SPATIO-TEMPORAL GENERALIZATION: THE CHRONOGRAPH APPLICATION

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ABSTRACT

This paper encompasses research conducted in order to expand the concept of cartographic information abstraction to include the temporal behaviour of objects. The basic principle to bear in mind is that both space and time are treated simultaneously, as identical notions. A coherent spatio-temporal framework was created, able to sustain the representation of Change. The effort is to formalize a way to describe and record temporal metric "units" – referred as Intervals. Temporal Change is classified and a spatio-temporal conceptual model is described, suitable for accommodating the temporal scale of objects.

By expanding the notion of cartographic information abstraction, we term Temporal Information Abstraction as the process of transferring a spatio-temporal schema into a new schema of different spatial and temporal detail. Temporal scale is compared to spatial scale, and the concept of generalisation (and "specialisation") among different time scales is examined, taking into account the more familiar concept of cartographic generalisation. The study on generalisation and its temporal analogy originated four (4) basic temporal information abstraction operators, derived from their normal, cartographic equivalents: temporal selection, temporal class generalisation, change aggregation and temporal topology association. Actually, the four basic generalisation operators used for information abstraction procedures are expanded, thus creating operators suitable for time scale transition.

Finally, an application was developed, implementing those temporal generalisation operators into the spatio-temporal model, in order to study their effectiveness and capabilities. "Chronograph 2002" includes a virtual spatio-temporal data set and a user interface able to implement basic temporal generalisation rules and operations. To check the operators' efficiency and the proposed model's suitability, it facilitates the study of temporal generalisation, by accessing the modelled spatio-temporal schema and producing a generalised version of its objects and Changes. The four operators are applied, according to specific user needs. The final result is visualised through a variation of methods and a fidelity ratio is calculated, in order to express the soundness of the temporally generalised schema and its suitability in representing dynamic behaviour.

1. INTRODUCTION

Cartographic generalisation has been identified over the years, not only as a visualisation problem, but also as an issue of representing the entities at a modelling level. Different levels of detail, as dictated by map scale, correspond to different conceptual descriptions of the attributes and relations of entities. Conceptual modelling, in reference to spatial databases and cartography, makes an effort to express an infinitely complex world through a particular view, which suits specific user and application needs. Generalisation is considered essential to such modelling procedures, as a representation issue of entities at different scale levels. These data models may well represent the variation of scale through variations of levels in the hierarchical classification schema.

This modelling of entities can be extended further from their spatial, static properties, to include their dynamic behaviour and interactions as well. Such spatio-temporal modelling presents difficulties, mainly due to the problematic combination of spatial models with the temporal Change of objects. It is Change that will eventually allow the study of phenomena's dynamic nature. By representing Changes, the system records "cause" and "effect" of events, and such information leads to cognition and learning.

This paper encompasses research conducted in order to expand the concept of information abstraction to include the temporal behaviour of objects. The basic principle to bear in mind is that both space and time are treated simultaneously, as identical notions. A coherent spatio-temporal framework was created, able to sustain the representation of Change. The study originated four basic temporal information abstraction operators from their normal, static equivalents. Finally, an application was developed, implementing those temporal generalisation operators into the spatio-temporal model, in order to study their effectiveness and capabilities.

Section 2 focuses on the representation of time and eventually, Change. The effort is to formalize a way to describe and record temporal metric “units” – referred as Intervals. Temporal Change is classified and a spatio-temporal conceptual model is described, suitable for accommodating the temporal scale of objects. The third section of the paper presents the study on map generalisation and its temporal analogy. Temporal scale is compared to map scale, and the concept of generalisation (and “specialisation”) among different time scales is examined, taking into account the more familiar concept of spatial generalisation. The four basic generalisation operators used for information abstraction procedures are expanded, thus creating four operators suitable for time scale transition. In the fourth section the developed application “Chronograph” is described. The application includes a virtual spatio-temporal data set and a user interface able to implement basic temporal generalisation rules and operations. It enabled the study of the operators’ suitability and the model’s efficiency in representing dynamic behaviour. Section 5 states the conclusions ensuing from the aforementioned research and takes a brief look to the various questions and problems arising.

2. REPRESENTING TIME AND CHANGE

The concept of Time is quite incomprehensible, thus turning any effort of modelling Change into a difficult task. While it is easy for people to comprehend their surrounding space, time is a different matter altogether. It is simple to understand where each object lies and model this fact. However, we do not have full understanding of the time period this fact took place, but we perceive it by its effects. We use abstract definitions of time periods, like «past», «present» and «future», without exactly knowing when this period is. All we know about the course of entities through Time is what happened to them in the «past», what information we collect for them in «present» and we can estimate their behaviour in the «future». What this proves is that, all understanding we have about time comes from perceiving and recording Change (5).

