THE CONCEPT OF GENERALIZATION IN SPATIO-TEMPORAL MODELING

George Panopoulos & Marinos Kavouras

Cartography Laboratory
Faculty of Rural and Surveying Engineering
National Technical University of Athens
9, Heroon Polytexneiou St., 15780 Zographou Campus, Athens – Greece
Tel: (3+01) 772-2731, Fax: (3+01) 772-2670
`[mkav, gpani]@survey.ntua.gr`

Abstract

This paper describes an effort to introduce traditionally static spatial concepts, like generalization, into a temporal schema and study their aspects concerning Change over Time. Temporal Generalization regards the representation of each object (or its Changes) over different Time Scales. It is within the logic of the proposed model to contain strict formalizations of the objects, their domains, their attributes and their Changes. This logic can be expanded to include formalized rules over the representation of each entity class during the course of time. Time Scales can be defined at different granularities, according to the application, as a part of the model. For those predefined Time Scales, there are formalized rules of how to generalize and represent each object over Time. In order to study the conceptual and cartographic aspects of Temporal Generalization, a specific application of large scale (cadastre) maps was selected. The model defines application specific Time Scales, at different granularities. Depending on the level of "detail" of each Time Scale, cadastre objects are generalized accordingly. For each object, the model includes rules regarding its generalization at the various scales. These rules refer both to information abstraction as well as the visualization of the object during those Time Periods.

Introduction

Cartographic generalization has been identified over the years, not only as a visualization problem, but also as an issue of representing the entities at a modeling level. Different levels of detail, as dictated by map scale, correspond to different conceptual descriptions of the attributes and relations of each entity. Conceptual modeling, 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. These data models may well represent the variation of scale through variations of levels in the hierarchical classification schema.

This modeling of entities can be extended further from their spatial, static properties, to include their dynamic behavior and interactions as well. Such spatio-temporal modeling 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.

The first part of this paper focuses on the basic primitives of Time, Change and Motion over Space. Its purpose is to study the representation of Time and eventually, Change. Various Temporal Taxonomies are taken into account, and their properties are examined. The effort is to formalize a way to describe and record temporal metric "units" – referred as Intervals. Then, the detail level of such units is discussed, namely the Temporal Scale of the stored information. Temporal Scale is compared to spatial scale, and the concept of Generalization (and Specialization) among different Time Scales is examined, taking into account the more familiar concept of spatial generalization. In the second part, those proposed formalizations and any logical conclusions are audited with a more practical view. The basic principle to bear in mind is that, if Change-related analysis is to be addressed, the necessary form of representation should better be suited to a specific application. For such a task, cadastre was selected. Under the prism of cadastre temporal data types, the nature of Change was examined, as well as the notion of generalizing and representing such data in various Temporal Scales.

2. Representing Time and Change

The concept of Time is quite incomprehensible, thus turning any effort of modeling 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 behavior in the «future». What this proves is that, all understanding we have about Time comes from perceiving and recording Change [Eschenbach & Schill, 1999].

2.1 Temporal Taxonomies

Throughout history, both Philosophy and Physical Science have made efforts to define and model Time. Two of the most predominant views are those of *Absolute* and *Relative* Time. Absolute Time, initially described by the Atomists in Ancient Greece, characterized the view of Space and Time in Newtonian physics. Space and Time exist in two different "axes", each one self-contained and independent from the other. What happens to an entity in space has no effect to its place in Time – and vice-versa. Time participates in Newtonian laws in the form of intervals. It has no direction (the formulas work just as well if Time is "reversed") and serves as background for Changes to occur. The Relative view of Time, adopted by Einstein and dominating modern science, regards Time as a fourth dimension, a portion of a spatio-temporal matrix where entities exist and evolve. Both Space and Time serve to define the "position" of each entity, than to exist by themselves.

In our effort to portray Time and its correspondence to space, we will adopt both the pre-mentioned views. Each one does not reject the other, but actually complements it. The absolute view comes closer to the cognitive patterns people use to perceive the passage of Time. It provides an "objective" method of measuring processes, using intervals, in the form of clocks and calendars. Its spatial and temporal framework is strict, never changing and rigid. Entities evolve upon it. The relative view comes closer to subjective measuring of Time, using topological methods to connect entities with their spatio-temporal properties, and with other entities.

Space and Time are not separate categories. 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 [Coveney and Highfield, 1990]. 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. Any temporal database addressing geographic information should aim in representing 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 cartographic entity definitions in order to classify the importance of their Changes.

