

# DESIGN OF SPATIO-TEMPORAL INFORMATION SYSTEMS FOR NATURAL RISK MANAGEMENT WITH AN OBJECT-BASED KNOWLEDGE REPRESENTATION APPROACH

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## ABSTRACT

Information systems for natural risk management typically use multidimensional information, integrating thematic, spatial, temporal and documentary dimensions. Thus, the design of Information Systems dedicated to Natural Risks (ISNR) requires specific data models and specific data interrogation and visualization techniques. Whether it comes from the natural risk management specialists or from the wide public, the demand for information diffusion through ISNR is significant, but few tools are available to facilitate their development. We propose a framework for ISNR design and development allowing designers to generate easily applications dedicated to natural risks, created using an object-based knowledge representation system. Our approach is based on the adaptation of a general and model-driven information system, which offers an interface for querying and visualizing natural risk information, integrating in a native and intuitive way spatiotemporal concepts. The conceptual framework we propose consists of general spatiotemporal concepts and concepts common to all types of natural risks, which can be specialized by ISNR designers in order to define the models corresponding to their own applications. Both the data model and the presentation model can be refined to meet the specific requirements of the ISNR to be developed. We present an ISNR called SIDIRA, an application dedicated to the historical survey of avalanches, developed using our framework.

**KEY WORDS:** Information system dedicated to natural risks, knowledgebase, modeling, natural risks, spatiotemporal and multimedia information system.

## 1. INTRODUCTION

The knowledge of past catastrophic events is an essential prerequisite for the management and the prevention of recurring natural risk events. The historical survey of natural phenomena is at the same time a means of increasing the awareness of the public, a means of helping decision makers make informed decisions for sustainable development and an aid for earth scientist in reconstituting extreme phenomena of the past, by providing them with the necessary technical elements. Historical information about natural risk events results from archive researches carried out by historians. For major past events, historians gather knowledge about their phenomenological (thematic) aspects and their historical and spatial context, from historical documents describing these events (texts, charts, reports, etc). Thus, the historical survey of natural risks is centered on past natural events with a four dimensional description. There are four types of information describing natural events:

- Thematic information describe their characteristics (for instance, the peak flow of a flood);
- Temporal information allow to date them with more or less precision, at different levels of temporal granularity (for instance, the occurrence moment of an avalanche);
- Spatial information allow to situate them in space with more or less accuracy, at various geographic scales (for instance, the approximate footprint of a flood),
- Documentary information describe additional aspects through multimedia content, sometimes bringing more detailed information about the other dimensions (for instance, a video recording showing the precise spot where a dike gave way during a flood) and sometimes more complex aspects (for instance, the impact of the events on the population as resulting from press articles).

In the field of the natural risk management, which includes recording past events, informational analysis and prediction, the use of a spatiotemporal reference information system brings a real added value (Coeur, 2000). However, the development of a spatiotemporal information system dedicated to natural risks is a long and difficult task, involving several modeling steps (the design of the data model and of the presentation model) and, subsequently, several development steps (the choice of the architecture, the development of the tools for data storage, manipulation and visualization). Moreover, the specific requirements of multidisciplinary historical survey of natural risks demand querying and visualization capabilities of spatiotemporal, thematic and multimedia content that are not satisfied by existing tools and, therefore, require important programming efforts from the part of the designers.

In order to respond to the diversity of needs of the risk managers we developed a set of tools that compose a generic information system, integrating spatiotemporal and multimedia capabilities. The main idea is to allow ISNR designers to develop applications suiting their needs without having to write code or to merge multiple applications, only by creating specific data and presentation models. In order to assist the designers in their modeling tasks, we provide them with a conceptual framework composed of general spatiotemporal concepts and general concepts dedicated to natural risks. Our generic ISNR contains a visualization interface based

on three synchronized frames (spatial, temporal and documentary) that allow analyzing all the dimensions of the information concerning natural risks simultaneously, as well as performing visual queries (Davoine et al., 2003; Davoine et al., 2004). A cartographic frame is used for the spatial dimension, a timeline represents the temporal dimension, and an information (or thematic) frame displays details of each entity of the information system. A documentary module makes it possible to access a set of multimedia contents related to these entities: text, images, maps, charts, videos, etc. The conception of this generic interface is a result of the factorization of experiences with previous ISNR developed so far by our team (the European project SPHERE\* and the SIRVA\*\* regional project).

The paper is organized as follows. In section 2 we detail our proposal: first, we present the methodological and technological choices we made in order to develop the framework, before exposing the modeling and the implementation of the spatiotemporal conceptual core of the ISNR. Then we present GenGHIS, a generic spatiotemporal multimedia information system for ISNR applications. In section 3 we present the example of an ISNR application dedicated to the survey of avalanche risk, called SIDIRA, developed with our framework. In section 4 we conclude and give some development perspectives for our approach.

## 2. A GENERIC APPLICATION FRAMEWORK FOR NATURAL RISK SURVEY

### 2.1 General Architecture and Technical Choices

The main idea behind our approach towards creating a very generic ISNR is to create a set of open software components capable of doing generic processing tasks, components that would be driven and integrated into coherent applications by specific models that would dictate their specific functioning. The architecture of our information system (see figure 1) is based on three main components: the data acquisition module, the data management and manipulation module and the visualization module. In order to create an application suited to his needs, the ISNR designer must accomplish two main tasks:

- customizing the data management module by specifying the data model, which means to specify which types of data are to be used by the application, how they are organized and how they are to be manipulated;
- customizing the visualization module by specifying the presentation model, more precisely how data are to be processed and how are they to be displayed.