2.1 Space and Time

Space and time are not separate notions. They are intrinsically related, but one does not substitute the other. The main focus goes on entities. They are the background, where space and time describe the Changes that occur, either to the entities themselves (life) or in reference to other entities (motion). While forming a four-dimensional system, we understand time as linear and directional, where space is not. An entity can move in space in every possible direction: forward or backward, up or down. But in time everything moves forward. This is best captured by the second law of Thermodynamics, which assumes that everything in the universe evolves in a state of increased entropy: we grow older, our environment becomes more chaotic daily, and we can never live in January 31, 2000 again. From a cognitive point of view, it is quite interesting that, if someone notices a picture of a glassware store with a bull standing in the entrance and all china in a perfect state on the shelves, and a picture of the same store, with the same bull in the entrance and all china destroyed, he or she will immediately think the second picture as the most recent one. In the second picture entropy has increased (3). Thus we assume that all processes are linear and irreversible and we picture time much like an arrow.

2.2 Properties of Change

This evolutionary, linear nature of time is still observed through Change. Yet, the conceptual definition of when we considered something as changed is by no means simple. In an object-based view, Change occurs when an event –or a series of events- alters the state of one or more entities, in regard to their identity, their location or/and their attributes. If we take a field-based approach, Change can occur when such an event takes place in a particular location and alters the state of everything related to this location. One way to classify Changes is in regard to their temporal pattern. There can exist gradual, continuous Changes and there can be abrupt altering events. Both those types are heavily depended on the application involved and the time scale utilized. For instance, Change in a forest’s shape may well seem sudden if observed after 100 years, and on the same time gradual, if recorded in a year-by-year basis.

Change of some short is always occurring, as entities proceed through time. A crucial topic is the definition of the degree of Change that alters completely the identity of an entity, forcing it to lose it and cease to exist. What kind of event would not simply amount to a new state for the entity, but would imply its disappearance and the birth of a new one? To represent this issue, we define two types of Change an entity may undergo. *Non-Essential Change* refers to internal Changes for each entity, which regard events that affect its motion and its relations with other entities. Such events mean that, suddenly or gradually, the entity has entered a new state. *Essential Change* affects the identity and the life of the entity. The causing event signals that the identity is no longer maintained, the entity disappears and a new one (or more) is created.

Categorizing specific Changes as either “essential” or “non essential” is not possible, if the conceptual definition of each cartographic entity and the exact registering of what constitutes its identity do not precede it. Thus, it is necessary to create application-specific entity definitions in order to classify the importance of their Changes. To further formalise Change into the conceptual model used in our research, a number of specific Change operators were utilised (1).

Operators that correspond to *Essential* Changes are: Create, Destroy, Kill/Reincarnate, Fusion, Fission and Evolution. *Non-Essential* Changes will be represented by operators like: Spawn (new identities created while the former one is kept), Aggregate and Disaggregate. By formalising Changes in the spatial data model, one can use those operators to track down the modification of identity, and therefore classify them as Essential or not.

2.3 Recording Time

Although Time is continuous, our model makes the concession that it can be broken into discrete units of measurement, which can be of the same or of varying length. The smallest temporal units used to record Time, no matter if they are seconds, months or decades, will be referred as chronons (9). The actual "size" and kind of the chronons depends heavily on the granularity used. Granularity defines the Temporal Scale, that is, the level of resolution by which time is measured. Temporal scale determines the duration of each chronon. As one may understand, the choice of suitable temporal scales is directly related to the map and application goals. Depending on the purpose of collecting the geographic information, it is quite possible that the analysis will require more than one temporal scale for the cartographic data.

In order to record temporal data in a spatial database, we adopt the temporal data types known as intervals, which describe a temporal period, from a starting time point ts to a final point te. Intervals can be open or closed at their ends, like [ts, te], [ts, te), (ts, te] or (ts, te). For these data types, literature can demonstrate a series of operators, including Scalar, Aggregate, Relation and Update operators (4);(7). By utilizing intervals, temporal queries and analysis will be possible. However, the resolution of the time points, which those intervals are going to contain, still depends on the selected time scale

2.4 The Conceptual Model

To accommodate most concepts presented above, we need an approach to suit spatio-temporal modelling of socio-economical phenomena. The basic principles of such a model will be presented hereafter. We define an entity as the abstraction of a real-world feature, while "objects" are the database representations of entities. The course of an entity is described through its object versions in the system. The objects that describe an entity may change, cease to exist or new ones may be born. These are actually the various states of the same entity. The object versions may change suddenly (time intervals with concurring ends) or between the versions may interject a time period. One of the first questions that arise is whether a changed object is actually a new object version of the same entity or rather a new object belonging to a different entity. Such a matter could be solved by the strict definitions of each entity in the model's data dictionary. As the model is application-specific it can contain formalised rules for each entity, which indicate the Changes that are *Essential* or *Non-Essential*.

One of the foremost principles would be that the model uses the object-oriented approach to define the data structures. All these objects share attribute sets common to their entity. These attribute sets are distinguished into three separate domains (2):

- The Thematic domain, where belong the thematic attributes of the object.
- The Spatial domain, where the geometric representation and location of each object are described.
- The Temporal domain, which represents the entity's temporal data.

