A Dynamic Landslide Simulation Algorithm Based on Multitask Spatio-temporal Data Model

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Abstract: - In traditional real-time landslide dynamic simulation, many problems such as cumbersome and inefficiency data interaction process would lead to the limit in landslide dynamic simulation engineering application. 4D spatio-temporal data model event-driven process will be adopted to address those problems. Aiming at intricacy of influent factors in moving process and multi-factor, the original model was improved and enlarged to support the landslide process in data and logical. We use this algorithm in a real test data, show an efficient landslide dynamic simulation. It solved the problems in landslide movement and sophisticated spatio-temporal process which can be hardly described, finally provided a new idea to solve the similar question.

Key-Words: - Geologic event, Multitasking, Spatio-temporal data model, Dynamic simulation of landslide

1 Introduction

Spatio-temporal data model is a geo-data model which is able to effectively organize and manage temporal geo-data attribute, spatial meaning, and temporal meaning to make it more complete. This model can fully save the storage space, accelerate storage speed and express spatio-temporal semantics which contains of the geographic entity's spatio-temporal structure, effective organization structure, spatial relation, temporal relation, geologic events, spatio-temporal relation etc. Hence one can see that the superiority of spatio-temporal data model in practical application, especially in area involving interactive influence of time and space, such as real-time dynamic simulation of complex movement and so on.

Considering the huge storage space in real-time dynamic simulation of landslide，the high speed demand of real-time storage and the interference of complicated s-t (spatio-temporal) relationship, algorithm based on multitask spatio-temporal data model was proposed to solve those problems. Dealing with landslide operation mechanism from the event-driven layer, provided a new idea to optimize landslide simulation and even the general simulation of complex motion.

2 Research Status

Currently, the method of establishment of standardized spatio-temporal data model is in exploration stage, and scholars in many countries did a lot of work about it. In the end of 1980s, Dr. Lagrange's graduation thesis "*The time in GIS"* was published，which opened a door to spatio-temporal data model[1]. In recent years, Worboys(1994), Raper(1995), Donna, et al. (1995) respectively proposed and discussed assumption of showing spatio-temporal data model by using different ways such as event mode, the snapshot model, time-space composite model and so on[2,3,4]. We can see that most the early models we just mentioned, which were applied to the GIS use the time as a single vector dimension. But there must be some defects in solving the problem of GIS, especially complex geological process of dynamic expression if we describe the time and space by the way of four dimensions model.

For landslide research, the early scholars focused on one certain aspect of landslide to do accumulation, such as Liu Hanchao, et al.(1989) published an article in which researched the activation mechanism of landslide debris such as water, soil and so on in the mass during the landslide process, then on this basis found the calculation method of landslide distance[5]. Lu Wannian, et al.(1991) analyzed the operation mechanism of landslide theory "aerodynamic resistance", then on this basis exported the prediction method of landslide distance and the calculation formula of landslide speed[6]. Wang Nianqin, et al.(2003) applied the regression to analyzed influential factors of landslide travel distance, achieved the estimated formula of landslide distance[7]. Gu Tianfeng(2006) researched the landslide movement of homogeneous mass under ideal conditions and achieved the relation equation between distance and speed of homogeneous mass[8]. However, these simplex methods concerned about certain aspects are just for local research. It's not enough to conduct the landslide dynamic simulation.

Through literature reviewing, we can see that various new types of efficient algorithms are applied to the landslide simulation, prediction, etc. Zhang Yongxin et al. concluded those methods and divided them into two directions [9]:

- Collection of technology, integrating different theories of landslide to solve the problems.
- Introduction of modern science and technology. Efficient and advanced algorithms were researched to blend into landslide simulation.

In recent 10 years, modern mathematical theory was widely applied to all walks of life. Intelligent landslide calculation algorithm (namely, genetic algorithm GA, fuzzy logic system fuzzy inference system FIS, artificial neural network ANN) is a solution to solve complicated problems, found in the end of 20th century. Especially, FIS and ANN are both used to find solutions of similar problems through the law of development of natural things and human beings.

