Spatio-temporal data model for landslide dynamic simulation

1. Introduction:

Temporal domain, spatial domain and attribute domain are the three basic characteristics of natural geography phenomenon and things themselves. They are also important components on reflecting the state and evolution of geographical entity. It seems especially important for researchers to follow the time sequence, so that they can explore ideas and methods suitable to discover knowledge on the internal mechanism and the development of variation of the objective world. Spatio-temporal data model is the foundation and core of Temporal GIS (T-GIS) study. The pros and cons of spatio-temporal data model, to determine the flexibility and effectiveness of the operation of the T-GIS, influence and restrict the development and application of T-GIS.

Now there existing a lot of event-base or event-driven spatio-temporal models to be able to express the temporal and spatial variation causality, but these models cannot express the internal cause of the event changes. Another problem is how can we extract specific events from our spatio-temporal process? How to describe the relationship between events? To solve these issues, we conduct a further research on the basis of existing real-time GIS data model[1], and come up with an extended spatio-temporal model. This extended model can support complex geological process simulation and analysis. We conduct our research on dynamic simulation of landslide to the Three Gorges area to verify the feasibility of the model.

2. Analysis and Discussion

2.1 Conceptual framework of spatio-temporal data model

As shown in Figure 1, the right black part is the concept part of real-time GIS data model. StProcess is an entire scene (need to study or simulation) changing over time and/or the course of evolution, namely geographic objects constantly generate events and response to the event. Events can not only be caused by object regularly or irregularly according to observation data, can also be produced by a logical judgment and other conditions. The generated event is sent to the StProcess, and pushed into the event queue of the StProcess. First the StLayer or StObject register events that they would response. Secondly the StProcess broadcast events to the StLayer or StObject according to the sequence of event queue. Then the StLayer or StObject would discard or response according to the information of these events (StEvent), new events may be generated during the procedure. The StObject is composed of a series of state (StState), each state has recorded StObject's snapshot of a moment. By default, the value between two StState, numerical attributes obtained by linear interpolation, non-numerical attributes using the nearest neighbor method.

[1] 863 project "key technology of real-time GIS data model and software platform" design document, Wuhan University.

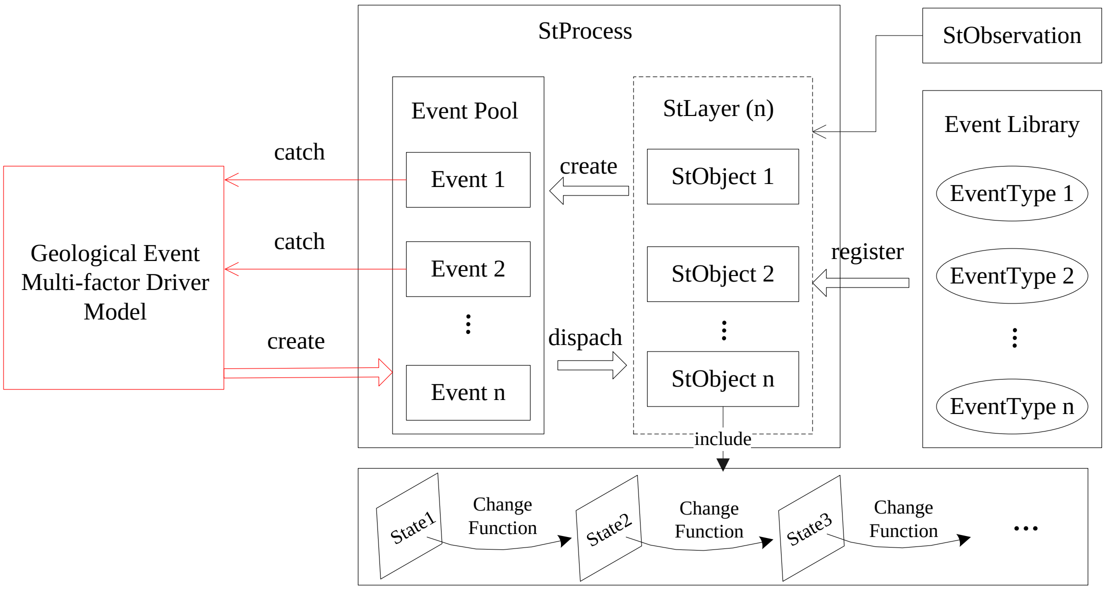
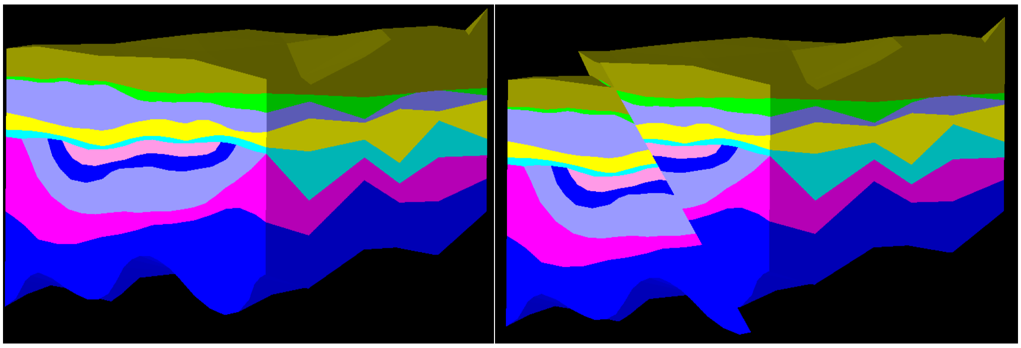