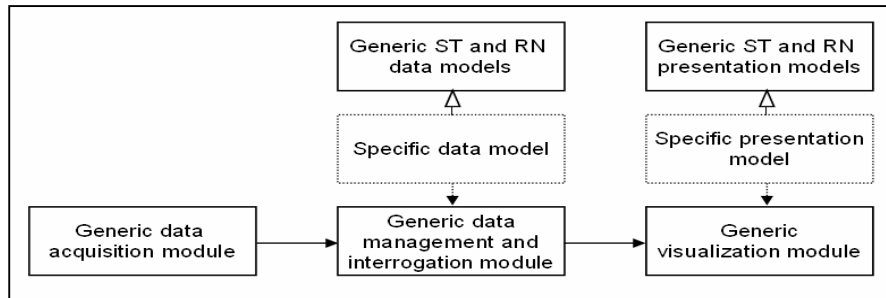


Figure 1. The overall structure of the application

The data acquisition module is simpler, thus it does not need the intervention of the designer, and it functions in the same manner in all the applications. As the models themselves may require considerable modeling skills, we provide a conceptual framework for the designers. They are provided with general spatiotemporal concepts, composing a spatiotemporal (ST) model, and with general concepts, common to all natural risks, composing the natural risk (NR) model. From these models they can design by specialization (see figure 1) their own (specific to their needs) data and presentation models.

Given the multidimensional nature of the information concerning natural risks, we need a spatiotemporal modeling tool and a data management tool with good spatiotemporal representation capabilities. Conceptual spatiotemporal modeling tools like *MADS* (Parent et al., 1999), *Perceptory* (Bedard, 1999) and *STUML* (Price et al., 1999) offer very good modeling capabilities with the possibility of generating data schemas for DBMS like *Oracle*, *MySQL* or *Access*. The drawbacks of this approach originate in the weaknesses of the underlying DBMS concerning the evolution of the data schema and of the data itself. Historical data related to natural risks are often incomplete, and DBMS are known not to handle well incomplete information (Cullot et al., 2003). Another problem is the evolution of the data schema itself, modifying an existing data schema in a “conceptual modeling + relational DBMS” approach means restarting the whole schema generation and data acquisition process. For these reasons, we chose a spatiotemporal object-based knowledge representation system (OBKRS), which, in addition to solving the schema and data evolution problem, simplifies the designer’s tasks: as the same tool may be used for modeling and for data management, it is no longer necessary to use multiple tools for the same application. The last, but not least advantage is the ability for the ISNR designers to manipulate data (for instance, to make analyses and evaluations, to define constraints) in a declarative manner, using an Algebraic Modeling Language (AML) similar to the mathematical formalisms. We chose to base our architecture on the OBKRS AROM\*\*\*, a knowledge representation system in the development of which our team took part.

\* SPHERE : Systematic Paleoflood and Historical data for the improvEment of flood Risk Estimation

\*\* SIRVA : Système d’Information sur les Risques naturels dans la haute Vallée de l’Arve (Information System on Natural Risks in the Arve Valley)

\*\*\* AROM: Allying Relations and Objects for Modeling: <http://www.inrialpes.fr/romans/pub/aron/>

AROM is a generic tool for knowledge modeling and exploitation, based on the concepts of class and association in order to model the objects and the relations between objects (Page, 2001). AROM represents an operationalization of the UML (Unified Modeling Language) concepts. AROM allows representing classes of objects (as in UML), and uses the concept of class of association to represent associations. Thus, the semantics of the relations between objects is preserved and attributes can be introduced in associations. Associations in AROM are represented by entities different from the classes of objects, which not only allows giving a different graphic representation in the integrated modeling environment, but also taking into account the specific behavior of associations, in particular for the heritage mechanism. AROM integrates most of the inference mechanisms present in knowledge representation systems such as default value, heritage, procedural attachment, filtering and classification. However, the specificity of this system is in the use of an algebraic modeling language (AML). This allows writing inference rules in a language very close to the mathematical formalisms, defining variables using equations solved by the system, applying integrity constraints for classes or associations and querying knowledge bases using a query language (AROM Query). AROM has a graphic modeling interface, the interactive modeling environment, which facilitates its use. The interactive modeling environment allows users to define class diagrams and to instantiate them, by adding class instances (objects) and association instances (tuples). It is however possible to access the AROM core through a complete Java Application Programming Interface. This has the advantage of allowing the definition and use of knowledge bases in applications based on Java technologies. The knowledge bases are written either in the "arom" format (a text format), or in an XML format (based on XML Schema).

Given its interesting knowledge modeling possibilities, AROM had already been used for natural risk management applications. In order to integrate the management of spatial and time in AROM, the previous approach consisted in implementing abstract data types for the design and the implementation of spatiotemporal applications (Bissler, 2004). However, this solution has the disadvantage of multiplying not only the objects stored in the knowledgebase but also the join operations at query time, with a direct impact on the performance of the system. In addition, using together the AML and the abstract data types has proven difficult: AML expressions describing operations on polygons, for instance, quickly become too complex and costly. In order to solve these problems and to allow the use of AROM for the storage and the interrogation of large volumes of data, we have chosen to extend both the AROM core with spatiotemporal types, and to add to the AML support for geometrical and temporal operators. The spatiotemporal extension of AROM is called AROM-ST.

For the visualization interface we needed a tool capable of dynamically displaying spatial, temporal, thematic and multimedia contents. Geographic information systems (GIS) like *ArctInfo* and *MapInfo* can be used for the visualization of spatial data. However, the integration of the concept of time (from both data storage and data visualization viewpoints) within these GIS is incomplete. *ArcView* is a GIS tool with an extension module (*Tracking Analyst*) for temporal data analysis and visualization. However, the visualization possibilities are limited and there are no visual querying capabilities. The thematic and multi-media dimensions are even less considered in GIS tools. For all these reasons, we chose to create our own generic interface capable of displaying spatial, temporal, thematic and multimedia information and of dynamically answering to visual queries. Being given the needs for diffusion of information related to natural risks, we chose a server-client Web architecture. In order to ensure a better portability, the interface is implemented in Java, the cartographic part being based on SVG (W3C, 2002).