In the field of GIS, the research of spatio-temporal data modeling has been done for decades, but how to express and store dynamic phenomenon in computers is mainly concerned in those researches. The current spatio-temporal data models such as snapshot model, incremental model, space-time cube, etc. are passive expression, which cannot fundamentally answer the question that how the spatio-temporal process happened and developed, which is the key point in processing and integrated management of emergencies. Especially in complex geological movement like landslide, etc., involving multiple factors, simple passive approach is not enough to express. So the traditional spatio-temporal data model is unable to do real-time and dynamic display of the process.

The data model we proposed is four-dimensional spatio-temporal data model whose process is driven by events: the extension and improvement of event-process model. The theoretical base of event-process model is that every factor, every event will be sent to a process, and then the process will give feedback and response to the event. However, for a complex geologic process, it's a spatio-temporal response to multi-factor and multi-event following certain accumulation superposition and modification in a certain time sequence. The dynamic description of landslide's formation and disastrous process involves much more events. As event-process model cannot fully describe and express this kind of complex geologic process, it's urging to put forward multi-factor and multi-event spatio-temporal data model to solve the problem.

3 Multitask Spatio-temporal Data Model

The majority of spatio-temporal subjects varied from time to time in the real world. However, the mainstream GIS did not take full account of the time factor, just the mixed data basically made up of data in a variety of times. Even if time factor was taken into account to form history database，longitudinal analysis of data in various time periods was not been done. Though spatio-temporal GIS based on spatio-temporal model was researched by few systems, they were without strong generality and lack of wide application, only focusing on a certain field. This spatio-temporal GIS data model, which can describe s-t process and provide foundation to dynamic spatio-temporal subjects' analysis, and it aimed at researching the ubiquitous dynamics of spatio-temporal subjects.

Multi-factor and multi-event spatio-temporal data model is based on event-driven process data model proposed by Wuhan University, aiming at demands of diversity expression of geographic spatio-temporal dynamic simulation, preliminarily enlarging the model. Focusing on geometrical, attributive, spatial relationship of geographic spatio-temporal subjects, relationship, and behavioral expression and so on, conceptual models of spatio-temporal subjects were initially established to support simple geographic process simulation

Event-driven process data model expressed spatial information from 3D perspective. Spatial features of subjects were expressed abstractly from the point of serial and discrete form. Serial expression uses formula to describe subjects precisely. In this way, the value of each position can be achieved by calculation. Discrete expression express subjects through primitive that can be subdivided to forms based on vector and grids.

This model mainly emphasized the description and expression of spatial process. Spatial process would be defined as a class. The general conceptual framework of spatial GIS data model was as followed:

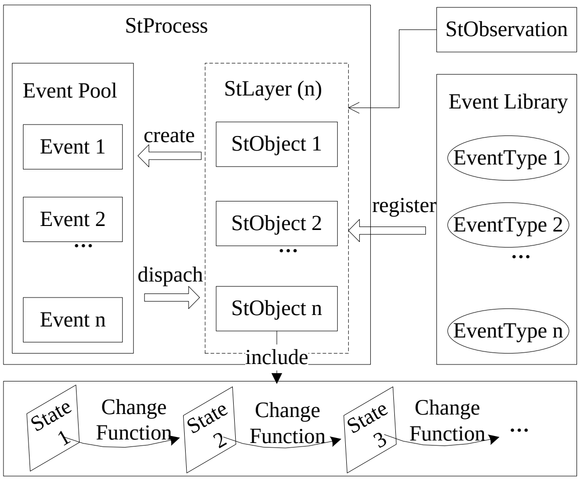

Fig.1: Concept Map for Spatio-temporal Data Model

3.1 Interpretation of the Model

Spatial process: In a certain time period, the evolution process of the researched spatial subject or assemble of spatial subjects changed by the time, namely the description of interactive relationship between spatial subjects and events.

Spatio-temporal object: Objects or phenomenon with specific or ambiguous geometrical boundaries in geographic environment of the real world. The collection of the spatio-temporal objects with the same geometric type and the same attribution is called spatio-temporal layer.

