The Semantics for the Determination of Temporal Relationships for Geographical Objects

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Abstract. The ability to examine the continuity of change of geographical phenomena has been given some attention in the past decade. However, none of the suggested models have been able to deal with the continuity problem nor to be implemented successfully. This paper aims to investigate a new conceptual model that will represent the semantics in order to allow the continuity and pattern of changes of the geographical objects to be determined over time.

1. INTRODUCTION

The current GIS approaches of representing changes of geographical phenomena does not provide the ability to examine the complexities within the changes, in order to allow the integration of changes for different themes (e.g. Social activities, infrastructure facilities, transportation, population etc). This has become a major problem because a change in one theme may have adverse effect on the others, thereby risking the work of urban planners. This situation is exacerbated by the fact that no adequate data models are available which could efficiently represent detailed changes, showing the pattern of relationship among the themes, the cause of changes and result of the changes over time (Sui 1998).

This paper aims to investigate the conceptual model that will represent the semantics to allow the continuity and pattern of changes of the geographical objects to be determine based on temporal relationships between the versions, events and the processes over a time period. In this work we start by considering the development of a model to determine the continuous links between different versions of geographical objects and the attribute changes such as temporal, spatial and thematic. Then, temporal relationships between the versions, events and the processes are presented. An object oriented tool, the Unified Modelling Language (UML) (Booch et al 1999), is then used to describe the design of the conceptual model, which gives the opportunities to examine the changes of spatio-temporal distribution and patterns of geographical objects over time. Finally, we present some conclusions and suggestions for future works.

2. OBJECT ORIENTATION AND GIS

Current modelling of spatio-temporal changes covers a wide spectrum of application, such as socio-economic, environmental science, epidemiological and transportation. Different types of data models have been used to represent changes of geographical phenomena. However, the concept of the data model had been based on raster and vector approach (Langran 1993). Recent research proposals have used temporal GIS and object oriented techniques to explicitly define the relationship between the events (or processes) and the objects with time. This include the triad model and the event- oriented model. Object oriented techniques have been used to identify pattern of changes (events) within the objects (Worboys 1994, Yuan 1997), effectively track versions of the original object that includes use version management (Wachowicz and Healey 1994, Wachowicz 1999) and identity-based method (Hornsby and Egenhofer 2000). The triad model (Peuquet and Qian 1996) is an integrated model and consists of three independent and interrelated domains (i.e. location, feature and time). Event-oriented models have been a topic of investigation in the past decade (Frank 1994, Peuquet and Dunn 1995 and Claramunt el at 1999). In the Peuquet and Duan model all changes are time-stamped as a sequence of events through time. The changes are time-stamped and stored in increasing order from the initial event. Frank represented an ordinal model where events (not time-stamped) are linked in sequential order. Claramunt and Theriault (1996) investigation describes object changes in the past, present and future.

Although, the triad model represents an integrated approach for representing changes, it does not relate events to the geographical phenomena. The event-oriented model represents events which are suitable for temporal staple changes but are not suitable for representing sudden changes (i.e. earthquake) and gradual changes (i.e. rainfall) (Peuquet 1998). The Claramunt and Theriault model represents the events related to the change but stores the changes as attributes of the object and the model is not suitable for tracking the evolution of the geographical objects involving splitting, merging or transition.

3. OBJECT ORINETATED MODEL FOR GIS

The object-oriented approach has the abstraction power to represent real object, provides the extensibility needed to create new geographical models (through "inheritance"), the semantic needed to construct complex object of similar spatial and temporal states (through "polymorphism") (Yourdon 1994). The attributes and behaviour are "encapsulated" within the objects, therefore providing a network of relationship with other objects, identifies the pattern of changes within the objects or predicting the effects of the changes (Yuan 1997).