## 2.2 The Conceptual Framework of the Application

### 2.2.1 The Spatiotemporal model

The spatial types of AROM-ST (see figure 2) respect the OpenGIS specifications (OGC, 2002). According to this standard, the necessary and sufficient set of types for representing spatial objects is composed of the simple geometrical types: *Point*, *Polyline* and *Polygon*. The types *Line* and *LinearRing* are defined by applying constraints to the *Polyline* type. From the simple types are defined more complex (composite) geometrical types: *MultiPoint* (point cloud), *MultiLine* and *MultiArea*. The simple temporal types in AROM are the *Instant* type and the *Interval* type. The composite types, built as collections of moments or intervals, are the *MultiInstant* and *MultiInterval* types (see figure 2).

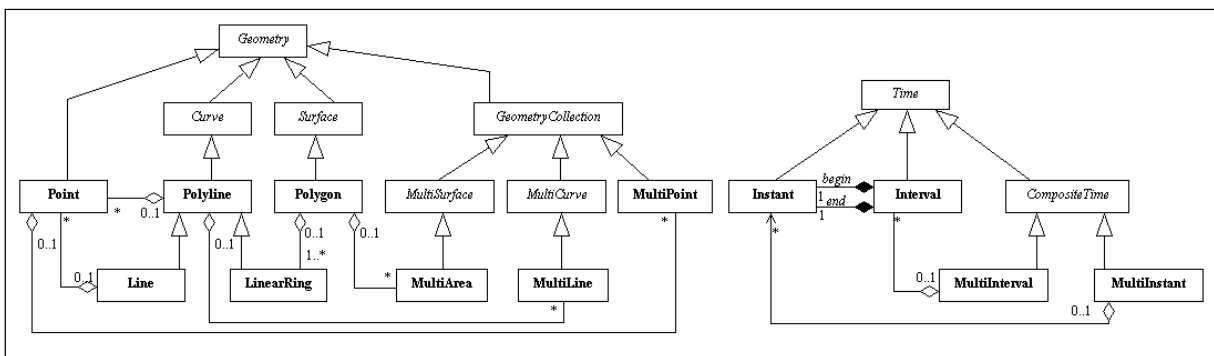


Figure 2. The geometrical and temporal types of AROM-ST.

AML operators available for the spatial and temporal types are divided into three categories: topological operators, set operators and operators of measurement. The topological operators are binary logical predicates that allow testing the relative position (spatial or temporal) of two objects. The spatial topology operators defined by the Open Geospatial Consortium (OGC, 1999) are *contains/within*, *intersect*, *disjoint*, *overlaps*, *crosses* and *equals*. In order to complete all the possible spatial situations, the *inAdjacent* operator, was added (Egenhofer and Franzosa, 1991). The complete set of temporal topology operators is composed of *before/after*, *starts/started-by*, *finishes/finished-by*, *during/contains*, *equals*, *meets/met-by*, *overlaps/overlapped-by*, defined in (Allen, 1983).

The spatial set operators (see figure 3) allow manipulating space and time like a set of points and respectively a set of temporal moments. For simplicity, these operators have the same form for both the spatial and the temporal dimension: *union*, *intersection*, *symmetricDifference* and *difference*. The measurement operators are operators who allow giving a quantitative description of space and time. For the spatial dimension, the defined operators are *dimension* and *distance*, their correspondents for the temporal dimension being *duration* and *timeLength*.

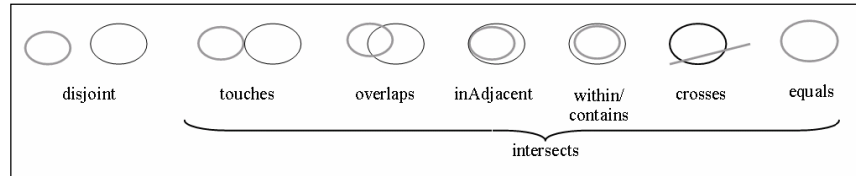


Figure 3. Spatial topology operators.

The temporal dimension has an influence over two aspects of the real-world objects. A first aspect is related to the existence of the objects themselves, their creation/destruction cycle. The temporal aspect concerns the object as a whole. The second aspect concerns the evolution of the objects during their lifespan, their changes of state. In this case, the temporal aspect concerns the attributes of the object. The temporal model of AROM-ST manages both aspects.

The introduction of temporality in the AROM classes aims at expressing the lifecycle of the real-world objects. From a conceptual point of view, based on their lifecycles, there are four types of objects: *perennial* objects, objects with a *limited lifespan*, objects with a *momentary* existence and *recurring* objects.

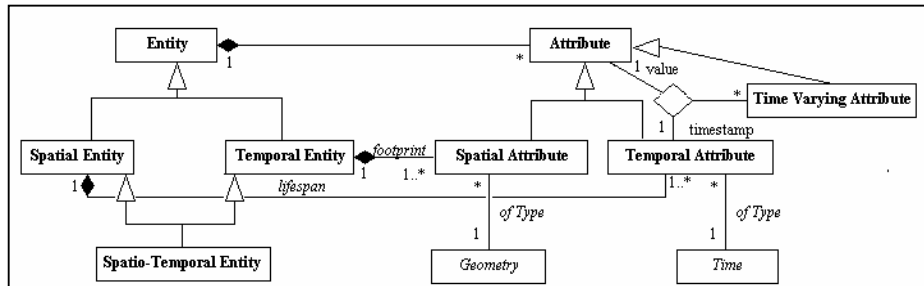


Figure 4. The spatiotemporal metamodel of AROM-ST.