The temporal domain is the most important for modelling Change. Into this domain all the aspects of the temporal object are concentrated. First of all, adopting the history-graph model concept, it is recorded whether this object is under Change, it is static or has ceased to exist. This information can be divided to «past», «present» and «future» states.
The time recorded at the intervals is «Valid» time, that is, the actual time the Changes take place. Transaction time (also

Spatial

Form	Centroid	Temporal Stage
Polygon A	X,Y	Past 2
Polygon B	X,Y	Past 4
Polygon B	X,Y	Past 6
Null	Null	Present

Thematic

Use	Ownership	Temporal Stage
Plantation	Owner A	Past 2
Plantation	Owner A	Past 4
Parking Lot	Owner B	Past 6
Null	Null	Present

Temporal

Stage	Type	Data	Changes
Past 1	Change	tPoint: 1963	Birth
Past 2	Static	tPeriod: 1963-1975	None
Past 3	Change	tPoint: 1975	Size Change
Past 4	Static	tPeriod: 1975-1978	None
Past 5	Change	tPoint: 1978	Ownership Change
Past 6	Static	tPeriod: 1978-1989	None
Past 7	Change	tPoint: 1989	Parcel Division, Death
Present	Ceased	tPeriod: 1989-	None

Figure 1. Example of the three Domains and their Stages, for the entity: Land Parcel

called database time) is also catalogued, in order to trace when the information was actually updated. If the transition between two successive object states is instantaneous, then the event took place in a time instant. If the object stays at a changing state for a time period, then it is under continuous Change. Figure 1 includes an example of the three attribute domains and the object states.

The developed model includes strict descriptions of the objects, their attributes separated into the three domains and the objects' classification into a hierarchy. Such a hierarchy is deemed necessary for class generalisation procedures, as each hierarchy level corresponds to a different level of detail and object map scale. For its temporal equivalent, the data dictionary formalises all possible Changes, whether they are *Essential* or not, and classifies them into a hierarchy as well. This Change hierarchy defines super-class Changes, that actually include a number of lower-class, more detailed changes. Such classification is necessary for temporal class generalisation procedures, as each level of the Change hierarchy corresponds to a level in the object hierarchy. Changes that alter an object from one class into another, always at the same object hierarchy level, are the only ones included in the corresponding Change hierarchy level.
To test the model's capabilities and its suitability for temporal generalisation procedures, we developed a virtual data set consisting of certain socio-economic units, namely land parcels, parcel owners, road network and land use. The conceptual schema was logically and physically implemented using the formalisations of a temporally extended E-R model.

The developed Relations included:

- The three domains necessary for all entities –spatial, non-spatial and temporal.
- A table including the definitions of various prescribed temporal scale granularities.
- A table containing user information, which actually allowed definitions of multiple map applications.

This last table recorded various user needs corresponding to different applications that utilise the four socio-economic units included in the data set. Depending on the cartographic application, the user can define which entities and Changes are essential to him or her, the priority of Changes and the temporal granularity of his or her application. Therefore, a more extensive study of the schemas' capabilities was made possible.

3. TEMPORAL GENERALISATION

Map generalisation is actually an analysis and decision-making tool. It helps portray information in a smaller scale, covering a bigger area, thus giving the map user an all-embracing view of the phenomena. This usefulness applies in generalising entities at a modelling level, and can apply in spatio-temporal analysis as well. Representing an entity in a time scale of different resolution than the one initially recorded, has a variety of advantages. Viewing a process, so far recorded in fine detail (high resolution) intervals, at a less detailed resolution would reveal its behaviour in the long run and any patterns, which an "observer" may not notice in the first place. While it may be useful for many applications to record Change in high granularity, spatio-temporal reasoning using such data would demand its temporal generalisation in various other scales.

3.1 Information Abstraction

Generalisation refers to all the processes involved in representing spatial data of a particular cartographic scale into a new (usually smaller) cartographic scale. Spatial modelling has adopted the generalisation operations and has extended them beyond graphic scale transition. Change of scale translates into change of detail level, which corresponds to different level in the conceptual spatial schema. These generalisation operations form a central point in any spatial modelling effort. Actually, by its very nature, every model representing real world phenomena utilises generalisation procedures to define more simplistic objects that describe those complex phenomena.

While map generalisation usually refers to the functions necessary to reduce graphical data complexity, this research focuses on the processes regarding generalisation of spatial data models, also known in literature as conceptual generalisation or Information Abstraction. Information Abstraction consists of the procedures necessary to transfer geographical data from one schema to another. Those two schemata are considered to differ in graphical scale, in their level of detail and, often, in the application scope they serve.

These procedures have been divided into four basic operators (6);(8):

- **Selection**
  Determines which objects will remain in the final database. It is resolved by means of object importance, object class and existing relations.
- **Class generalisation**
  Regroups objects into more generic classes in their hierarchical schema. For example, land use "wheat" is generalised into "annual cultivation", its super-class.
- **Aggregation**
  Several connected objects are aggregated into one single object.

- **Association**
  Redefines the relations between objects in the new database, especially existing topological associations. Association acts as validation of the newly generalised schema.