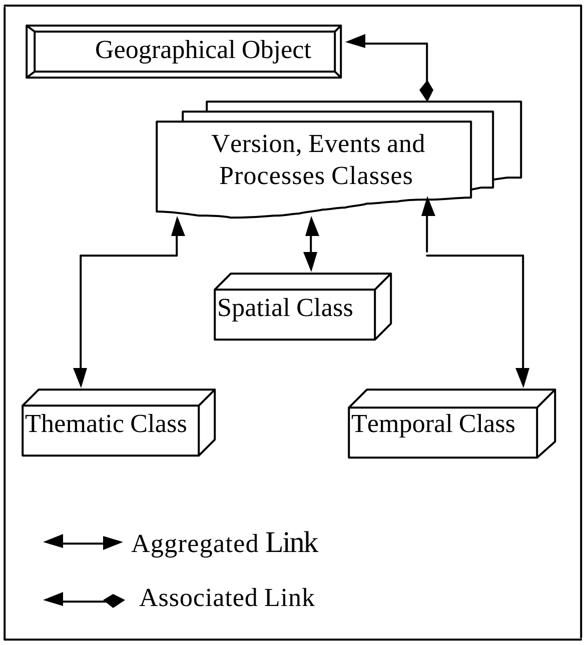

Figure 1: Composite classes of a geographical object

This approach provides the flexibility to make the changes attributes of the object independent of each other to allow the examination of detailed information of the geographical phenomenon (Worboys 1994, Wachowicz 1999). The object-oriented approach had been used in different ways to effectively track versions of the original object through the use of version management (Owen 1993, Wachowicz and Healey 1994, Wachowicz 1999) and identity-based method (Hornsby and Egenhofer 2000).

Thus, the proposed model is based on object oriented techniques and it will be referred to as Object Oriented model for GIS (OOGIS). The OOGIS model supports both object and attributes versioning. According to the OOGIS model, changes of geographical phenomena are handle by version management. A version of the object consists of composite classes as in figure 1. The aggregated composite classes include thematic class, spatial class and temporal class. The associated composite classes include events class and processes class. The spatial class deals with queries about the location of the object (e.g. where is the best museum in this city?). The thematic class deals with queries about the features of an object (e.g. what is the highest building? or what is the speed limit of this road?). The temporal class deals with the queries about the time attributes of the object (e.g. when was the first hospital built in London?). Furthermore, an event class deals with the cause of the changes of the geographical object (e.g. why did they reduce the speed limit of this road?). And, a process class deals with effect of the changes of the object (e.g. how much of this rain will cause a flood?).

3.1 The Versions Class

As figure 2 illustrates, geographical objects are represented as generic object, the first object and any subsequent changes can be represented as versions. Each version of the object consists of changes (involving an attribute or behaviour) of the aggregated classes (spatial, thematic and temporal) and the associated class (events and processes). Subsequent changes of attributes of the versions will generate related dynamic attributes and temporal links to be updated to the respective versions (Owen 1993). The relationships between the generic object and the versions of the object are represented by temporal version management approach (Dadam et al 1984, Wachowicz 1999). The version management uses temporal operators (e.g. during, after, before etc) to handle gradual and sudden changes (Allen 1984). To avoid the use of large storage space, only the generic object or the current object holds the complete attributes and behaviour of the object whiles the other versions represents the changes of their attributes and behaviour.

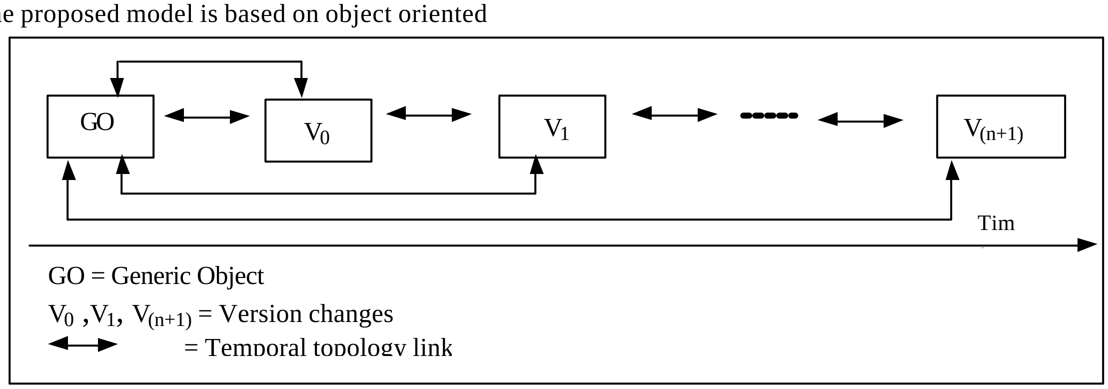

Figure 2: Relationship between the versions and generic object

The temporal relationships between current object and versions can be verified by equation (1):