*Perennial* (or eternal) objects are the objects with a perpetual existence compared to the duration recorded by the database. These objects can be represented by the kind of class already supported by AROM. It is important to note that, even if these objects do not have of a temporal dimension (lifecycle), they can have attributes that vary in time. Objects with a *limited* lifespan are objects whose lifecycle (creation/destruction) is recorded in the database and who continue to be recorded even after their destruction. From the modeling point of view, it is necessary to make the difference between these objects with a temporal component and the *temporary* objects, which are present in the database only as long as they exist in the real world. The classes that represent this type of objects contain an attribute of the *Interval* type, which indicates the lifespan of the object. Objects with a *momentary* lifetime represent events (natural or social phenomena, etc.) that require, because of their importance, to be modeled as such in the database. Their representation on the temporal axis is a point and the classes that represent this type of objects contain an attribute of the *Instant* type. Recurring objects are objects whose creation/destruction cycle is repeated several times, they represent processes or phenomena that appear and disappear at certain intervals. The classes that represent this type of object have an attribute of the *CompositeTime* type.

In associations, temporality can appear in two ways (see figure 4). Temporal associations with a lifespan describe a relation in the real world that exists as long as the related objects coexist. For example, it is possible to represent a situation of neighborhood between two buildings by an association. This association is valid only for the period during which the two buildings exist; the destruction of one of the buildings implies the destruction of the association. This kind of association can link several classes of objects, among which at least one must be temporal. The duration of this type of association cannot exceed the temporal interval resulting from the intersection of the intervals that represent the life spans of the objects involved in the association. The second type of temporal association describes a connection that persists after all of the objects that compose it no longer exist. This type of association has a historical perspective. This type of association typically represents the relations of the “cause-effect” type. An example would be the representation of the evolutions of relations between land parcels. An association that describes the relation of

neighborhood between two parcels is a temporal association; it is valid only as long as the parcels coexist. On the other hand, an association describing a relation of the type "cause-effect" (a parcels was divided, thus generating two others) is a historical association, the fact that a parcel generated the other remains valid independently of the lifecycle of the implied objects.

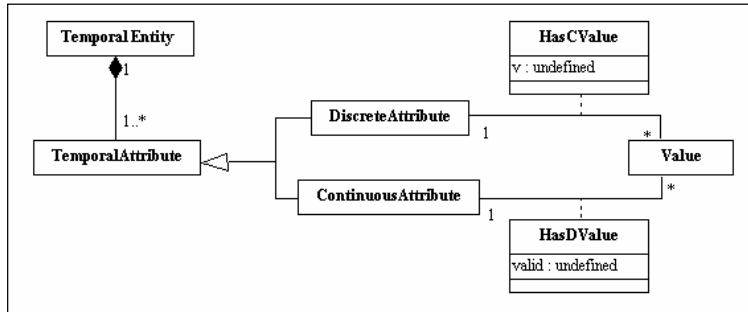


Figure 5. The representation of continuously and discretely variable attributes.

In order to manage the evolution of object attributes in the course of time, it is possible to represent in AROM-ST time-varying attributes (see figure 5). It is necessary to note the distinction between the time-varying attributes (see figure 4, class *TimeVar Attribute*) and temporal attributes (class *Temporal Attribute*). Time-varying attributes may be of any type and their value changes with time (for instance, the population of an administrative region). The temporal attributes have a fixed value (don't change with time), which is of temporal type: *Instant*, *Interval*, *MultiInstant* or *MultiInterval* (for instance, the lifespan of an administrative region). Time-varying attributes form two categories, depending on the type of change that they undergo. There are attributes whose variation in time occurs in a continuous way, and thus the validity of the measured value is restricted to the tie measurement moment. Other attributes undergo a discrete change (in successive steps), their value remains the same during a certain time and then changes abruptly. In this case, the period of validity of the value is described by a temporal interval.

The general spatiotemporal model (ST model) of our application is that of AROM-ST and is based on the independence between the temporal the spatial dimensions (Parent et al., 1999). An object can be spatial, temporal, spatiotemporal or with no spatial and temporal dimensions at all (see figure 6). The objects become spatial (respectively temporal) as soon as some spatial attributes are added to them (respectively temporal). A spatial object contains at least one spatial (geometrical) attribute that describes its geographical representation or position. A temporal object contains at least one temporal attribute that represents its lifespan. The spatial objects can have geometrical representations for only one or several cartographic scales.

### 2.2.2 The "Natural Risks" Model

The "natural risks" model (NR model) inherits the ST model (see figure 6). The NR model is the result of a synthesis of the specific models used in the applications designed within our team, dedicated to natural risk management (for hydrological risks, avalanches and rock crumbling) previously developed by our team. It is composed of the following elements:

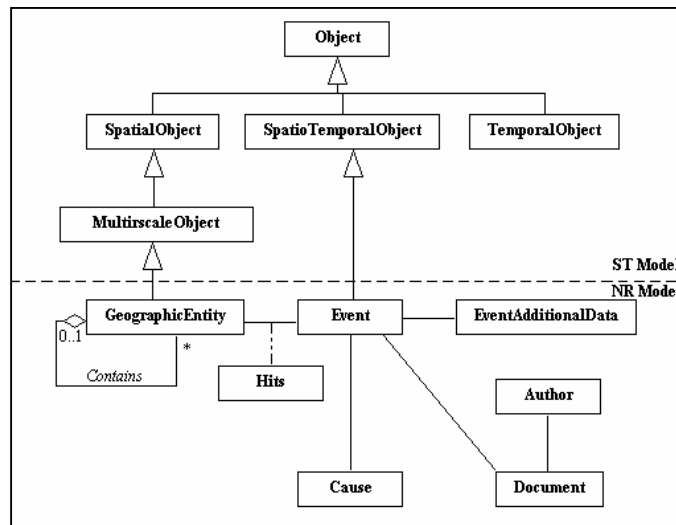


Figure 6. The NR model, specialization of the ST model.

- The class *Geographic Entity* allows defining any entity with a geographical character necessary to the application. Rivers, communes, barrages, or avalanche sites of are entities likely to be represented geographically.