3.2 Temporal Generalisation Operators

Our effort is to introduce and study such a traditionally spatial notion into a temporal schema. Generalisation associates with the change of map scales. Temporal generalisation relates with the alteration of temporal scales or, to make things even more complex, with the transition between different spatio-temporal scales. We define the introduction of generalisation concepts to the transfer of spatio-temporal data from one temporal schema to another as Temporal Information Abstraction. These two temporal schemata will differ in both graphical and temporal scale, in their level of detail and in the application needs they serve. Temporal generalisation enables the study of entities at different temporal scales, therefore accommodates analysis for their behaviour over a course of time. We perceive Temporal Information Abstraction procedures by using simultaneously the temporal equivalents of two widespread views of feature generalisation: the object-based generalisation approach and the field-based generalisation approach.

By an object-based (also called “vector”) view, we refer to the generalisation of objects and Changes in the model to a different detail level. Very much like the generalisation of vector graphics in map data, where lines are simplified and vectors are either eliminated or not, objects and Changes are considered the nodes of the dataset and temporal generalisation attempts to reduce their complexity.

In a field-based (or “raster”) view, we refer to the generalisation into a different temporal scale. Similar to generalising raster images by changing their resolution, in a raster approach we take into account the change in granularity. Considering objects and Changes uniform during the first time scale, we alter the size of the temporal “pixel” and generalise all the events that took place in it.

Vector and raster approaches actually compliment each other and both were included into our study. Under the prism of these two approaches, we expanded the four basic operators of information abstraction to tackle the temporal aspects of the model.

Thus, we define four basic Operators for Temporal Information Abstraction:

- Temporal Selection
- Temporal Class Generalisation
- Change Aggregation
- Temporal Topology Association

3.2.1 Temporal *Selection*

This operator includes all the processes of opting which data will most likely be maintained into the new schema. In a vector approach, temporal selection refers to estimating which object Changes are important enough to be kept into the database and which are not. It is clear that temporal selection heavily depends on defining *Essential* and *Non-Essential* Changes in the model itself. By a raster view, temporal selection is responsible for selecting and preserving the most prominent states in the temporal domain of each object, for the new temporal scale.

An example of both temporal selection views is presented in *Figure 2a*. In its initial dataset, the object, for a certain temporal scale, undergoes a number of essential and non-essential changes. In the vector approach, temporal scale is of no concern, and only the essential Changes are maintained. In the raster approach, the object’s life is studied through the new temporal resolution and its various states are generalised accordingly.

3.2.2 Temporal Class Generalisation

Temporal Class Generalisation makes use of the Object and Change Hierarchies implemented into the model and regroups both objects and Changes into more generic classes, higher in their classification schema. Therefore, to apply this operator, the existence of a Change hierarchy in the model is indispensable. By a vector view, temporal class generalisation considers each Change as an object (a “vector”) and groups it into a higher class (lower detail). As mentioned before, such super-class Changes correspond directly to the super-classes of objects. The raster approach takes classification a step further, maintaining the most prominent super-classes of Changes that occurred during the new temporal resolution.

Both approaches are presented into *Figure 2b*, where the initial object undergoes a series of land use Changes. In the vector approach, temporal scale is disregarded and the Changes are generalised into super-classes, according to the super-classes of land use. In the raster approach, those super-class Changes are reallocated according to the new scale.