$$Versions(x)=(?_x(n,n_0),?_x(n-1,n_0),....,?_x(n_0+1,\ n_0),CV_x(n_0))\ (1)$$

where $CV_x(n)$ stands for the complete version number n of the object x whiles n_0 indicates the generic version. The changes between the current version *(k)* and the previous version *(k')* is represented by delta, $?_x\ (k,\ k')$. As shown in equation (1), the current versions are derived from the previous versions and this strategy is referred to as forward based versioning. All the versions are related to the basic version n_0, hence any of the versions can be accessed at equal time. The delta value remained the same when new version is created.

A shown in equation (2), previous versions can be evaluated from current versions and this strategy is known as the backward based versioning. The method in equation (2) provides a quicker access to the current versions.

$$Versions(x)=(CV_x(n),?_x(n,n-1),?_x(n-1,n-2),...,?_x(n_0+1,\ n_0))\ \ (2)$$

When a geographical object splits, the generated dynamic attribute locates the versions and creates temporal links between the previous version and the new versions. Similarly, when geographical objects merge, the generated attributes will establish the location of the new version and creates temporal links between the previous and the new version [Owen 1993].

3.2 Spatial, thematic and temporal classes

A version of an object consist of changes (attribute or behaviour) of the spatial, thematic and temporal classes. Subsequent attributes and behaviour of the classes automatically updated to the respective class. Each attribute or behaviour changes is contained in a version, linked bi-directional to the respective spatial, thematic and temporal. Also, the attribute and behaviour changes of the versions of the object are linked respectively to the previous and next changes. The relationships between the attribute and behaviour changes are linked through the versions by the version link (? V). Spatial attributes and behaviour changes of the versions have relationships through the spatial links (? S). Similarly thematic and temporal attributes and behaviour changes of the versions have relationships using the thematic link (? H) and temporal links (? T) respectively. The relationships between the attribute and behaviour changes improve the efficiency of the query mechanism of the OOGIS model and reduce the data access time (figure 3). They record only the attribute or behaviour changes to minimise redundancy and data storage. To promote detailed and continuous analysis of the changes, there is relationships (bi-directional) between the changes (attributes and behaviour) of each version.

3.3 Events and Processes Classes

Events are regarded as communication between two or more objects that causes an alteration of attributes or behaviour of any of the objects. The data about a specific event linked to the geographical object come from an external source and are handled by the event class. The event class has an initial associations link with the version class. Subsequent association links between the event class and the version class are produced through the bi-directional links. In view of this, the OOGIS model is to deal with attributes changes (dynamic attributes) and to handle both static and dynamic changes. Recording of events are time-stamped as both absolute time and relative time, in order to be able to deal with known dates of events; but the recording can also be sequential using temporal relationships to determine unknown dates of events. The recording of the attributes of the events (e.g. starting time, ending time, speed, position etc.) enable the OOGIS model to deal with sudden changes (such as earthquake) as well as gradual changes (such as rainfall). As shown in figure 4, there are temporal relationships between the first events and the subsequent events, and between the current event, the