- The *Contains* reflexive relation of the class *Geographic Entity* allows defining semantic inclusion hierarchies between geographical entities, in the broad sense of the term. The semantic inclusion is often administrative (departments are included in regions, hamlets in communes). The semantic inclusion implies the geometrical inclusion (a department is spatially contained in the region to which it belongs to), but it is not reducible to it. For instance, the fact that a region contains more departments also means that the population of the region is composed of the populations of the departments. In all the cases, the inclusion results in considering that the events that affect an entity also affect the entity that includes it. For the needs of the cartographic representation, the class *Geographic Entity* inherits the class *Multiscale Object* of the ST model: each geographical entity has a constant geometrical representation for a given time period and for a given cartographic scale.
- The class *Event* allows representing events (avalanches, floods, etc). This class is at the center of the natural risk model. It inherits the class *Spatiotemporal Object* of the model ST. This way, an event has a spatial representation and a lifespan.
- The *Event* class is connected to various other classes. One can note among them the class *Geographic Entity*. The *N-to-N* relation between *Event* and *Geographic Entity* allows representing the fact that an event may affect several geographical entities. It is necessary as well to distinguish between the spatial footprint of an event and the set of the spatial footprints of the geographical entities that it affects.
- The *Cause* class, which represents the known causes of an event (climatic conditions, human factors, etc). This class inherits neither the *Spatial Object* nor the *Temporal Object* classes. A cause can generate several events (a very rough weather can cause floods, but also landslides, in the case of an application integrating several types of natural risks);
- The class *Event Additional Data*, which contains additional data related to the event. This class allows, in the case of multidisciplinary information systems, to fragment information, in order to optimize the resources necessary to each point of view. Indeed, it is inefficient to handle only one *Event* class in which appears too much information related to the event. The applications that extend the NR model should partition information concerning an event into several thematic groups (such as for example the damages, side effects, visible traces left, etc.), each group should be represented by a class inheriting from *Event Additional Data*.
- The *Document* class allows storing all the relevant documentary contents for the application, may them be weather reports, air photographs, ancient maps, various testimonies, newspaper excerpts, books, computer files, etc. Each document can be related to one or more events.
- The *Author* class contains the authors of the various documents.

We present hereafter the generic information system: its modular architecture and its presentation model, which allows the ISNR designers to build dynamic visualization interfaces specific to their needs.

### 2.3 GenGHIS, a Generic and Adaptable ISNR

GenGHIS (Generic Geographical and Historical Information System) is a generic application for the visualization of spatiotemporal data related to natural risk management. It allows visualizing spatiotemporal and documentary data stored in an AROM-ST knowledgebase. The design of the interface is based on a multidimensional vision of information, providing methods of visualization adapted to each dimension (spatial, temporal, thematic and documentary). The ISNR designer can specify a presentation model in order to configure the functioning of the visualization interface. The presentation model specifies which are the objects and the attributes from the knowledgebase to be displayed on screen, how are they to be analyzed (statistical methods, etc.) and displayed (the visual styles to be applied). The designer can specify a presentation model for each frame of the interface. The data analysis methods available in GenGHIS are statistical indices (means, medians, variances, quantiles), correlation indices, regressions and principal component analysis. If the designer chooses not to create a presentation model (for simplicity), GenGHIS uses the default presentation model, which means displaying all the information contained in the knowledgebase and applying default styles.

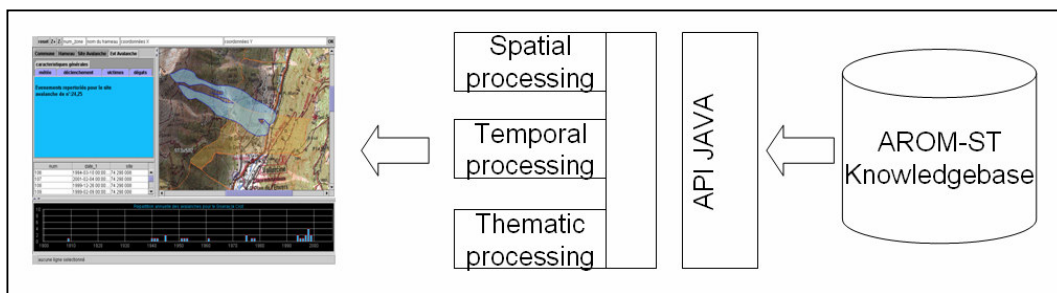


Figure 7. GenGHIS functional schema.

The interface of GenGHIS is composed of three windows each corresponding to one of the three dimensions that describes the information dedicated to natural risks: a spatial frame representing the spatial dimension, a temporal frame displaying temporal dimension and a third frame displays thematic and documentary information. Each one of these frames corresponds to a component of the visualization interface. The frames are synchronized and interact when user actions occur, such as a visual query formulated by means of mouse clicks on one of the three frames. An interaction manager ensures the synchronization between the components of the interface. The software components apply a generic processing of the information extracted from the AROM-ST knowledgebase,

in order to present the three informational aspects (cartographic, temporal, and documentary) on the screen. The architecture of GenGHIS uses AROM-ST for the data storage and interrogation. The AROM-ST core allows accessing multiple knowledge bases (but not in a simultaneous way). GenGHIS is based on Java technologies and the access to the AROM-ST core is made through a Java API.

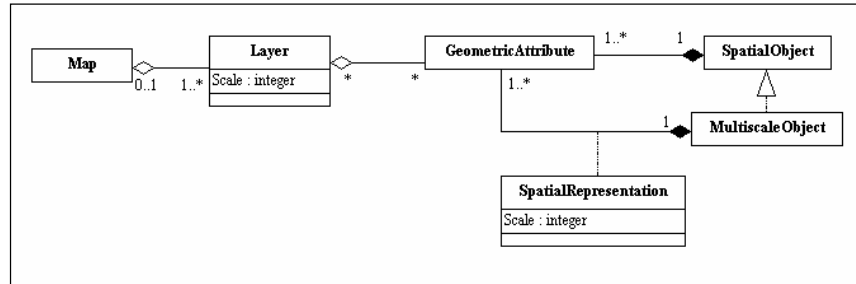


Figure 8. The cartographic meta-model of GenGHIS.