Fig.1 Conceptual framework of spatio-temporal data model

We may encounter previously described issues in the analysis of specific process. In fact, any temporal data management has the so-called object granularity issues, in other words the structure of the object will become more complex as the granularity refinement. Similarly, the event-based or event-driven process simulation has the "event granularity" issues. Further, there even exist a variety of different granularity events in the specific process simulation. Therefore, we should extract different granularity events from the actual process according to the basic information and the needs of our simulation. There are two types of event in our research, one is the atomic event, and the other is composite event. The former is indivisible event in the spatio-temporal process, while the latter is complex event that can be triggered by a series of events or other factors.



（a）　　　　　　　　　　　　　　(b)

Fig.2 Union Change case with constraint relations description. (a)before the formation of fault, (b) after the formation of fault.

Relations play an important role in the real world; it is no exception for events. For example, during the regional fault formation process (see Figure 2), the fault geological body split events are triggered when the fault event occurs. These body split events can further trigger the division of body property value event and the spatial topological relations events, and then trigger the event of strata displacement along the fault plane.

In order to be more realistic simulation of the landslide process, we try to improve the expression efficiency of various types of composite events and composite spatial and temporal changes in its semantic level. So we propose an event multi-factor drive model (abbreviated as MFDM), its running mechanism is described as follows (the left read part of Figure 1 and Figure 3):

