Fuzzy Interoperable Geographical Object (FIGO). An approach of enhancing spatial objects with fuzzy behavior

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Abstract
The application of object-oriented technology in GIS is not something new. Geographical, or spatial object is basically a geometrical shape with spatial description and attribute information along with methods describing a position or an area or a phenomenon on the earth. On the other hand, due to the static nature of the spatial objects, GIS is not possible to monitor and to represent the real world dynamic changes so that their spatial description inherits fuzziness. This work examines the utilisation of object-oriented technology with incorporation of fuzzy logic, for the modelling and the representation of spatial characteristics and phenomena, in a completed geographical environment. For the majority of GIS applications it is assumed that the modelled world is precise and bounded. The examination includes an exploration on the concept of spatio-temporal applications and on the changes of spatial objects characteristics in time. In addition, the production of geographical data assumes the use of fuzzy interpolation methods, as well as the use of data taken from other sources, i.e., historical or statistical. Thus, the integration of the two technologies, namely, the fuzzy set theory and the object data modeling into a Fuzzy Interoperable Geographical Object, called FIGO, introduces a new approach of enhancing spatial objects.

1. Introduction

Nowadays, the interest about the GIS applications has been focused on the so-called dynamic or '*spatio-temporal*' applications, which examine the changes of phenomena or '*space over time*'. In the strict sense, a GIS is a computer based information system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations. The analysis and modelling of dynamic applications such as the above, require the integration of both spatial and temporal attributes of data. To the best of our knowledge, three types of problems have been identified so far:

- Current GIS have severe limitations in manipulating the temporal components of data. These data are related to a series of snapshots associated to a particular instant in time but the information about the changes happened between two consecutive instants lost.
- No observation of geographical phenomena or area will ever be exact (Duckham et al., 2001). Imprecision is an inherent feature of geographical information and spatial description cannot be based on crisp geometrical boundaries and cannot be always identified using constant characteristics (Molenaar et al., 2000).
- The geographical data used by a specific system, usually cannot be shared globally through many systems. The major obstacle to share and integrate effectively geographical data from different sources is data incompatibility. Data intend to support specific requirements and the collection methods are optimised for a particular need as long as the resulting data structures are not usually readily comparable in a cross-sectional study.

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In order to solve the above problems the use of Object Oriented modelling coupled with Fuzzy Logic theory is exploited. The application of object technology in GIS primarily began using geometric entities, called spatial objects, which are based on vectors or raster models. The enhancement of the spatial objects methods with fuzzy logic aims to extent the spatial boundaries over time and to model the behaviour of each object changing its characteristics, according to the type of environment this object is intended to present. Furthermore, an overview of fuzzy spatial interpolation methods, which model the gradual changing of a spatial entity, is presented. Object oriented models coupled with fuzzy logic, accomplish the interpolation in various steps. In each step spatial entities may overlap with each other, so that objects may have fuzzy transition zones. In these the points might belong to multiple objects with different degrees of membership in each zone.

Additionally, it is quite easy to use data from other sources in an object-oriented model. These data could be geographical or other descriptive which called *ancillary data*. By enhancing the fuzzy interpolation methods of the object with ancillary data, more realistic results can be produced.

The work presented in this paper firstly concerns some fundamental modelling concepts of spatial objects, relationships, time points, periods, events and how influenced by uncertainty. The spatio-temporal fuzziness also is presented as the change of the combination of the above concepts, which are affected by the uncertainty to a various degree according to four scenarios. Next, an example of spatio-temporal interpolation is introduced showing how spatial objects change their geometry over time.