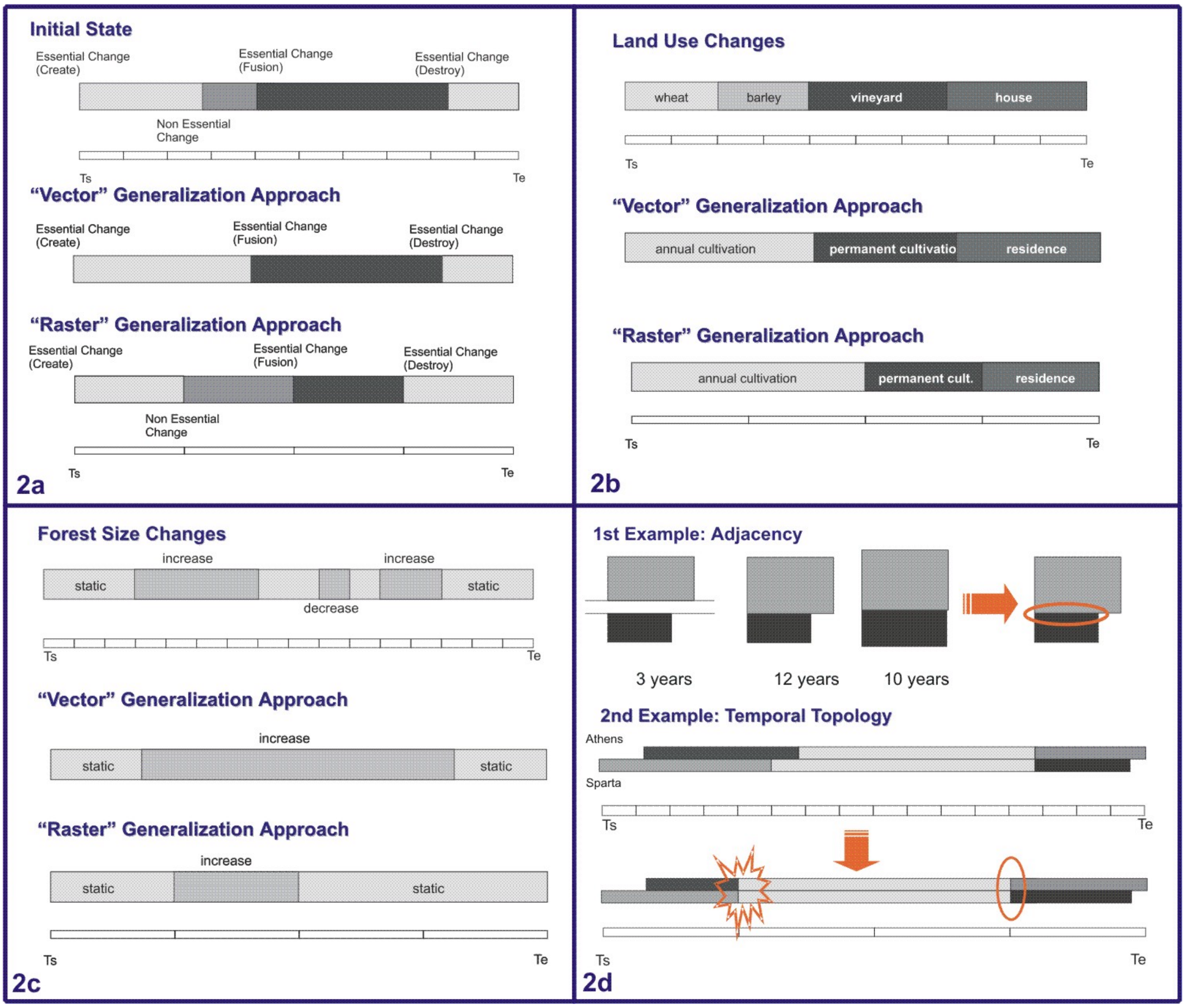


Figure 2. Temporal Information Abstraction Operators - Examples

3.2.3 Aggregation of Change

This operator is responsible for aggregating initial objects and Changes into single units. In a vector equivalent, Changes constitute vectors; therefore Change aggregation would merge all Changes of close temporal proximity into one, long Change. In a raster approach, all Changes are examined under the new temporal resolution step and all Changes taking place during the same time period are aggregated into one.

Figure 2c shows an example of Change aggregation. The initial object, a Forest, undergoes a series of size Changes. By a vector view, all those Changes are considered to have occurred in time points close to each other. Therefore, the three Changes are aggregated into one Change, which starts at the starting point of the first one and terminates at the ending point of the last one. Since "increase" is more prominent than "decrease" and they both belong under the same super-class "size alteration", the final Change is labelled as "increase". Time scale is irrelevant. In a raster view, there is a different granularity. At the first period the most prominent Change is "static", at the second period the most prominent is "increase", while at the third "decrease" and "increase" cancel out each other.

3.2.4 Temporal Topology Association

This operator follows up the previous three, by redefining the relationships between objects and Changes in the newly generalised database. Actually, this operation re-establishes all spatial, aspatial and temporal relationships. For the temporal topology association to be effective, it requires the definition of the allowed temporal topology among the states of objects. This way, it can act as validator of any renewed links.

There are two examples of temporal topology association in *Figure 2d*. The first one examines the generalised form of a spatial topology relation between two parcels. During the first three years, there was a road between the two parcels. For the next 12 years, the road ceased to exist and the parcels were expanded to become adjacent to each other. During the last 10 years the parcels remained adjacent, although their size increased. In a generalised representation of the two objects, while their forms are generalised, their topological relation of Adjacency is maintained as the most prominent for 22 out of 25 years. The second example presents the life quality level in two prominent city-states of ancient Greece, Athens and Sparta. Life quality was exceptionally high during the first years in Athens, while people in Sparta did not fare so well. As the Peloponnesian war erupted between the two cities, life quality in Sparta increased, and after a short period, it decreased in Athens. The war ended, with Sparta victorious. At that precise time point, life quality in Athens was dramatically reduced, and at the same point radically increased in Sparta. All those events were generalised into a larger time scale. While the second relation of the two Changes occurring at the same time point is preserved, generalisation forces the relation of the two other Changes to alter. Where the temporal topology relation was "one Change occurring after the other", now they seem to have occurred at the same time point. This newly created relation should be examined whether it is valid or not.