### 2.3.1 The Spatial Frame

The spatial frame is based on software components that allow retrieving the spatial attributes of the objects stored in an AROM-ST knowledgebase and generating maps. The application works with or without a cartographic model. By default (in the absence of a cartographic model), GenGHIS searches the knowledgebase for spatial classes. For each class of spatial objects, GenGHIS retrieves its geometrical attributes and gathers them in vector cartographic layers, by applying a default graphic style.

The specification of a cartographic model (figure 8) is necessary for the generation of multiple types of maps from one knowledgebase containing data corresponding to multiple scales or to multiple viewpoints. In this case, it is necessary to specify:

- The scale of the map, if the knowledgebase contains geometrical representations for multiple scales.
- The classes of objects to be represented on the map.
- The geometrical attributes to represent for the classes of spatial objects, if these classes contain more than one geometrical attribute.

The classes that have to be instantiated within the cartographic model are presented in figure 8. The resolution of the cartographic layer is deduced from the resolution of the map, using an AML expression:

```
Resolution = this!Contains.Map.Resolution
```

By default, the AML expression that calculates the set of geometrical attributes composing a layer has the form:

```
Geometries =
if (not (isVoid(AttributeName))) set (g in ClassName.AttributeName: true)
else set (g in ClassName!SpatialRepresentation.GeometricAttribute: true)
```

AML expressions can be refined by applying a filter on the attribute values, in order to create layers with different levels of detail. Here is an example that selects only the avalanches of big size or those that have caused material damages:

```
o in Avalanche,
Geometries = set (o.Geometry: ((o.Volume > 10000) or
not (isVoid(o!Causes.Damages))))
```

The available methods of interaction with the spatial frame are the selection of the layers to be displayed, the zoom in/out (dimensioning of the visible part of the map), the pan (repositioning of the view box) and the selection of spatial objects.

### 2.3.2 The Temporal Frame

The temporal frame is based on software components that allow retrieving the temporal attributes of the objects stored in a AROM-ST knowledgebase and generating a chronological representation of the objects. In the current stage of development of the application this graphic component displays only momentary temporal objects. Other methods of visualization and interaction are considered. The available methods of interactions with the spatial frame are the zoom in/out (dimensioning of the visible part of the temporal axis), the pan (repositioning of the temporal frame) and the selection of an object or a set of temporal objects

### 2.3.3 The Information Frame

The information frame allows the display of thematic, textual and documentary information related to the objects contained in the knowledgebase. Documentary information corresponds to multimedia documents (copies of ancient maps, excerpts from texts, images, photographs, resulting from historical documents) and allows to complete the structured information, stored in the form of objects and attributes in the knowledgebase. The management of the historical documents is a specificity of the survey of natural risks. By default, GenGHIS creates in the documentary frame a tabbed panel for each class contained in the BC. In the current version, only two levels of detail (semantic resolutions) are available. It is possible to visualize either the list of objects of a class, or detailed information about an object (hamlet, avalanche, etc). The tuples (association instances) are not displayed explicitly, for each object of a class, the other objects with to which it is connected in associations are displayed as a list of attributes. For example, for a hamlet is displayed the list of the avalanche events that have affected it). In parallel with the objects, the documentary frame also

displays, as a list of hyperlinks, the documents (textual or audio-visual) which refer to these objects (events, spatial entities, etc). For example, in parallel with the communes, hyperlinks for the documents describing the events that have affected these communes are also displayed. The methods of interaction available for the information frame are the semantic zoom (displaying a list of objects or the attributes of an object) and the selection of objects.

### 2.3.4 The Interaction Manager

The interaction manager is the component that manages, on the one hand, the interaction with the user, and, on the other hand, the synchronization between the visual components. It interprets the actions of the user and allows navigating the informational space of the knowledgebase. Each action of the user is interpreted as a query in the knowledgebase. The generic request is, in OQL formalism (Cattell et al., 2000), of the form:

*Select O.geometry from C where SR and TR*

where *O* represents the set of objects to be displayed in one of the frames of the application, *C* represents the class of the objects to be displayed and *SR* and *TR* respectively represent the spatial and the temporal restriction to apply to the query. Each action on the spatial frame modifies the spatial restriction applied to the query. The spatial restriction is defined by:

- coordinates of the spatial frame when there is no selection;
- the spatial footprint of the object, when a spatial object is selected.

Each action on the temporal frame modifies the temporal restriction applied to the query. The temporal restriction is defined by:

- the visible temporal interval in the temporal frame when there is no selection;
- the selected moment.

An action on one of the components triggers an update for the other components. The repositioning of the spatial frame (pan) activates, for instance, an update of the temporal frame, thus displaying only the events affecting the visible spatial entities. A zoom in on the temporal axis, for instance, reduces the number of events displayed in the information frame.

In order to evaluate the functionality and the applicability of our approach, we present hereafter an application of ISNR dedicated to the survey of the avalanches. This ISNR has been generated using the GenGHIS environment.