After the review of the basic spatio-temporal concepts, the integration of two technologies, fuzzy set theory and object data modelling into an interoperable geographical object called FIGO is introduced. The processed methodology is determined by the need to represent space over time, using interpolation methods and to handle the uncertainty associated with the geographic data each time used. Another contribution of this work is to control and to change the behaviour of spatial objects according to the environment this object intended to present. This can be done by integrating models for the storing of rules that change over time into an embedded knowledge base. This brief review will become the basis for future work that will determine the principles for the development of an object, called Fuzzy Interoperable Geographical Object (FIGO), able to represent the same space in different times using consecutive snapshots, ancillary data and other environmental criteria. FIGO also can provide a standard way to handle spatio-temporal uncertainty and to represent environment under specific conditions.

The rest of this paper is organized as follows. Section 2 briefly presents the fundamentals in the spatio-temporal application domain. Section 3 explores some basic meanings in temporal the fuzziness domain. Section 4 deals with spatial fuzziness. Section 5 and 6 analyse spatio-temporal fuzziness and interpolation methods accordingly. Finally, section 7 gives some principals for the development and the evaluation of the proposed Fuzzy Interoperable Geographical Object (FIGO), whereas section 8 presents the conclusions.

2. Spatio-Temporal Application Concepts

Spatio-temporal applications can be categorized according to the type of data they manage:

- Applications dealing with moving objects, such as navigational. These objects change their position in time, for example, a moving "car" on a road network.
- Applications involving objects located in space, whose characteristics, as well as their position may change in time; for example, in a cadastral information system, "land-parcels" change positions by changing shape, but they do not "move".

- Applications dealing with objects which integrate the above two behaviours; for example, in environmental applications, "pollution" is measured as a moving phenomenon which changes properties and shape over time.

The third category of spatio-temporal applications is most important and the following meanings are involved in the modelling of environments like the abovementioned.

2.1. Spatial objects and their geometry

Objects in real world have a position in space. In GIS applications, the objects position in space is only important. These objects are called spatial objects, e.g., a moving "aircraft" in Radar is a spatial object. Many times it is not only the actual presence of the object's position that is important, but its geometry as well. For example, while in a radar system only the actual location of the aircraft matters, in a cadastral system the exact geometry of a "land-parcel" is important. The geometry of a spatial object can be a point, a line, and a polygon indicating area, or any of the above combination.

2.2. Spatial relationships

Spatial objects are related in space. A spatial relationship relates spatial objects, or more precise, the positions of the related objects. For example, two land-parcels are neighbours if they share common borders.

2.3. Spatial attributes and their geometry

Objects have attributes, which characterize them. Spatial objects consists of descriptive attributes as well as spatial attributes, e.g., the "vegetation" of a "land-parcel." Values of spatial attributes depend on the referenced position and not on the object itself. If the spatial object "land-parcel" changes position, then the value of "vegetation" will also change. Spatial attributes are also related to geometries in space. There are two basic types of spatial attributes: (a) Those representing by points each of which has a specific value e.g. the temperature or humidity value of a specific location. (b) Those representing by polygons with discrete boundaries, e.g., "vegetation". In case (a), classification techniques may be used to create "zones" of average values, for example, "high temperature" or "low temperature".

2.4. Time

Many sophisticated methods to handle time in databases and in Artificial Intelligence area have been proposed (Baudinet et al., 1993), (Lorentzos et al., 1999 a), (Lorentzos et al., 1999 b). Here time is assuming as a line consisting of equally space fragments called *time elements*.

2.5. Time points and time period

A time point t_1 is located somewhere between *time elements* representing a particular instant in time while time period is the difference between two consecutive time points t_i, t_{i+1} and is defined as a set of *time element*.

2.6. Time stamps and space in time

Temporal information is either associated with individual layers for different time points, called snapshots, or individual spatial objects with different shape and size representing space in a time period. The snapshot approach results in significant data redundancy and it is used more from GIS vendors. The space in time approach requires the application of interpolation methods to simulate the transition states of the spatial object in a time period.