Event: the evolution of spatio-temporal process caused by spatio-temporal objects' abnormal changes. The event is triggered by spatio-temporal objects, then dispatched to the registration object that could response our event. The objects that respond the event must give a reaction, and in this time they could create some other event.

State: collection of the features in a certain moment during the changes of spatio-temporal objects. The constituent parts of state, which were used to express spatial and thematic attribution of spatio-temporal objects in the certain state, were called features.

Change function: functions reflecting the regularity of changes of values according to fields or relative experience, scientific calculating, in effective time scope using observed values.

Spatio-temporal observation: observing attribute's behaviour to generate new event type in event base.

Real-time GIS data model mainly researches the relation and changing law of spatio-temporal process, spatio-temporal object situation， events and etc. on the timer shaft. According to what is said above, the following conceptional relation could be achieved.

Spatio-temporal process class is the base class of spatio-temporal GIS data model and a changing process of spatio-temporal objects along timer shaft contained by a series of coverage. The process is composed of two parts, one is the object layer, and the other one is the event can influence the object as shown in Figure 1. At the same time, the s-t process is related to the sensor observation class, which can get observation data, and with this data the s-t object could create s-t object state.

Description of Spatio-temporal object class is that artificial or phenomenon or natural objects which are the research object and data carrier in real world will be abstracted from the real world and described and operated in computers through cognition. In this model, spatio-temporal object is with the feature can vary with time, and the changing features are expressed through spatio-temporal objects' situation in a certain moment and the changing process between situations. Data sources of spatio-temporal objects are probably from historical database，or the access of data of real-time sensor.

Event class describes the evolution of spatio-temporal process caused by abnormal changes of spatio-temporal objects. Event triggered by spatio-temporal objects, was distributed to other register spatio-temporal objects by process. The other objects can react in a certain mechanism according to received events. The process of reaction may produce other events. In the model, event is served the position of delivering information for spatio-temporal objects and spatio-temporal process. This class contains a pointer pointing spatio-temporal objects, explaining a spatio-temporal event is sent by which spatio-temporal object.

Generally speaking, the whole process is : using an external sensor to observe the, if any change were found, then spatio-temporal objects were informed and respond primitively, sending the event to event pool, which begin sending the next event after dealing with the previous one.

3.2 Improvement of the Algorithm

The improved multi-event and multi-task spatio-temporal data model open to landslide was added a new mechanism, the multi-task and multi-event operation pool.

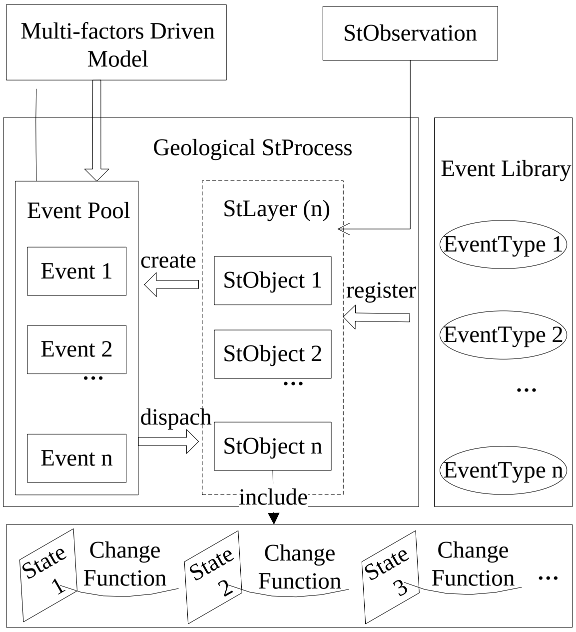

Fig.2 Extended Conceptual Diagram of Spatio-Temporal GIS Data Model

The spatio-temporal process layer mainly referenced spatio-temporal GIS data model of Wuhan University. For the problem of expressing multi-factor geological process, the early s-t GIS data model can only deal with the expressing of s-t process's causal relationship, it can't do the work of expressing the relationship between the event and event, also the work of explaining the internal mechanism of event's changing process. So we propose a geological s-t data model driven by multi-factor and multi-event, as shown in Figure 2.