## 3. SIDIRA: AN APPLICATION FOR THE HISTORICAL SURVEY OF AVALANCHES

The SIDIRA project aims capitalizing on the historical approach for the prevention of natural risks. The objective is to increase the awareness of the actors of the civil society to the avalanche risk existing on a given territory, by informing them on the avalanche events which occurred in the past. The idea is thus to propose a Web-based information system for the historical survey of the avalanches which occurred on the commune of Vallorcine in Haute-Savoie, France. The SIDIRA project records the avalanches that have occurred in the commune of Vallorcine in the 20th century. For each avalanche event, the occurrence date is recorded (day-month-year), and is assigned to an avalanche corridor. The complete set of avalanche corridors existing on our territory of study is represented through the Probable Map of Localization of Avalanches (CLPA\*) defined at the scale 1:25 000. For each hamlet of the commune of Vallorcine, it is thus possible to identify the history of the avalanches that have occurred during a certain period. For each event, other attributes are recorded: the altitudes of the starting and arrival points of the snow slide, the climatic conditions having preceded the event, and, if necessary, the number of casualties and the damages caused. We present hereafter the approach used for the design of the SIDIRA application with GenGHIS. The approach is composed of two phases: on the one hand, the data modeling and construction of the knowledgebase, on the other hand the generation of the visualization interface.

### 3.1.1 The Data Model Design

The figure 9 illustrates the specific model for avalanche risks of SIDIRA. The documentary part of SIDIRA, being able to be entirely reconstituted on NR level, does not require a specialization of the classes *Document* and *Author* at the specific level, they are used just as they were. The geographical entities, which specialize the *Geographic\_Entity* class, can be of three types: communes, hamlets and avalanche sites, which are connected by relations of hierarchical inclusion (the communes are composed of hamlets, the hamlets are composed of avalanche sites). The relations hierarchic are represented explicitly using two associations that specialize the *Contains* association of the NR model:

- *Administrative\_Partitioning* represents the administrative partitioning of the commune of Vallorcine in hamlets;
- *CLPA\_Partitioning* symbolizes the relation between the avalanche corridors (class *Site*) and the hamlets. This relation is in conformity with the Probable Map of Localization of Avalanches. The *Affects* association specializes *Hits* to guarantee that an *Avalanche* is always assigned to a *Site*, which represents in SIDIRA the finest level of spatial localization of an avalanche event.

The effects of the events are propagated in the classes *Hamlet* and *Commune* by inference. For exemplification, we give the Boolean expression (expressed using the AML of AROM-ST) that allows deducing whether or not a hamlet, identified by an identifier ID, was hit by a certain avalanche event.

```
exists (id in this!CLPA_Partitioning.Site!Affects.Avalanche.Indicator: id = ID)
```

This expression determines whether a certain avalanche event (identified by ID) is among the avalanches that have affected the sites that are part of the hamlet. The *EventAdditionalData* class is specialized by the *Damages* class, which represents the human victims and the damages that were caused by the avalanche events. For SIDIRA the *Cause* class is not used. After the creation of the class

\* CLPA : « Carte de Localisation Probable des Avalanches » (Probable Avalanche Localisation Map), edited by the Cemagref.

diagram by heritage of the NR model, attributes specific to SIDIRA were introduced into all the classes. Here are some, for exemplification:

- Properties in the class *Avalanche* concerning the starting and arrival altitudes of the snow slide, the inclination of the slope, as well as the thickness of the snow cover having broken;
- Thematic attributes for the three classes of spatial entities: the number of inhabitants, surface, etc.

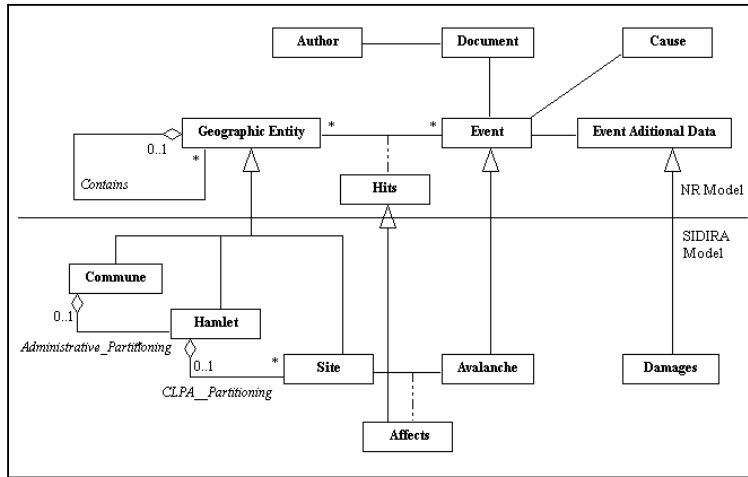


Figure 9. The data model of SIDIRA, specialization of the NR model

The knowledgebase thus built was filled with data coming from text and Excel documents and with multi-media documents (textual and audio-visual).

### 3.1.2 The Visualization Interface

The visualization interface of SIDIRA (see figure 10) uses the three-dimensional vision of the information of GenGHIS, implemented with the three synchronized frames. The spatial frame represents the vector spatial data in the shape of communes, hamlets and sites, superimposed on a raster layer that adds information on the relief. The temporal dimension is represented by a timeline on which the events are represented as juxtaposed points, which creates histograms of various heights for each moment represented on the axis, depending on the number of events that occurred at each temporal moment. The documentary frame displays several tabs that allow exploring the objects and the attributes of each class of objects contained in the. The lower part of the documentary frame displays hyperlinks towards the documents available in the knowledgebase, related to the displayed entities.

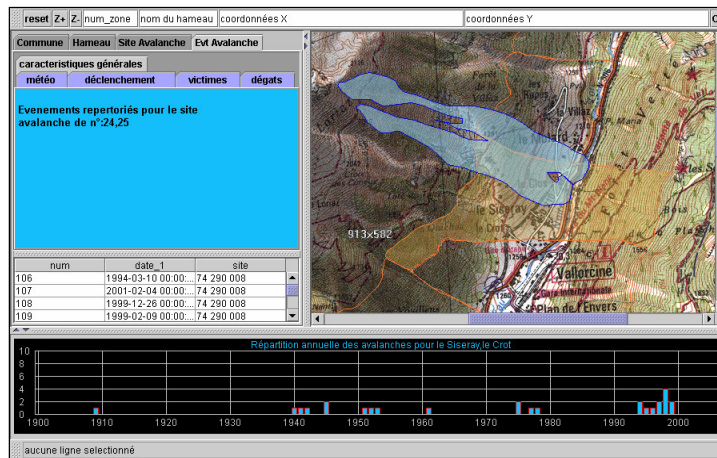


Figure 10. The visualization interface of the SIDIRA application.