3. Temporal Fuzziness

Temporal applications are interested in events and their occurrence time. However, sometimes we only know approximately when an event occurred or, the time when an event occurred cannot be stated accurately. Fuzzy events are events that do not have a clear defined beginning or end, by a lack of knowledge or incomplete information (Dyreson et al., 1993). In the following, some basic meanings are presented, regarding to temporal fuzziness domain.

3.1. Fuzzy time points

A time point is clear defined if it is known between which time elements it is located. A time point become fuzzy, if it is not known *exactly when*, but approximately within which time elements it is located. Such a point is delimited by two time elements and is defined by fuzzy function that describe where the time point is located within the range of the upper and the lower time elements.

3.2. Fuzzy time periods

A time period is a subset of the time line, bounded by two time points. Depending on whether the bounding points are fuzzy or not, a time period is defined accordingly. An example is given in Figure 1. The time period T is limited by the time points 1 & 10 defining the maximum duration of period T (T_{max}) whereas the minimum duration of T ($T_{\min}$) is limited by the time points 3 and 8.

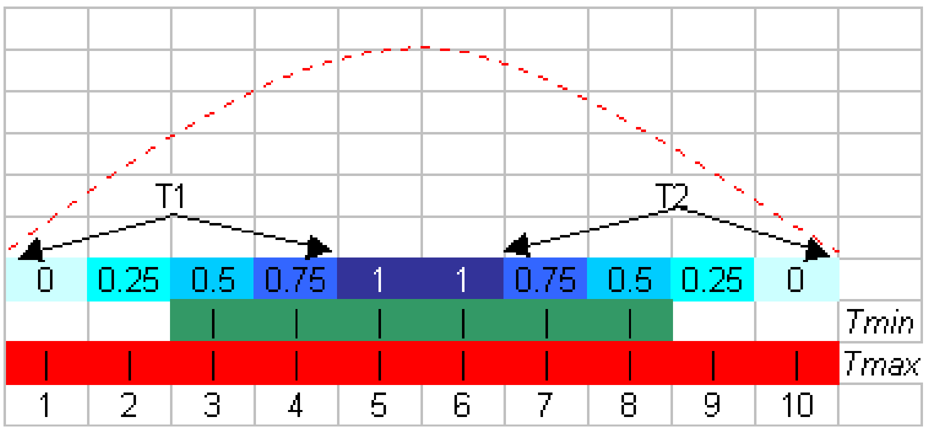

Figure 1

To define the membership degree of a time element into T, the period must be divided into three parts; the ‘*core*’ period, the intervals T_1, T_2, excluding the ‘*core*’, and the outside period area. All time elements in the ‘*core*’ have a grade of 1.0 whereas in the outside period area the membership grade is 0.0. The function describing the membership degree of time element into a time period is as follows.

$$\mu_T(x) = \begin{cases} 1 & y \quad in \quad core \\ \sum p(x) & y \in \quad I_1 \vee I_2 \\ 0 & otherwise \end{cases}$$

4. Spatial Fuzziness

As it is pointed out in the introduction, imprecision is an inherent feature of geographical information. Furthermore, because GIS processes deal with phenomena that are fuzzy, their spatial representation cannot be based on crisp geometrical boundaries. If it is not possible to decide where a spatial element belongs to, then a blurry zone can represent this situation. Spatial fuzziness occurs in the following situations:

- If it is not possible to define an area with crisp boundaries
- If it is not possible to describe precisely the spatial relationship between this object and its neighbors.

Spatial relationship is expressed by the position and the geometry of the spatial object. If the position is not known then the object cannot be identified. The most common geometries met in spatial application are *Points* and *Polygons*. The geometry Point if exists, can only be crisp or uncertain. Uncertain is the point whose the location is not known exactly but can be defined it with a degree of confidence or uncertainty. The geometry *Polygon* can be *uncertain* or *fuzzy* and is defined as in sequel:

- *Uncertain polygon* is the polygon whose boundaries not exactly known. Consider a map made up of two discrete polygons, A and B, sharing a common boundary. Trying to digitize the boundary line repeatedly, a set of point is obtained that is lying more or less close to the boundary line. However, there will be more points closer to the actual location of the line than away from it. To determine the probability an arbitrary point belongs to the actual boundary line, a positional probability function may be used. However, this approach is feasible in case the probability function, describing the distribution of all points in the boundary line, is known.