3.3 Event Pool and Module Driven by Multi-factor

The structure of extended spatio-temporal data model in Figure 2 shows that the improved model algorithm is mainly added the module driven by multi-factor, which mainly communicates with the event pool. The communication mechanism is the core of this article. The following picture demonstrates the mechanism of event pool and the geological event model driven by multi-factor in detailed way.

There are different types of glo-events in glo-event pool. For research process, the objects of each glo-event can be divided into two types，the atomic events and compound events. Each object of the event is with two types of counters, layer counter and breadth counter.

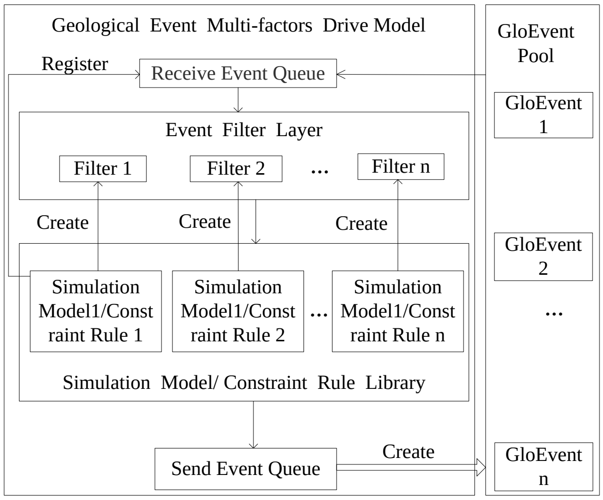

Fig.3 Structure Chart of Geological Event Multi-Factors Drive Model

Every geological multi-factor driven model is responsible for maintaining a receive event queue and send event queue. Simulation model and constraint rule will be loaded by users in accordance with the need in practical process simulation. In simulation model, the corresponding process simulates corresponding algorithm library, and the result event is put into send-event queue after glo-event simulation algorithm operation. After the simulation of simulation algorithm library, the layer counter of result event is added one layer based on original input event.

Constraint rule is defined in advance by users, using to express entities' rank and associations between the changes of entities, supporting triggering new events(e.g. Earthquake event leading to tsunami event, etc.). In dealing with the new simulation or constraint result event, multi-factor drive model cannot realize the control to result events. Therefore, there is a kind of special multi-factor drive proxy object defined in object layer, these objects can deal with the events which other object cannot respond, such as object A splitting into object B and object C and the output processing of intermediate data. Breadth counter of result events produced by constraint rules is added one layer on the basis of the original input event.

A complex geological spatio-temporal process may contain multiple simulations of simulation algorithm or constraints of constraint rules. When the geological spatio-temporal process simulation ended, users can quantificationally evaluate the influence's breadth and compound layer rank of this geological spatio-temporal process through checking the values of the two counters.

- Load the application model which s-t simulation used to simulation model library.
- Create the event filter when the user load the model to model library, and put it into the event filter layer.
- According to the parameter that a simulation model need, build an event type to the Event received queue.
- Receive the event and put it in the Event received queue when the queue find a suitable event in the event library, and start the event filter's work.
- When event filter monitored that the entire event was ready, it would get the entire needed event and send it to the relevant simulation model.
- The result of the simulation would be sent as a new event to the event pool, and start a new circulation.

When the Multi-factor Driven Model sent some particular event that the common objects could not respond, the Multi-factor Driven object in object layer would receive this kind of event and deal with that relevant particular event.

In conclusion, the interaction mechanism between event pool and Multi-factor Driven Module can be simply described as these, first, the event pool kept sending the event produced by object layer to Multi-factor Driven Module, at the same time the physical model in the multi-factor driven module would start choosing and matching that event, when the event set was sent as a given sequence, the driven model would start working, producing one or some event to event pool, the event pool would notice objects to respond after receiving.

4 Dynamic Simulation Solution of Landslide

The application of improved spatio-temporal data model to landslide is using the landslide mechanism into the model, through establishing extended spatio-temporal data model aiming at landslide, including standard setting of abstract model, physical storage scheme of the model, and compatibility test of basic spatio-temporal data model.