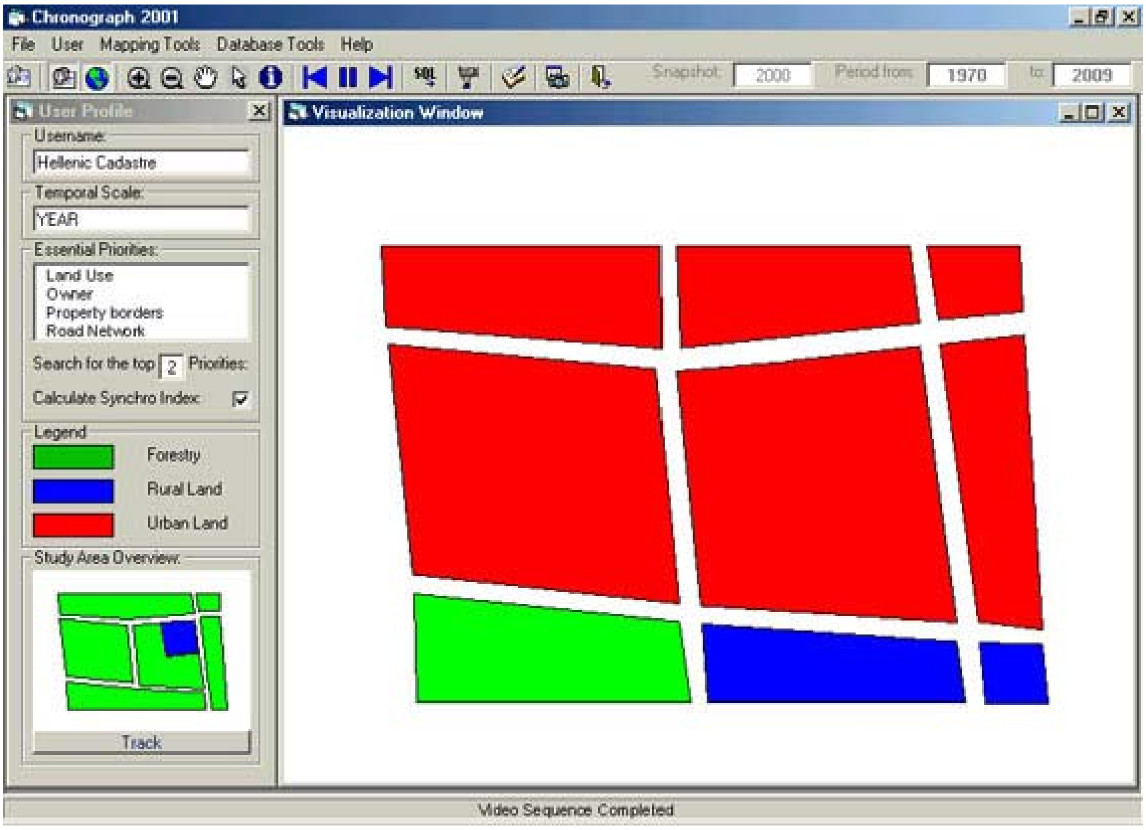
4. THE "CHRONOGRAPH" APPLICATION

In terms of our research and to audit the suitability of the proposed on Temporal Information Abstraction operators, an application was developed, called "Chronograph". Its purpose is to implement and examine the results of the introduction of generalisation in a spatio-temporal model, while the possible database structures are studied in order to improve the support of this function in future Geographic Information Systems.

4.1 Basic Application Operations

"Chronograph" is an application that deals with the means of storage, recovery and visualisation of selected spatial data, created as a result of continuous database research to put into practice the models of spatio-temporal generalisation. The output is a set of spatio-temporally generalised layers with overlaying abilities with the corresponding levels of visualisation of the initial or final map of the research area, at different detail levels. During application planning, the main guiding principles of introducing temporal generalisation in the object-oriented model were defined, based on the information abstraction operations applied to the initial data model. More specifically, the five following concepts were implemented in the final application:

- *User and Application profile based generalisation*: According to that principle, the significance of the changes of objects through time is defined by the personal demands of each user or map application. That means that for instance an employee of the Ministry of Agriculture considers the changes in land use as essential but on the other hand, changes of ownership status in the estate might be useless. In order to cover the subjective factor of the essentiality of Changes, the "Chronograph" GUI imposes the original input of data importance for each user or application by a thorough "User Profile Manager". Each user is called to choose whether he follows an already saved "profile", the characteristics of which can be seen in a form, or he creates a new profile in accordance with his present demands. Registering a new profile requests a selection of feature levels of interest and priority among them in addition with the type of generalisation he wishes for each independent feature level.
- *Use of basic operators of information abstraction in time altering data*: The simultaneous approach of temporal and spatial generalisation allows the experimental use of the four basic operators of spatial information abstraction in their temporal equivalent, as defined in the previous section. The way these operators function is transparent to the user, in contrast with the result of their intervention. The batch generalisation begins with Temporal Selection, always considering the characteristics of each user as deduced by the User Profile Manager. Afterwards, the Temporal Class Generalization operator intervenes, considering if the Changes have such a level of interest for the user so as to be visualised at a super class level. For the needs of "Chronograph", a twin level hierarchy in *land use* and *ownership* status has been created. When the previous operators have completed their interference, the main creation process of generalised model continues with the Change Aggregation operator which groups the essential objects in order to reduce the complexity of the output model. Finally, Association operator is used for confirmation of correlation accuracy in the rejoined objects collection. "Chronograph" takes only little advantage of this forth operator by using the elementary ability of MapX to correct visual misbehaviours by ordering each object in different level.
- *Simultaneous use of a single generalised map containing overlaid snapshots*: The visualisation result of generalisation cannot, in any case, be an abstracted project deduced by statistics control of the dominant states of objects included in an area. If, for example, we generalise the history of a century in an area that had been rural for 51 years while the rest 49 was urban, its representation as rural does not constitute a reliable sample of generalisation.
- *Use of the well-known cartographical generalization algorithms*: In accordance with Douglas-Peucker spatial phenomena point abstraction algorithm, some changes exceed the resistance limits (known as tolerance), and therefore should appear. This is the reason why creating and incorporating any change of the model in "Chronograph" should meet this criteria. To achieve that, it is essential to reschedule successively the objects included in area of interest, right after the pre-mentioned change. The layer, which represents each snapshot, follows the pattern standards of Animation Layers, in order to smooth polygon movement or stretching without influencing the rest overlaid static layers. Of course, the user is in position to also view the single generalised subject level,