The development of the SIDIRA application allows us to validate our approach, both from the model and from the interface viewpoint. The development of the application took a few days, but most of the time was dedicated to the data acquisition process. For the creation of the model with the GenGHIS framework, we used exclusively concepts defined in the "natural risks" model. The presentation model was the default one, the application presenting only one viewpoint and only one cartographic scale. The application was developed in collaboration with geographers, historians and geologists who found the interface very intuitive and easy to learn. At present, we are using our framework with success for building a multiscale application integrating several points of view for the study of rock crumbling, called SIRHeN.

#### 4. CONCLUSIONS AND DEVELOPMENT PERSPECTIVES

The needs for information systems dedicated to natural risks, integrating spatiotemporal and multi-media dimensions, correspond to a strong social demand, but currently there are no any development tools facilitating their design. This conclusion led us to propose a framework for design of Information Systems dedicated to natural Risks (ISNR). We have designed a generic information system for multidimensional (thematic, spatial, temporal and documentary) data related to natural risks that can be adapted by ISNR designers to their specific application needs by the creation of specific data and presentation models. The information system is based on a knowledge representation system extended with spatiotemporal types and operators. In order to assist the designers in the modeling task we provided them with a conceptual ISNR core composed of general spatiotemporal concepts and concepts dedicated to natural risks. The utility of our proposal has been tested by the development of an information system dedicated to avalanche risks and it is presently used in other ongoing projects. Among the future directions of development of our approach can be cited:

- The management, in the spatiotemporal model, of the data imprecision (from a thematic, spatial and temporal viewpoint), with the design of a visual query system and the development of adequate forms of visualization for imprecise data;
- The adding of an user model in order to manage the users' preferences, viewpoints, in order to ensure a better usability of the final applications created with our approach.

#### REFERENCES:

- Allen, J., 1983. Maintaining Knowledge about Temporal Intervals, *CACM*, 26(11): 832--843.
- Bédard, Y., 1999. Visual modeling of spatial databases: Towards Spatial PVL and UML, *Geomatica*, 53(2): 169-186.
- Bissler, T., 2004. Conception et développement d'une plate-forme générique pour les Systèmes d'Information Spatio-Temporelle pour la gestion des Risques Naturels, Mémoire CNAM, Grenoble, France.
- Cattell, R., D., Berler, M., Eastman, J., Jordan, D., Russell, C., Schadow, O., Stanienda, T., Velez, F., 2000. *The Object Data Standard: ODMG 3.0*, Morgan Kaufmann.
- Cœur D., Davoine, P.-A., Lang, M., Martin, H., Strazzeri, D., Villanova, M., 2000. Intégration de l'information historique dans un système d'information : l'exemple du projet SPHERE, SURNAT 2000: 42-53.
- Cullot, N. Parent, C., Spaccapietra, S., Vangenot, C., 2003. Ontologies: A contribution to the DL/DB debate, Proc. SWDB 2003: 109-129.
- Davoine, P.-A., Brunet R., 2003. SIDIRA : un système d'information basé sur le Web dédié à la consultation des avalanches : application à la commune de Vallorcine (74), Proc. ISNRAT'03, Orleans, France : 29-42.
- Davoine, P.-A., Martin, H., Coeur, D., 2004. *Systematic, Paleoflood and Historical Data for the Improvement of Flood Risk Estimation, Methodological Guidelines*, Centro de Ciencias Medioambientales, Madrid, Spain, pp. 95-101.
- Egenhofer, M. and Franzosa, R., 1991. Point-Set Topological Spatial Relations, *IJGIS*, 5(2): 161-174.
- Jensen, C. and Snodgrass, R., 1996. Semantics of Time-Varying Information, *IS*, 4(21): 311-352.
- Lardon, S., Libourel, T., Cheylan, J.-P., 1999. Concevoir la dynamique des entités spatio-temporelles, *Revue Internationale de Géomatique*, 9(1): 45-66.
- Manche, Y., Villanova, M., Martin, H., Burnet, R., 2002. Un système d'information dans le domaine des risques naturels : le projet SIRVA, *Revue Internationale de Géomatique*, 12(1): 59-76.
- Moisuc, B., Gensel, J., Martin, H., Représentation de connaissances par objets pour les SIG à représentations multiples, Proc. Cassini-SIGMA 2004.
- OGC, 2003. OpenGIS Reference Model, <http://www.opengeospatial.org/docs/03-040.pdf>.
- OGC, 1999. OpenGIS Simple Features Specification for SQL, <http://www.opengeospatial.org/docs/99-049.pdf>
- Page, M., Gensel, J., Capponi, C., Bruley, C., Genoud, P., Ziebelin, D., Bardou, D., Dupierris, V., 2001. A New Approach to Object-Based Knowledge Representation: the AROM System, Proc. IEAAI/ES'01, pp. 113-118.
- Parent, C., Spaccapietra, S., Zimanyi, E., 1999. Spatio-Temporal Conceptual Models: Data Structures + Spatial + Time, Proc. ACM GIS: 26 – 33.
- Price, R., Ramamohanarao, K., Srinivasan, B., 1999. Spatio-Temporal Extensions to Unified Modeling Language, Proc. IEEE DEXA'99: 460-461.
- Rumbaugh, J., Jacobson, I. and Booch, G., 1999. *The UML Reference Manual*, Addison-Wesley.
- W3C, 2003. Scalable Vector Graphics (SVG) 1.1 Specification, <http://www.w3.org/TR/SVG11>.