2.3 Recording Time

Although Time is continuous, we will make the concession that it can be broken into discrete units of measurement, which can be of the same or of varying length. This is closer to the view of Absolute Time, which requires an objective way to represent its passing. The smallest temporal units used to record Time, no matter if they are seconds, months or decades, will be referred as *chronons* [Tryfona & Jensen, 1998].

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 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.

On a more practical level, *chronons* prescribe the duration of *Intervals*. 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 t_s to a final point t_e. Intervals can be open or closed at their ends, like $[t_s, t_e]$, $[t_s, t_e)$, $(t_s, t_e]$ or (t_s, t_e). For these data types, literature can demonstrate a series of operators, including Scalar, Aggregate, Relation and Update operators [Darwen, 2000; Lorentzos & Mitsopoulos, 1997]. 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

3. Temporal Generalization

Generalization refers to all the processes involved in representing spatial data of a particular cartographic scale into a new (usually smaller) cartographic scale. Many call the inverse process, of portraying data from a smaller scale into a larger one, as Specialization. Spatial modeling has adopted the generalization 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. This conceptual generalization usually means aggregation of spatial entities into entities that are higher in the model hierarchy, or vice-versa [Panopoulos and Kavouras, 1997; Kokla and Kavouras, 1999; Molenaar, 1998].

3.1 Temporal Scale transition

Our effort is to introduce and study such a traditionally spatial notion into a temporal schema. Generalization associates with the change of scales. Temporal Generalization relates with the alteration of Temporal Scales or, to make things even more complex, with the transition between different spatio-temporal scales.

Even in its graphic form, generalization 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 generalizing entities at a modeling level, and can apply in spatio-temporal analysis as well. Representing an entity in a Time Scale of different resolution than the one recorded can have a variety of advantages. Viewing a process, so far recorded in fine detail (high resolution) intervals, at a less detailed resolution would reveal its behavior 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 (cadastre, for instance) to record Change in high granularity, spatio-temporal reasoning using such data would demand its Temporal Generalization in various other scales.

The choice, of which new Temporal Scale (or Scales) to generalize into, is heavily application-dependant, the same way the choice of the initial map scale is. Each application accounts for a different real-world view, thus defining different entities. So far, map goals prescribe the spatial scales suitable for those entities. Our proposal is to include the suitable temporal scales to monitor the entities' activity as well.

3.2 Generalization of Change

As mentioned before in this paper, people comprehend and represent the temporal aspects of entities by recording their Change. We propose a spatio-temporal model where spatial Changes will be represented separately from the spatial entities. Both are related to each other and recorded in reference to Time, using intervals. This means that modification of the Temporal Scale will cause the generalization not only of the entities, but of their relating Changes as well.

However, generalizing Changes into a different level of temporal resolution can be more complex than generalizing entities. Actually, the various Changes that a geographic entity has undergone will probably be aggregated into a more generic form of "Change". If successful, such aggregation will substantially represent the general behavior of the entity and of its relationships, making it a powerful analysis tool. On the other hand, if inaccurate, either due to lack of sufficient data or to deficient aggregation operators, the generalization may well be deceiving.

The major issue of *Essential* and *Non-Essential* Changes is of paramount importance in generalization. Could there be spatial entities that, while they undergo a series of Non-Essential Changes, by generalizing their Change over Time the aggregated Change becomes Essential? A most common problem is the aggregation of both Essential and Non-Essential transitions. For instance, for a period of ten years, a land parcel submits to a sequence of minor variations (Change of land use, Change of ownership etc.), all non-essential and all recorded with a granularity of 1 day. In the last moth of this decade, this parcel undergoes an essential Change (as the application regards it), by splitting in two and ceasing to exist. Although this last Change lasted only for small interval, when the temporal scale turned to 10 years it would play a major part in the aggregation and the final representation of the parcel's behavior over 1 decade.

Since Essential and Non-Essential Changes have to do with the entity's identity, the model defining the entities should also point whether an entity is classified as *Fiat* or *Bona Fide*. This characterization is part of the geographic entities' ontology. It distinguishes entities that are human creations, without physical boundaries –known as *fiat* boundaries- from genuine entities with apparent boundaries, based on spatio-temporal discontinuities - known as *bona fide* boundaries. Most socio-economic units fall into the category of *fiat* entities, as they usually have boundaries created by humans [Smith, 2000]. For instance, in a socio-economic application like cadastre, the identity of Land Parcel is not connected with its boundaries –these may not even exist. The Parcel is not connected with the grass and the gravel it contains, so by losing part of it does not mean it forsakes its identity. This is a Non-Essential Change, if viewed under the prism of a cadastral application. However, for the needs of a Land Cover application, the land parcel can be a genuine entity, since it may be represented by the boundaries of its grass. If this grass were taken away to be replaced by a vineyard, the parcel would undergo an Essential Change.