Snapshot: 2000 Period from: 1970 to: 2009

Username: Hellenic Cadastre

Temporal Scale: YEAR

Essential Priorities:
Land Use
Owner
Property borders
Road Network

Search for the top 2 Priorities:

Calculate Synchro Index: ☑

Legend
🟩 Forestry
🟦 Rural Land
🟥 Urban Land

Study Area Overview:

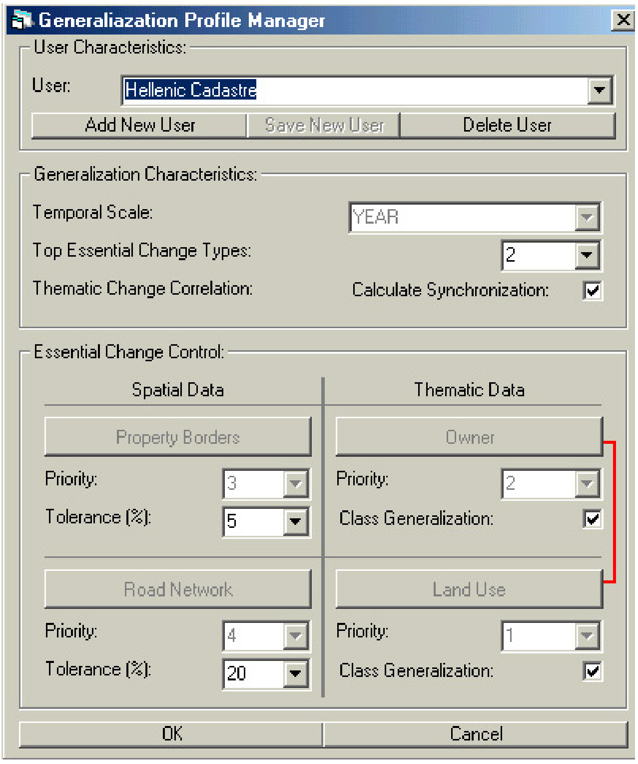
Video Sequence Completed

Figure 3. Chronograph's User Interface

whose accuracy is considered satisfactory in case of slight time depth or limited essential changes but its change is inverse in relation to them.

- *Simultaneous use of vector and raster* approaches: During the creation of overlaid snapshots, the user chooses if he wishes these snapshots to represent the area in the temporal nodes of Changes or in regular steps of temporal resolution. The first choice refers to the vector time resolution, where the beginning of each vector constitutes the Change of its birth and the end represents its death or its transformation to another object -since that exceeds the model tolerance level. That method maintains only the significant visualisation snapshots. The number of images is automatically suggested by the system, deduced by the characteristics of each user. On the other hand, the second choice refers to the raster resolution of time in equal intervals (corresponding to the pixel of raster image). The points of image shift are deduced by a simple division of time by the number of snapshots selected by the user, and in no case are they related with the Change points. Using that method partly solves the accuracy problem of an individual snapshot, while it can be used to observe the process of a moving object, but it does not achieve the same accuracy with the vector shortcut creation method.

The final implementation acts as a custom geographical information system, integrating a cartographic representation interface, a user characteristics profile manager and a number of spatio-temporal SQL queries (see *Figure 3*). It accesses an object-oriented database with spatial extensions, containing a virtual dataset for research purposes. It applies the Temporal Information Abstraction operators, taking into account user characteristics and



User Characteristics:
User: Hellenic Cadastre

Generalization Characteristics:
Temporal Scale: YEAR
Top Essential Change Types: 2
Thematic Change Correlation:
Calculate Synchronization: ☑

Property Borders
Priority: 3
Tolerance (%): 5

Owner
Priority: 2
Class Generalization: ☑

Road Network
Priority: 4
Tolerance (%): 20

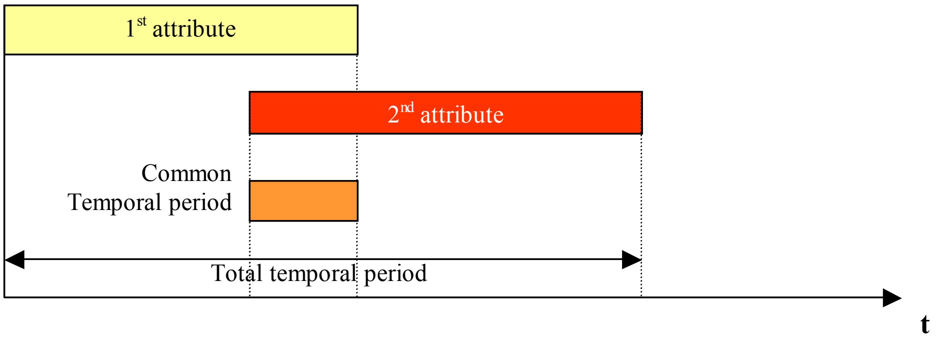
Land Use
Priority: 1
Class Generalization: ☑

Figure 4. User characteristics

vector or raster visualisation approach. The output can be displayed either as temporally generalised snapshot of the study area, or as a series of generalised snapshots in the form of an animated visualisation.

