the sea

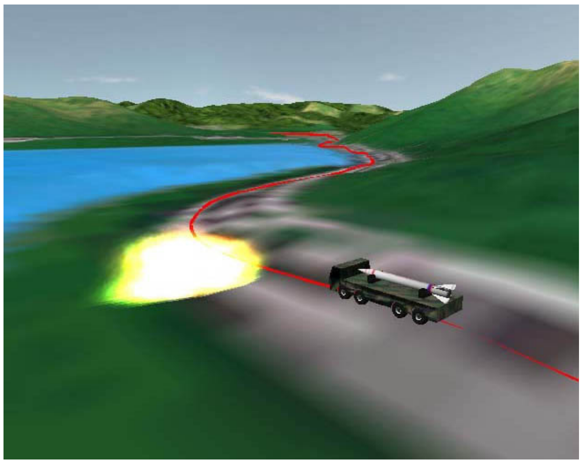

Figure 6b. moving object on ground

Figure 6. Modeling and Visualization of moving objects on earth

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