For the need of diversity expression of spatio-temporal dynamic simulation, we research the geometrical, attribute and spatial relationship of various kinds of spatio-temporal phenomenon; and the digital expression of semantic and behavior models. For the actual demand of landslide dynamic simulation, researching the digital expression of landslide spatial objects, and establishing the multi-dimensional landslide spatio-temporal object model which supports landslide dynamic simulation.

4.1 Conceptual Model and Execute Solution

In order to make better use of this model, the slip mass was divided into several sliding surfaces which were made up of several sliding blocks in the research. Sliding blocks interact with each other by friction, cohesion and the qualities of slide block itself such as soil constituent, friction angles and so on. Inputting the real-time observation and qualities itself into model, a sliding surface's state can be achieved. Through analyzing situation of several sliding state, the state of the whole slip mass can be achieved.

To facilitate the research, we divide the complete slip mass into two layers: 1, sliding block layer; 2, sliding surface layer. For sliding surface layer, the whole landslide is regarded as a spatio-temporal object, the analysis and process of all the events and physical drive models are targeted at landslide. In a similar way, for sliding block layer, landslide is abstracted into several sliding blocks, the response and analysis will be targeted at sliding blocks as spatio-temporal object.

In sliding block layer, the main observation events are such as data changes of temperature, humidity, slip mass's landform constituents, hardness, roughness and etc. Through registering of the event base, sending changes above into event base. As shown in the Figure 4.

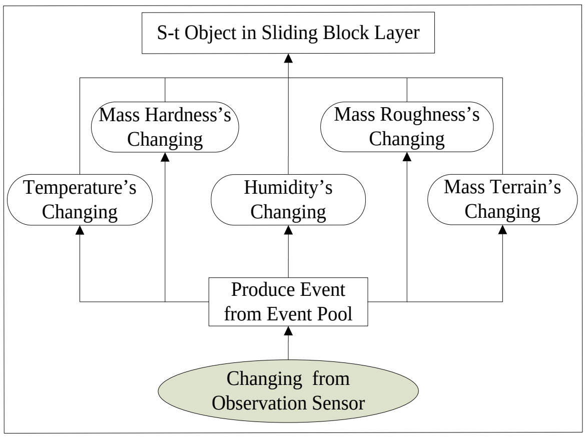

Fig.4 Event Driven Processes in Sliding Block Layer

It's known from the figure above the environment changes can be received and several events can be created into spatio-temporal process by sensors. The events are received by landslide block and sent into the event pool. Then the event pool sent these events to multi-factor drive module. In block layer, for the physical driven in the layer multi-factor drive module contains frictional angle model (judging the energy produced during a block in a certain inclination angle), and cohesion model (judging energy produced by cohesion between a block in a certain geo-environment and the surroundings), which can influence the following sending events such as changes of frictional angle and cohesion and so on into spatio-temporal objects in landslide layer.

So landslide layer is given feedback to event pool through the events above in the event pool driven by multi-factor model, then influenced the spatio-temporal objects in landslide layer.