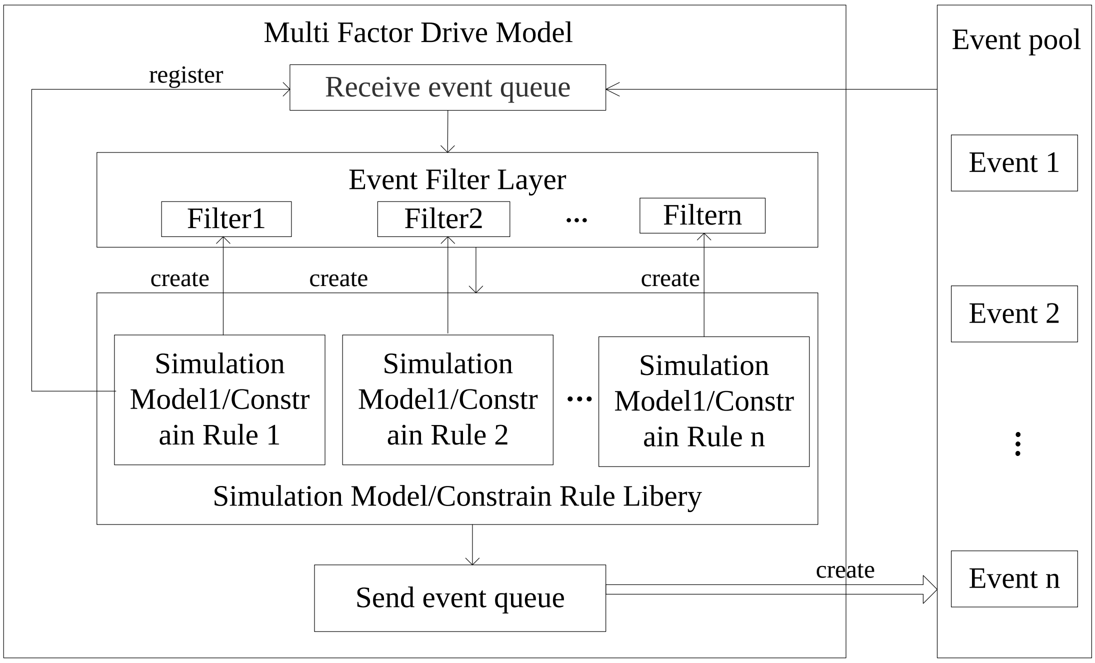


Fig.3 MFDM running mechanism

(1) The simulation model and constraint rule are loaded into the library according to the needs of simulation process.

(2) When the user loads the simulation model or constraint rule, the corresponding filter is created.

(3) The user identifies the different types of event according to the input parameters of the loaded simulation model or the constraint rule. These types of event are registered to the receive type list.

(4) When events in the event pool meets the receive type list, the MFDM will push these matching events into the event queue and notify the filter.

(5) Every filter gets events from the receive event queue and then sends them to corresponding simulation models or constraint rules.

(6) The simulation result is the form of events; these new events are put back to the event pool.

In a word, the MFDM can be regarded as an event processing plants; a composite event is generated after processing. This MFDM is capable of handling the issues caused by multi-object state changes, but also help to address the difficulty of grasping and/or describing various levels of event as well as the "event granularity". It is worth noting that this MFDM should be based on the actual needs of clients and the specific simulation process. This MFDM should be integration of their professional models, constraint rules, experience and algorithms to achieve better apt actual results.

The event is not only the process records, and is the key to the state of the object changes. So it is necessary to clarify the classification in the specific simulation process. In order to provide ideas to solve the issue, we have divided events into four basic categories: space change event, time change event, property change event, and relationships change event.

(a) Space change event include split event, combined event and adjustment event, wherein, split event including line split, surface split, body split event, combined event including point merger, line merger, surface merger, body merger event, adjustment event including shape adjust, position adjust, range adjust event.
(b) Time change event include time division event, merger period event, adjust-time event, deadline event, wherein, adjust-time event including early termination, period shortened, expand period event.
(c) Property change event include division of property value event (triggered by split event), property values combined event (triggered by combined event), attribute adjustment event.
(d) Relationships change event include spatial relationship event, time relationship event, temporal relationships event (not listed here), causality relationship event, function relationship event, wherein, spatial relationship event including spatial location relationship, space metrics relations, spatial order relations, spatial topological relations events, time relationship event including time metric relations, chronological relationship, time topological relationships event.

In addition to the above basic events, thematic events have an important role in the scientific analysis. Thematic events are divided as follows:

(1) Landslide observation events, including rainfall monitoring, groundwater level monitoring, topographic depression observation, topographic survey, geotechnical structural investigation, deformation monitoring, pressure observations, stress Monitoring events.
(2) Observation time events, including observation period, observation start/end event.
(3) Landslide internal parameters events, including length, density, cohesion, angle of internal friction, deformation modulus, Poisson's ratio, the acceleration due to gravity, stress, strain, displacement, permeability coefficient, time, flow rate, rainfall intensity, angle of inclination, side pressure events, etc.
(4) Landslide movement events, landslide peristaltic, landslide resurrection, slope stability, landslide overall slide events
(5) Manual intervention event, including engineering control, artificial destruction events
(6) Landslide relations events, including monitoring network, spatial topological relations event, etc.