4. Nature of Change in Cadastre

In the two previous parts of this work we explored ways of representing temporal aspects of real world entities and recording Change. We formulated a number of suggestions to incorporate the notion of Temporal Generalization, in order to achieve substantial learning and better utilize such representations. In both these sections, a basic view was repeated: to reach a practical, working version of everything said, it is necessary to conceptually design those representations with particular cartographic applications in mind. In this section we select such a socio-economic application, Cadastre, to study how the proposed notions would serve a particular field.

4.1 The Conceptual Model

To accommodate most concepts presented above, we need an approach to suit spatio-temporal modeling 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. Since the proposed model is presented at a conceptual level, 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 (large scale-cadastre entities), it can contain *formalized 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. Object-oriented models provide a natural method of describing entities [Worboys, 1994], avoid data fragmentation and enable useful capabilities for managing Time. In the model a number of entities are defined. Each entity acts as a class that contains a set of objects. All these objects share attribute sets common to their entity. These attribute sets are distinguished into three separate domains [Claramunt and Thériault, 1996]:

- 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 modeling 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 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.

4.2 Changes in Cadastre

The temporal domain will not only contain each object's present state (static, changing and ceased). It will also record the kind of Change that actually became the event, during which the object was altered. The model will predict all the Changes that can transpire. Each entity will be associated with certain Changes that it can undergo. These rules, part of each entity class definition, can act as integrity constraints when temporal information is concerned. The prescribed Changes, recorded into the temporal domain of each

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

object, will be linked with the respective Changes that affect other objects. For instance, in the cadastre model, an event in the life of the entity «Parcel A» (split) is linked to the Changes that objects «Parcel B» and «Parcel C» sustain (birth). This way, not only the history of each object may be traced, but also the events that lead to any transition in its life can be confirmed. With the a-priori definitions of each Change, it can be made possible to detect the "cause" and "effect" for each new state that an entity enters.

Cadastral Changes pose certain peculiarities. First of all, they are not continuous. Changes to the three main entities of a cadastre schema, namely a Land Parcel, a Building and an Owner, happen in zero-duration intervals. It is quite rare for a cadastre entity to be under continuous Change. Even if the particular state of an entity is in question, the last legal state is considered active, until the dispute is resolved. Law dictates most forms of Change. Only legal transitions can be recorded -of course, there can be exceptions. Since most Changes are legally prescribed, this facilitates the strict formalization of such Changes, and how they relate to entities.

One important fact about cadastre Changes is that they regard *fiat* objects. That means they refer initially to the identity of each entity. Al-Taha [Al-Taha, 2000] groups a number of operators that track the evolution of features' identities. 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 formalizing spatial Changes in the cadastre model, one can use those operators to track down the modification of identity, and therefore classify them as Essential or not.

4.3 Utilizing Generalization in Cadastre Spatio-Temporal Data

As it was mentioned, switching over to a new Temporal Scale is quite useful as an analysis method. Cadastre data are recorded at high temporal resolution, usually at the granularity of one day. Any Change that occurs must be documented in a legal act, which is signed on a certain day. Therefore, any modification to an entity is automatically recorded and attributed to this particular date. The new state of the object is considered active from this day onward. It is quite similar to the prescribed spatial scales that cadastre uses: map scales of 1/1000 for urban areas and 1/5000 for rural areas, as well as temporal scale with *chronons* of 1 day.

Usual queries in a cadastre application make use of these scales only. For instance, "display any property of a certain person as of May 19th, 1995" utilizes the 1-day resolution. However, it is possible to employ such spatio-temporal information for further analysis. Its high level of detail and accuracy, both on spatial and temporal aspects, characterizes cadastre data. It may well serve as infrastructure for analysis irrelevant to the limited queries of cadastre applications. Socio-economic information of this kind can