4.2 Profile Manager Sequence

In order to record the generalisation criteria separately for each cartographic application, Profile Manager prompts the current user to fill in the appropriate boxes with certain information provided by the system database. According to "Chronograph" design, four change types are available for elemental research, two of which are spatial and the rest thematic. More specifically, when the User Interface is running, all combo boxes are filled with all alternative compatible data (see *Figure 4*). The first to be selected is the Temporal Scale, where possible time granularities are Day, Month, Year and Decade. Then, the user selects which Change categories are essential, and in which order. For spatial categories there is also a tolerance ratio that decides how large should the Change be to name it *Essential*. Thematic categories on the other hand have a check box for class generalization. Afterwards, the user selects how many top priorities of the above should format the generalised model, and if the *fidelity ratio* should be calculated. All the above information is stored in the database after finishing the current form.



$$\textbf{Fidelity Ratio} = \frac{\textbf{common existence temporal period}}{\textbf{total temporal period}}$$

$$0\% < \text{F.R.} < 100\%$$

Figure 5. Temporal Generalisation Fidelity Ratio

4.3 Measuring Generalisation Fidelity

Although the visualised output of the spatio-temporal generalisation procedure seems like a common cartographic snapshot, actually its input data is totally different. Objects that appear simultaneously may or may not have existed in a common time period. For instance, if the dominant land use of a polygon object during total time era had been rural and the dominant owner of the polygon was an individual, the common temporal period of both the above could be equal to the total time period, smaller than it or even non-existing (in case of relational domination which can be less than 50% for each attribute). As a result, attributes visualised in the same "generalized snapshot" might never had existed together.

To portray the above peculiarity, we included in the application a mathematical index called *spatio-temporal generalization fidelity ratio*. Its role is to calculate the common existence ratio of two or more different attributes between the given time limits. To achieve that, the system locates the starting and ending point of each attribute and afterwards overlays those points to calculate the created periods, known as common temporal periods. The division of this number by the total time period equals to the fidelity index. The percentage expression of the above results the fidelity ratio (see *Figure 5*). Its value varies from 0%= zero level fidelity to 100%=full fidelity. The highest percentage practically refers to existing real world snapshots and the lowest to theoretical, abstract snapshots. The same procedure is used to calculate simultaneous existence of objects or object groups.

5. CONCLUSION

As each cartographical application prescribes its own temporal resolution scales, this research introduces a traditionally spatial notion like generalisation into a temporal schema. But to actually comprehend and record time, people rely on events to depict its passage. These events reflect Change in the state of entities. We classify Changes into Essential and Non-Essential. Since transition between temporal scales can be utilised as an analysis tool, we propose a model for recording objects and their Change independently, thus facilitating the generalisation of Change as well. The model regards both space and time as equivalent concepts, therefore accommodating spatial concepts like topology and generalisation to include temporal behaviour. The conceptual schema aims to formalise Changes and to classify then into class hierarchies.

We expanded the notion of conceptual generalisation to Temporal Information Abstraction, in order to describe the process of enabling a spatio-temporal database to be altered into a different temporal level of detail. The four basic information abstraction operators can be applied to achieve a new schema, suitable for a different temporal scale and, quite often, for a new application purpose as well. We defined the four temporal generalisation operators as: Temporal Selection, Temporal Class Generalisation, Change Aggregation and Spatio-Temporal Topology Association. Both the model and the suitability of these operators were audited by the development of an appropriate application, called “Chronograph”. A database was implemented, following the principles of the model and containing a virtual dataset. The application creates a generalised view of the database on the fly, steered by specific user needs. It applies all four operators and produces a visualised output, along with a fidelity ratio regarding the consistency of the generalised schema.

During this study and its evaluation with the implemented application, a number of research issues arose. The four proposed temporal generalisation operator seem effective and sufficient in their results, much like their spatial equivalents are. However, the exact processes each one of these operators will include require to be defined in detail. Especially the fourth operator, regarding re-association, becomes exceedingly complex in cases of multiple spatio-temporal topological relations among objects and Changes. The fidelity ratio, although it is quite indicative of the validity of the applied generalisation processes, requires including more auditing factors. There is also the need to move a step further from simply creating a generalised version of a schema, to actually remodelling and recording the whole schema into a new database. Finally, the way of visualising the new schema is by no means exhaustive, since the proper way of portraying the temporally generalised objects cannot be easily determined.

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SPATIO-TEMPORAL GENERALIZATION: THE CHRONOGRAPH APPLICATION

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