2.2 Simulation models and constrain rules

Some simulation models should be loaded into the MFDM for better apt actual results. These models can be linear regression model, cluster analysis model, artificial neural grid model, multi-factor quantitative analysis model, the Saito model, the Fu bounded model, the Verhulst model, non-linear dynamic model, the Pearl model, gray clustering and fuzzy mathematics model, etc. We have two of them as an example, the linear regression model and multi-factor quantitative analysis model. The former create a filter accept two types of events, the observation time events and displacement length event; the latter accept most of the landslide internal parameters events. Both of the two models can produce the landslide movement events.

Some constrain rules should also be loaded into the MFDM for a more realistic simulation. We can create some constrain rule from the landslide observation events to the landslide internal parameters events. For example, constrains rule of the angle of inclination event trigged by the topographic survey event.

Many other constrain rules can be defined and loaded to the MFDM for your spatio-temporal process analysis. It is worth noting that the relationships constrain rule describing is relation between process changes. It means the process of development toward a certain direction under the constrain rule. However, the relations events describe the changes of the relationship between the objects.

2.3 Landslide process description

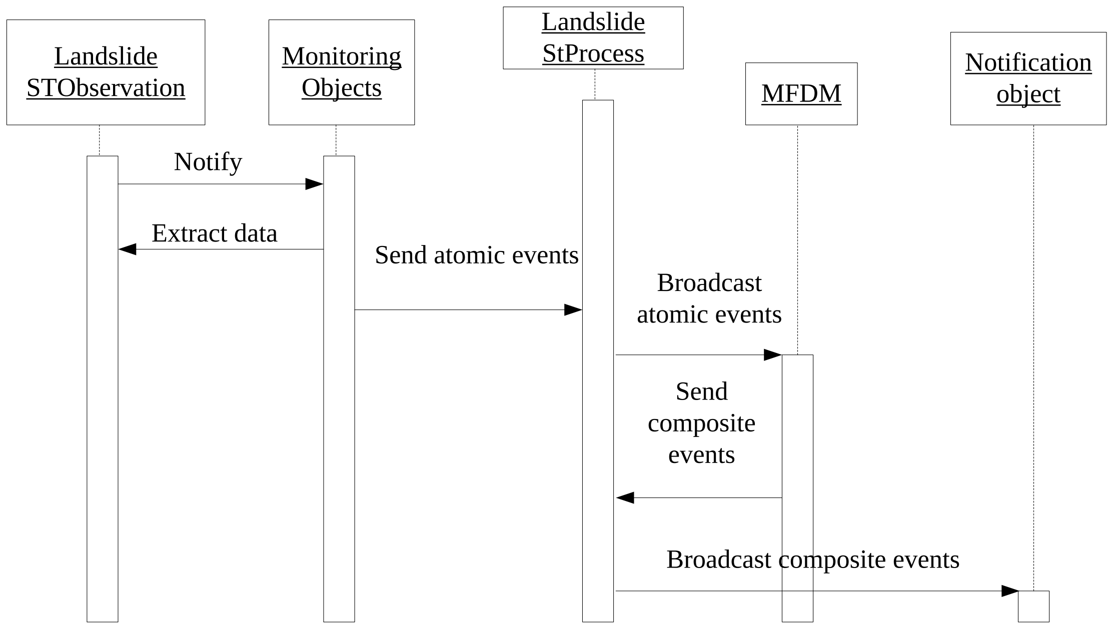


Fig 4 Sequence diagram of landslide spatio-temporal process

Here we describe the core of the system process (Figure 4):

(1) Landslide STObservation observe landslide area geology, topography, hydrology, geotechnical, rainfall and other information through the sensor network.

(2) Landslide STObservation notify the landslide area monitoring objects, and then the monitoring objects decide whether to extract relevant data as a response.

(3) The landslide area monitoring objects send atomic events such as rainfall increased events and seismic events to the Landslide StProcess.

(4) The Landslide StProcess push these atomic events into event pool and then broadcast them to the MFDM or the StObjects.

(5) The MFDM receives and process events, some new composite events are generated after the processing of the suitable model or constrain rule. These composite events include landslide peristaltic, landslide resurrection, slope stability, landslide overall slide events.

(6) These composite events are sent back to the event pool and then be broadcasted to the Notification object.

(7) The Notification object inform the relevant decision-makers, and gives emergency

recommendations.

(8) Landslide STObservation continue to next cycle until the end of the simulation.

3. Acknowledgements

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4. References

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