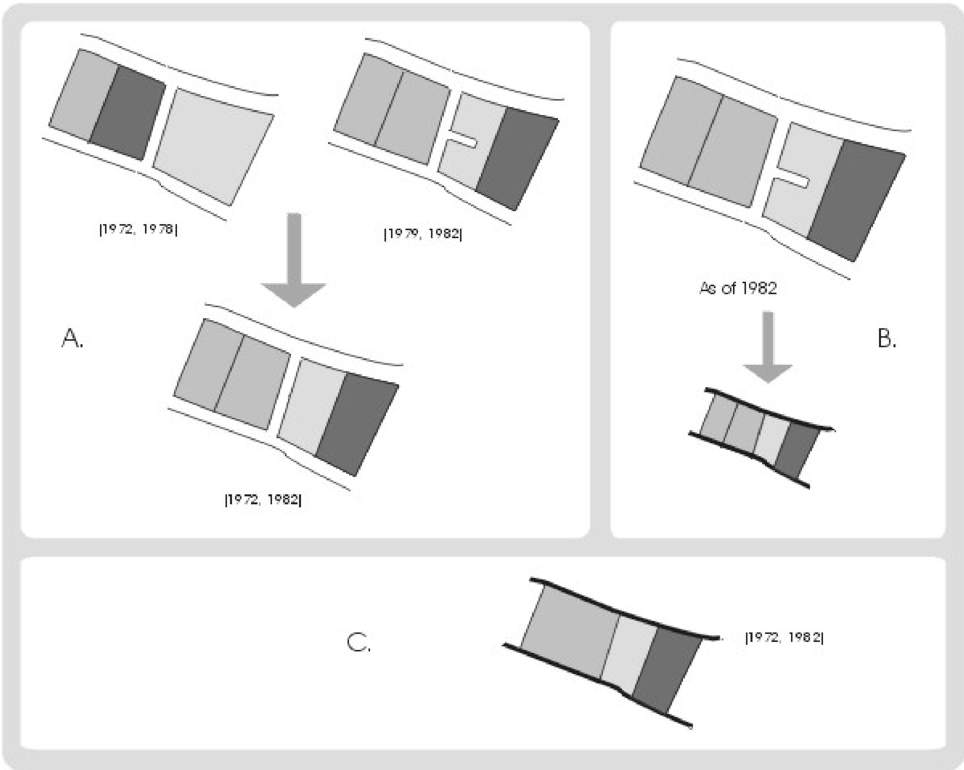

Figure 2: A. Temporal Generalization, B. Spatial Generalization, C. Spatio-temporal Generalization

reveal a lot over the social interaction of people with the land. Thus, it possible to apply the concept of generalizing in much smaller temporal scales, aggregating the highly detailed data.

Figure 2 presents a visualization of such a generalization case. Example A generalizes two states involving three parcels. After the first 6 years, one parcel had a Change of ownership, one has remained the same and one was split, spawning a fourth parcel. A utility road farther modified the remaining third parcel. Generalizing in a scale of 10 years, the new utility road modification is disregarded (it's a Non-Essential Change lasting four out of ten years) while the Change of ownership and the split are represented (although they exist for four years, they are considered by the application as Essential). Example B describes a normal spatial generalization to a smaller scale, of the situation as it was during the year 1982. Example C is more complex, portraying generalization over both spatial and temporal scales. In this representation, the smaller roads are gone, and the larger ones are reduced to line symbols. For the 10 years period, the split is represented, as well as the ownership Change. What is peculiar is that, since parcels 1 and 2 belong to the same person and have a common border, spatial representation visualizes them as one, uniform parcel. Such an operation suggests an Essential Change of Fusion, which, according to the high-resolution data, never happened (till 1982).

5. Concluding

This work attempts to describe the essence of Time and focuses on the importance of Change for its representation. We consider Space and Time as relevant, acting as a positional matrix for geographic entities. Time differs from Space in its linearity and its direction, moving towards behaviors of increased entropy. We consider Time constitutes from a series of measurement units, called chronons. A chronon defines the duration of the Temporal Intervals, which are used for recording Time Periods. 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. Any important Change that affects and completely alters an entity's identity is called Essential Change. Changes that dictate a new state for the entity without altering its identity are considered as Non-Essential.

As each cartographic application prescribes its own temporal resolution scales, we attempt to introduce a traditionally spatial notion like generalization through a temporal schema. Since transition between Temporal Scales can be utilized as an analysis tool, we propose a model for recording objects and their Change independently, thus facilitating the generalization of Change as well. The model is further detailed under the specific view of a socio-economical cartographic application like Cadastre. The essence of Change in Cadastre is investigated and operators are proposed to use in formalized cadastre Change definitions. We conclude by studying the usefulness of high-resolution land property data, like those of Cadastre, in further analytical applications, which may employ Temporal Generalization operations to derive results.

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