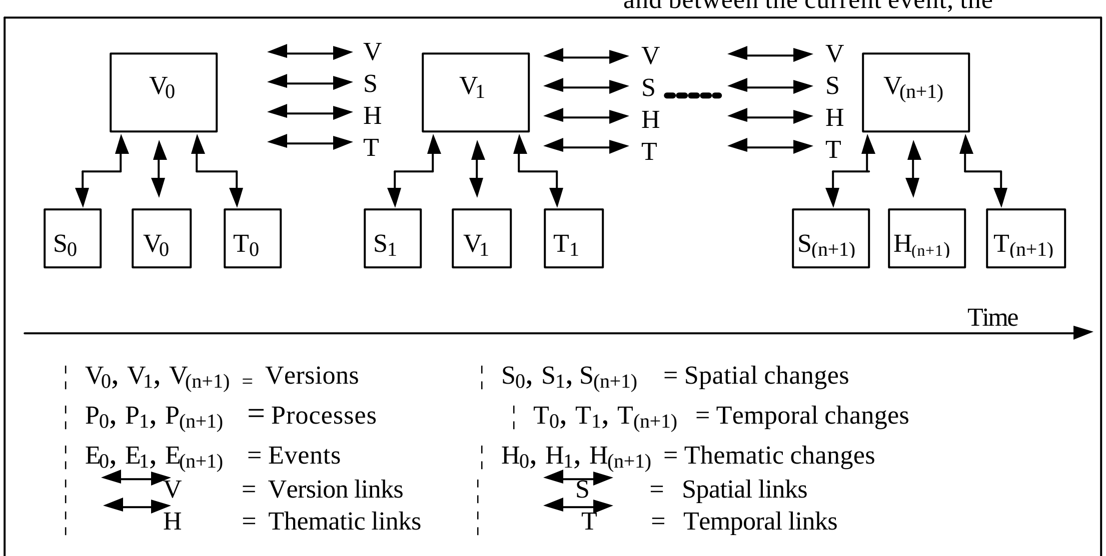

Figure 3: Relationships between the attributes and behaviours changes of the spatial, thematic and temporal classes of the versions of the object.

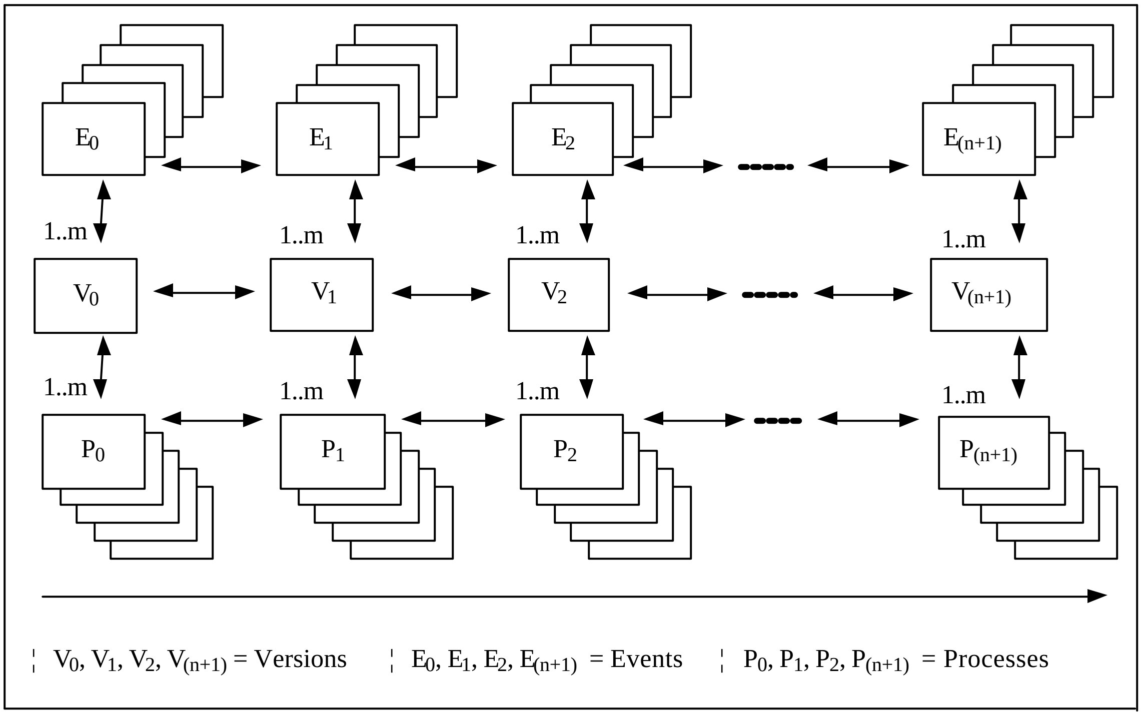

Figure 4: Temporal links between versions, events and processes of an object

previous events and the next event. Also, there is a relationship between different types of events related to the same version of a geographical object (figure 4)

The processes have attributes such as start time and end time to be able to handle sudden changes (such as structure damage) as well as gradual changes (such as urban flooding). In certain situations an event will generate more than one process. Also, different types of events related to the same version of geographical object can generate specific processes. In such a case, there are temporal relationships between set of processes (figure 4).