- *Fuzzy polygon* is the polygon whose boundaries are not crisp but transitional, characterizing areas that for various reasons cannot have, or does not have sharply defined boundaries. Consider the boundary between two soil zones. Land evaluators and scientists can define a specific area as suitable or unsuitable for a particular kind of land use, but they are often unsure about where the boundary line should be drawn.

The above notion illustrates the critical case for which fuzziness relieves uncertainty. Assuming a smooth and steady transition zone from the polygon A to the polygon B, a valid membership function can be defined. A membership function that describes the area between two soil zones (A) and (B) could be as follows:

$$\mu_A(x,y) = \begin{cases} 1 & if\,(x,y) \in A \\ 1 - \dfrac{d_a}{d_a + d_b} & if\,(x,y) \notin A \wedge (x,y) \notin B \\ 0 & otherwise \end{cases}$$

Where d_a and d_b are the distances from a point (x, y) to the central concept area of the soil zones A and B.

A formula for a distance d from an arbitrary point given by its coordinates (x, y) to an area A with boundary B_A is as follows

$$d\left((x,y),B_A\right) = \min\left\{\ dist\left((x,y),(m,n)\right)\ \middle|\ (m,n)\ \in B_A\ \right\}$$

Where *dist(p,q)* is the Euclidean distance between two points *p,q*. If it is required to take into account the earth surface, then the distance of the *great circle,* that is the circular arc connecting two points with coordinates $\{lat1, lon1\}$ and $\{lat2, lon2\}$, is given by the equation:

$$d = a\cos\left(\sin(lat1)\times\sin(lat2)+\cos(lat1)\times\cos(lat2)\times\cos(lon1-lon2)\right)$$

Regarding the selection of the membership function, there are two possible ways of deriving membership functions for fuzzy sets. The first, called 'Similarity Relation Model' (SR), is analogous to that taken by cluster analysis and numerical taxonomy in that the value of the membership function is a function of the classifier used. The second approach, known as Semantic Import Model (SI), is much used because is simpler. The membership grade is assigned using a membership function, derived by an objective or subjective process depending on the way in which the experts agree to define classes. This model is useful in situation where users have a very good idea how to group data, but for various reasons are constrained from using the standard Boolean model. There are several suitable functions that can be used for defining flexible membership grades, which can be easily adapted to specific requirements. One of the functions which is much used is as follows:

$$\mu_A(x) = \frac{1}{\left(1+\alpha(x-c)^2\right)}$$

Where α is a parameter governing the shape and C is the value of X at the central concept (in that case a=0,0004 and C = 100).

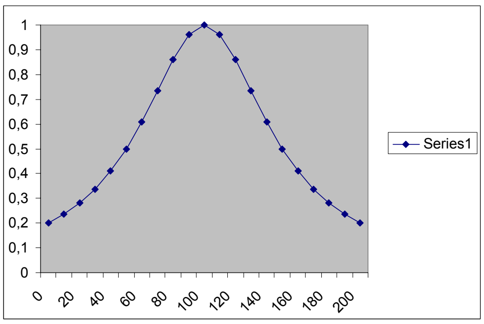

Figure 2

5. Spatio-Temporal Fuzziness

The modeling of dynamic change of geographical space over the time or the plotting of a moving object whose position is sampled in time, require the consideration of both spatial and temporal fuzziness and the their integration into a GIS environment.