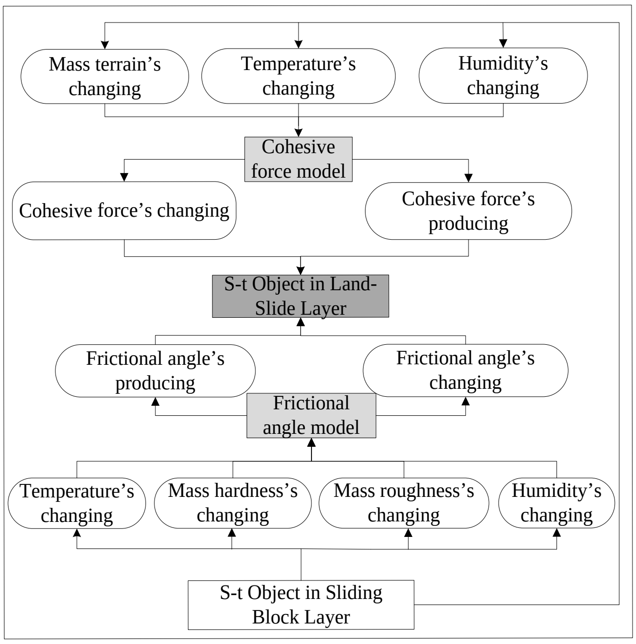

Fig.5 Event Driven Processes in Landslide Layer

In this paper, the physical driven model for spatio-temporal objects of landslide layer is cellular automaton model, namely, this model receiving such driven events as changes of friction angle, cohesion and landslide mass's inclination angle. Through recording whether the block move or not and move distance, it can be judged comprehensively whether the landslide is stable or not and the data information such as the current move situation and so on if it's not stable. Dynamic landslide simulation can be conducted through visualized simulation.

4.2 Detailed Embodiment

The previous work has got the system embodiment off the ground, such as multifactor driven model supporting the physical expression of landslide process, conceptual model of landslide simulation, design and embodiment of the logic model. Now, the only need is establishing an appropriate data base and a visual platform, and that is to say the land-slide dynamic simulation can be conducted well.

Based on the guiding thoughts and combining the theoretical work above, it's found that the main task of system design is processing the spatio-temporal data of landslide process first, then the encoding of visualization. VS2010 is adopted in this article to do programming test for this model's algorithm and conduct the visual presentation.

The designing embodiment flow chat of the whole landslide simulation system is as shown in the following figure:

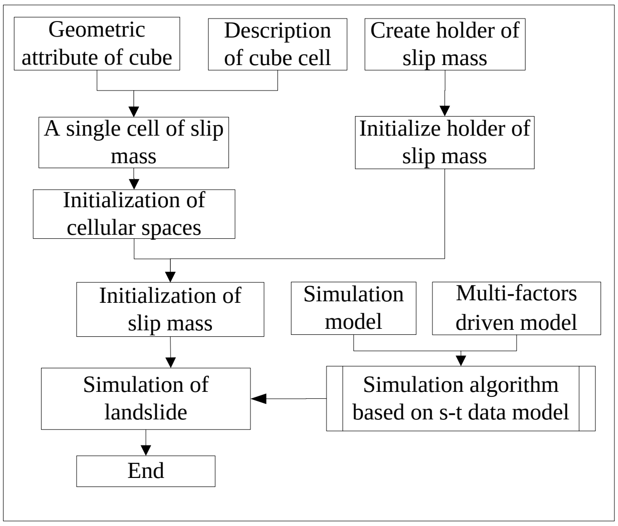

Fig.6 Complete Embodiment Flow Chat

4.2.1 Create a Block

Create a cube block cell, containing two parts: density and initial position. We can get the size of a cube at the initialization of cellular spaces, so we can calculate a cube's mass.

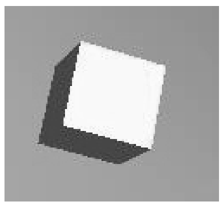

Fig.7 Cube of Slip Nass

4.2.2 Create a Holder of Slip Mass

In this experiment, the holder is a random generated smooth curved surface which seems like most of common slip mass's shape.

The surface contains four attribute object, material-Ice, material-Rock, material-Mud, material-Grass, every object has different physical attribute. Such as, for the material-Rock:

```
m.restitution        = 0.1f;
m.static-Friction    = 1.2f;
m.dynamic-Friction   = 1.0f;
material-lRock = gScene->createMaterial(m)->getMaterialIndex();
```

In this code, m.restitution，m.static-Friction，m.dynamic-Friction mean a different attribute of a Rock material.

The next is the initialization of slip mass. Produced by the system, the figure of landslide mass carrier space can be achieved as follows. The whole carrier space is curved with high sides and low middle, and a small flat ground underneath. The carrier space is made up of three colors, which represent soil, stone and grassland respectively.