The temporal relation between versions and processes of a geographical object in the OOGIS model is illustrated in figure 4. The process class has relationships with the spatial, thematic and temporal classes. The relationship between the process class and the spatial determines the actual affected section of the geographical object. Similarly, the relationship between the process class and the thematic class shows which themes were affected and the process-temporal class relationship indicates the actual time of the effect.

Moreover, there are no direct association relationships between the event class and the process class. There is, however, an initial relationship between the event class and the process through the version class. When an event occurs to a geographical object, dynamic attributes of the event are created. A process generates dynamic attributes when it is created. Subsequent temporal relationships between the event class and process class through the version class are set up by dynamic attributes of the events or processes (Owen 1993). Specific event(s) and process(es) is identified by the version of the geographical object. The relationship between the versions of a geographical object, the events and processes are shown in figure 4.

4. DESIGN OF THE OOGIS MODEL

The visual modelling tool known Unified Modelling Language (UML), which was developed by (Booch et al 1999) for object oriented modelling, is used to describe the design of class hierarchies and their interacting relationships within the OOGIS model. The UML describes the design of the versions and the relationships between the classes of the geographical objet. As shown in figure 5, the attributes and behaviour geographical object can be identified into independent classes that are inter-related. This technique allows specific changes of attributes and behaviour to noted and altered over time without affecting the rest of attributes and behaviour of the geographical object. The UML is used to demonstrate the semantics of the versioning and temporal GIS by showing the versions of the geographical object with the events and processes related to the changes. The aggregated relationships between the version class and the spatial class, thematic class and the temporal class can be identified. The associated relationships between the version class and the event class and the process class can be determined.