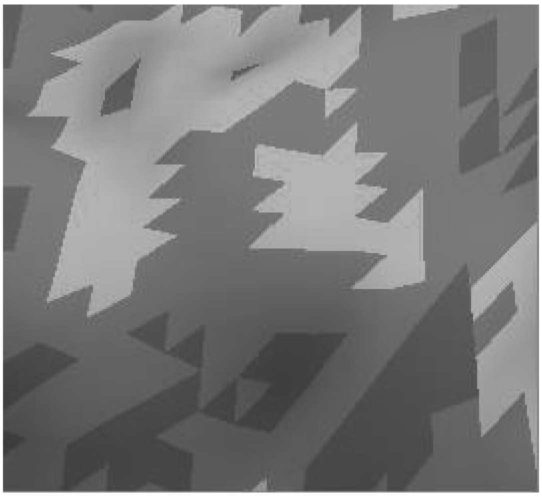

Fig.8 Initialization of the Holder

4.2.3 Landslide Initialization

When the carrier is done, then it follows with landslide initialization process. In this landslide simulation, we divided a landslide mass into a lot of small blocks, which own the all attributes of a landslide mass. When the balance of these blocks was broken, all of these blocks began moving and influencing each other, then we can simulate the process of landslide.

After creating landslide blocks and carrier space, the landslide visual simulation can be conducted. We can create a block cellular space (100*100), and front view and side view as follows:

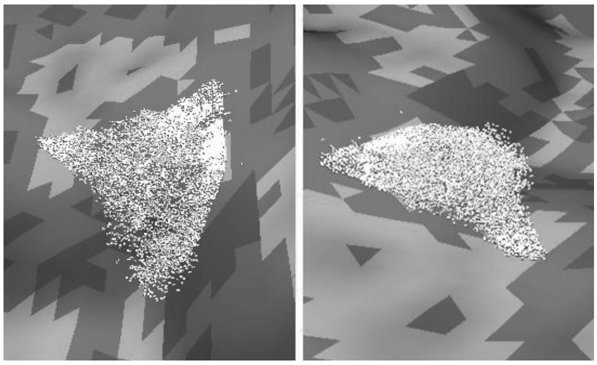

Fig.9 Initialization of the Slip Mass (frontal and side view)

4.2.4 Landslide Dynamic Simulation

After initialization, then is the landslide operation process. The front view and side view's screenshot of operating 5000 steps is shown as follows:

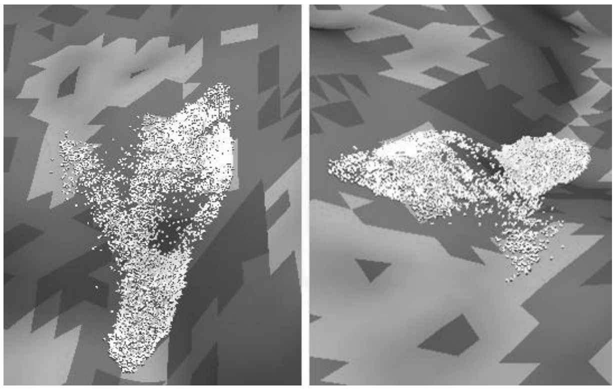

Fig.10 Operate 5000 Steps (frontal and side view)

During almost 100000 step operation, it's found that landslide movement tends to be static basically, not active any more, just a few parts of block sliding slightly.

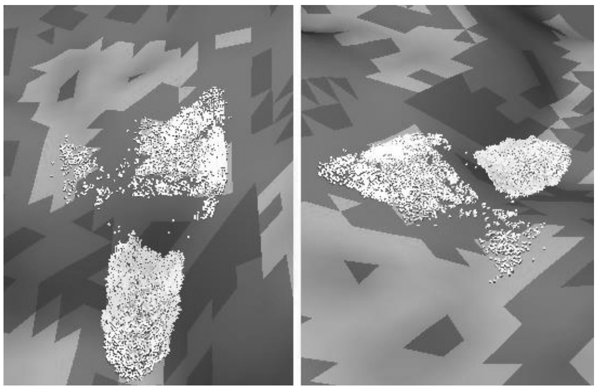

Fig.11 Operate 10000 Steps (frontal and side view)

Through encoding, simulating to specific landslide example and validity verifying, it shows that multitask spatio-temporal data model introduced by the paper can soundly describe the practical landslide interaction process and have application value in certain extent.