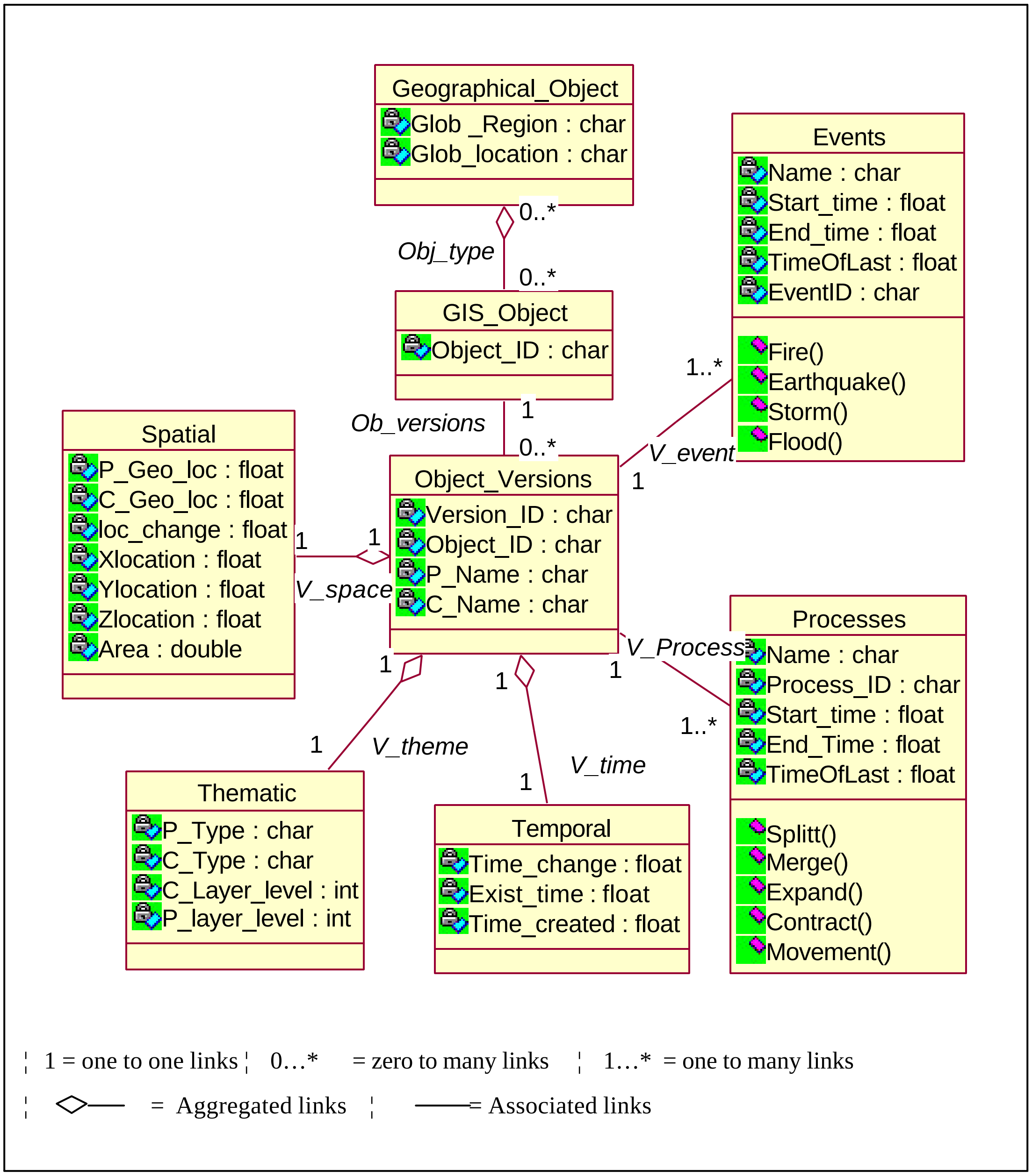

Figure 5: UML design showing semantic of the versioning and temporal relationships

Each class is represented by a rectangle that has different compartments that show attributes and behaviour of each class.

As shown in figure 5, the classes are represented by the departmental rectangle with the attributes shown at the top and the behaviour below. The rectangles have links to show the type of relationships between the classes. The rectangles and the links have labels and the following represents their meaning:

Rectangle:
Geographical_Object – Map or GIS output device; GIS_Object – Geographical objects such as road, building; Object_Versions – Versions of the objects; Spatial – Spatial class; Temporal – Temporal class; Thematic – Thematic class; Events – Event class; Processes – Process class.

Links:
Obj_types – aggregated relationships between the map and the geographical object.
Ob_versions – associated relationships between the object and the versions.

V_space – aggregated relationships between the spatial class, and the object class and the version class. Similarly, V_theme for thematic class, V_time for temporal class, V_event for event class, V_Process for process class.

As shown in figure 6, the interaction between the classes which results from attributes and behaviour changes over time can be represented using the time sequence diagram. The time sequence diagram will show the interaction between the attributes and behaviour changes such spatial, thematic and temporal that results into versioning of the geographical object. Furthermore,

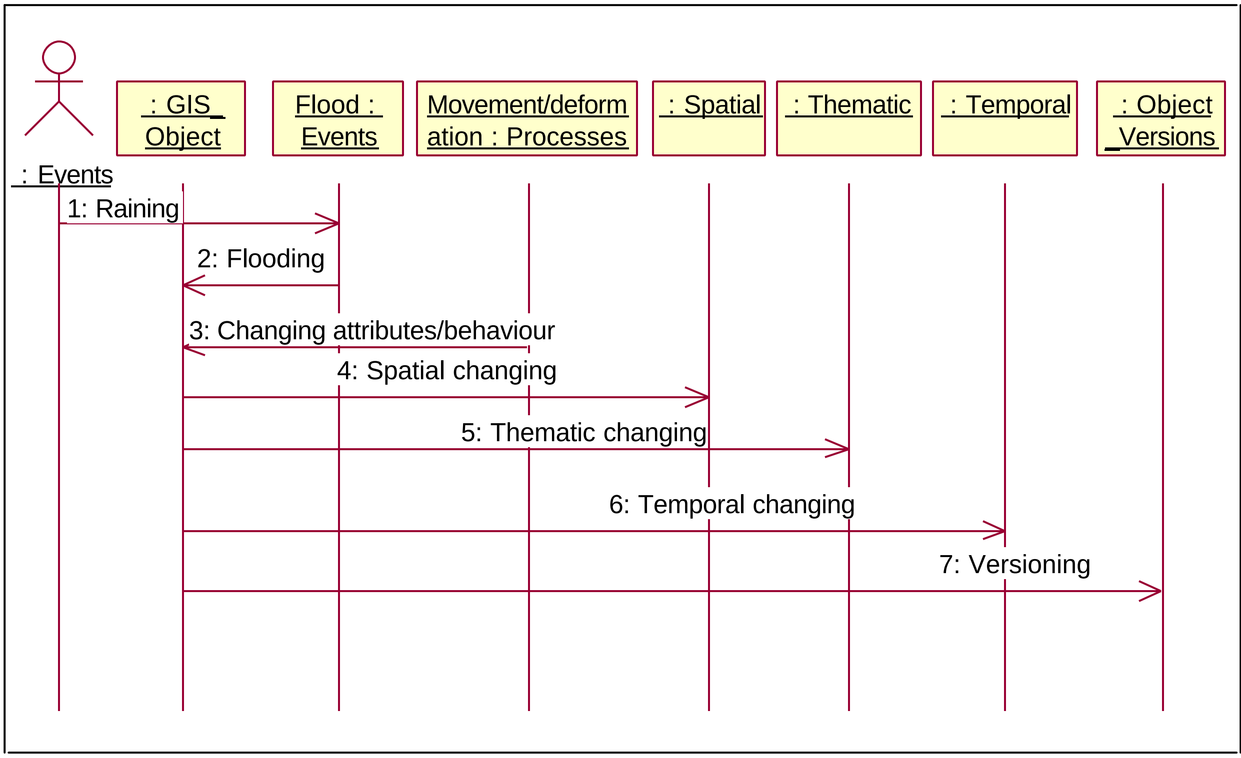

Figure 6: Showing interaction of the changes of geographical object over time using the time sequential

the interaction between the geographical object, the events and the processes are represented. Also shown in figure 6 an event (flooding) which can produce a process such as the evacuation (movement) of people (attributes) from a town.

4.1 Query Component

The query technique of the OOGIS model was classified into different components in order to identify the to be relate the attribute and behaviour changes to the classes of the model. Due to object oriented approach, the attributes and behaviour queries changes over time are directly related to geographical object. The query components of the OOGIS model are independent of each other and are co-related. They are defined with relation to the spatial class, the thematic class, the temporal class, the event class and the process class. Temporal queries enable the time that the changes of the geographical object occurred, the time that event occurred and the time the process was noted to be determined. For example, when was these houses changed to a supermarket? The temporal queries allowed the relationships between versions (including spatial and thematic attributes), the events and the processes. For example, when was this site changed from golf course to race course? Spatial queries are based on the changes such as area and location. For example, which areas in the UK are affected by rainfall that causes heavy flooding? Spatial topology relationship between versions will be determined using the spatial queries. For example, which houses within ten kilometers of the river were affected by the flooding? Thematic queries are related the changes of the theme of the geographical object. For example, which parks in this in this county had been replaced by commercial building? The event queries provide the ability to determine of the nature event that causes the changes and the relationships between the events over time. The process queries allow examining of the effects of the changes and the relationships between subsequent actions.

5. CONCLUSION

Different approaches to representing changes of geographical phenomena for analysing and tracking the evolution of objects have been discussed, many of which have not been successfully implemented. The OOGIS model tackles the limitations of the previous work and provides an integrated framework for effective tracking of the evolution of the geographical object. It produces a good temporal modeling because the temporal attributes and behavior of the versions are independent and have relationships to enable tracking of pattern of changes. Moreover, the temporal attributes include temporal operators to promote continuous analysis of pattern of changes. The OOGIS model also deals with gradual and sudden changes because attributes of the events have temporal operators and events of the versions have relationships between them. Also, less data storage will be required when implementing OOGIS model since only the changes of the object are represented as versions, which will be carried out in future works.

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