4.3 Performance Analysis and Comparison

Before inventing the dynamic simulation algorithm, our Landslide Team had studied the CA (cellular automaton) algorithm and GA (genetic algorithm) to solve our problems; we compared these two algorithms with our new algorithm. The veracity of the simulation result and the speed of the simulation process were the main comparison factors.

Our team got a lot of real landslide data in different time from Chinese Three Gorge Huangtupo landslide mass by sensors. We did two comparisons, the speed comparison and the accuracy comparison.

Firstly, we recorded the real landslide data with the time of 5s, 50s, 500s, 5000s, so we could get four different landslide states. Then we used three algorithms to calculate, get each algorithm's calculating time and the result is in Table 1.

Table 1 The Speed Comparison (U: s)

	State1	State2	State3	State4
CA	15.2	173	1609	15893
GA	3.1	20	312	2976
Multitask S-T	6.8	59	587	5726

This is the comparison figure:

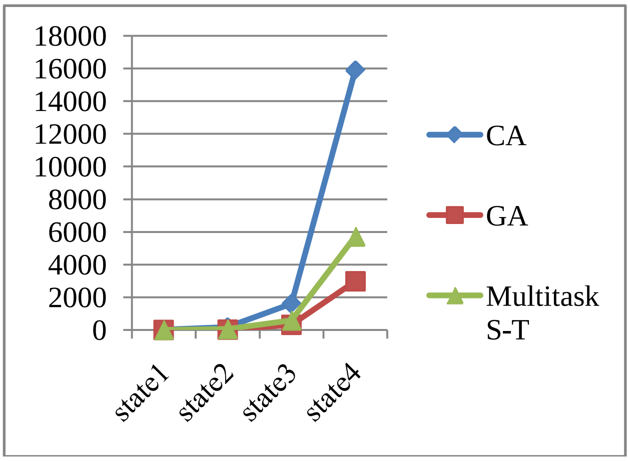

Fig.12 The Speed Comparison between Three Algorithms (U: s)

In the accuracy comparison, we compared three algorithms' result with real data in a same time. We used the observation point to judge if the simulation result is right. The final result is shown as follows:

Table 2 The Accuracy Comparison (U: %)

	Time1	Time2	Time3	Time4
CA	90	93	95	96
GA	21	13	15	12
Multitask S-T	88	87	90	92

After that we found the cellular automaton method can get a simulation result with great accuracy, but with low speed. So it couldn't solve the dynamic real-time simulation problems. The GA had high calculating performance but the simulation result is very poor. Only our new algorithm had high performance both in veracity and speed.

This research is grounded on the 863 project "Spatiotemporal Process Simulation and Real-Time GIS System" (863 plan, Chinese National High Tech Development Plan Fund, NO.2012AA12401), and the algorithm was employed in landslide simulation module in the project, which was finished successfully in Mar 2015.

5 Conclusion

In this paper, an operable, extensible spatio-temporal data model of geologic process driven by multi-factor and multi-event was proposed through theory research and development. Based on this spatio-temporal data model, landslide dynamic simulation software which can soundly solve the temporality and visualization problems in three-dimensional simulation process of landslide, realizing the dynamic simulation to landslide process and spatio-temporal features was developed. Through specific simulation practice, rationality of the model was verified. Aiming at the limitations of current spatio-temporal data model of landslide that cannot describe complicated spatio-temporal process, the extended spatio-temporal model driven by multi-factor and multi-event was put forward and multi-factor driver module was developed, which solved the problem that complex spatio-temporal process of landslide movement and disaster development can hardly be described.

Multitask spatio-temporal data model, with the spatio-temporal feature and characteristic of management and storage of dynamic data and so on, belongs to data models applied to dynamics. These features ensure this model the merits that can simulate the landslide movement and process in spatio-temporal environment on the basis of researching and simulating the general complex system. Verify the feasibility of the model by dynamic simulation of specific landslide.

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