Both approaches are based on the idea that geographical data (representing space or movement) are stored in a series of consecutive instantaneous pictures, called 'snapshots' which carry the information about entities and their attributes at a particular *time element*. To obtain the *missing values* between the snapshots, the available data must be interpolated. According to the problem examined each time, spatio-temporal interpolation could be influenced by different dynamics of spatial and temporal evolution. Taking into account that the spatial evolution either occur on a discrete or on a continues basis and that it may be recorded in time points or in time periods, four scenarios on the context of spatio-temporal fuzziness are examined:

- *Discrete change of geometry recorded in time periods.* The geometry stays constant for some time and then changes instantly. The geometry is sampled at constant time intervals d_t. The geometry may or may not differ from the previously recorded one and it is not known when the change occurred.
- *Continues change of a geometry recorded in time.* The geometry is changing constantly and is sampled at constant time intervals d_t. This case implies that space and time are independent and the essential information about the geometry change prior or past the time point remains undetected.
- *Discrete change of geometry recorded in time intervals.* The objective is to start recording and to create a new time interval, when a spatial change occurs. The geometry remains constant between consecutive time intervals and it is valid for that given time period. If a change occurs a new time period starts. In this case spatial and temporal components affect each other. Dealing with fuzzy spatial extents, implies that the time point at which a change occurs cannot be detected precisely. On the other hand, fuzzy time points propagate fuzzy spatial extents.
- *Continues change of a geometry recorded in time intervals.* This case is based on the assumption that for a given time interval $T=[t_i,t_{i+1}]$, there is a function that model the transformation from geometry G_i to G_{i+1}. This scenario is the most complex case because the time interval, the geometry, and the function can be fuzzy. In the simplest case, the time intervals are determinate and the change function interpolates in between two known geometries G_i, $G_{i+1}$and return a fuzzy transition zone. An example based on this concept is the transition of rural to urban land use that will be analysed in the next section.

6. Spatio-temporal Interpolation

Geographical data are essentially observations about features or phenomena, referred to as 'geographic reality". Geographic reality often cannot be measured exhaustively because it is nearly impossible to obtain measurements for every point across an entire landscape. Accurate measurements are also difficult to be obtained because of continues (slow or rapid) variation of the landscape over time and because of the limitation of instruments, financial budget, and human resources. Thus, when geographical data are created, they are merely approximations of geographic reality. The basic GIS schemes (Couclelis, 1992) for representing geographic data are not dynamic but invariable instantaneous pictures of the world called *snap-shots*. To find or better to estimate the data between to consecutive *snap-shots* spatial interpolation methods are used. The basic role for interpolation in GIS is to fill in the missing data for those areas where the real world observations are note available. Furthermore, enriching the selected interpolation method with fuzzy logic aims to create a set of intermediate layers and to simulate the evolution of a geographic entity between consecutive *snap-shots*. This ap-

proach accomplishes the interpolation in various steps. In each step spatial entities may overlaps with each other, so that spatial objects may have fuzzy transition zones. The points might belong to multiple objects with different degrees of membership in each zone. For example the fuzzy spatial interpolation method used to model the gradual changing of rural to urban land-use between two consecutive snapshots is accomplished in three steps (Dragicevic et al., 2000). The first step is to determine the appropriate temporal resolution, which yields the exact number of intermediate layers. These layers correspond to the shortest possible transition time for each cell in the initial layers to change from one geographic class to another. The second step is to determine the generic layer, which contains the information about the change of spatial boundaries for the given number of temporal intervals. This generic layer is defined using standard GIS methods such as surface interpolation. In that study, the creation of the generic layer is performed using the inverse distance method. The third step consists of applying the fuzzy membership functions in order to generate the missing information about the change of the geographic entity for each cell of the initial snapshot layer. The membership functions are defined by using the semantic import model (P.A. Burrough, 1989) where the user a priori assigns the membership grade based on his experience or throughout the consultation with experts in the related domain.
In case of the example, the temporal resolution is 1 year and the generic layer created using two consecutive snapshots corresponds to the interval of ten years. Because it takes several

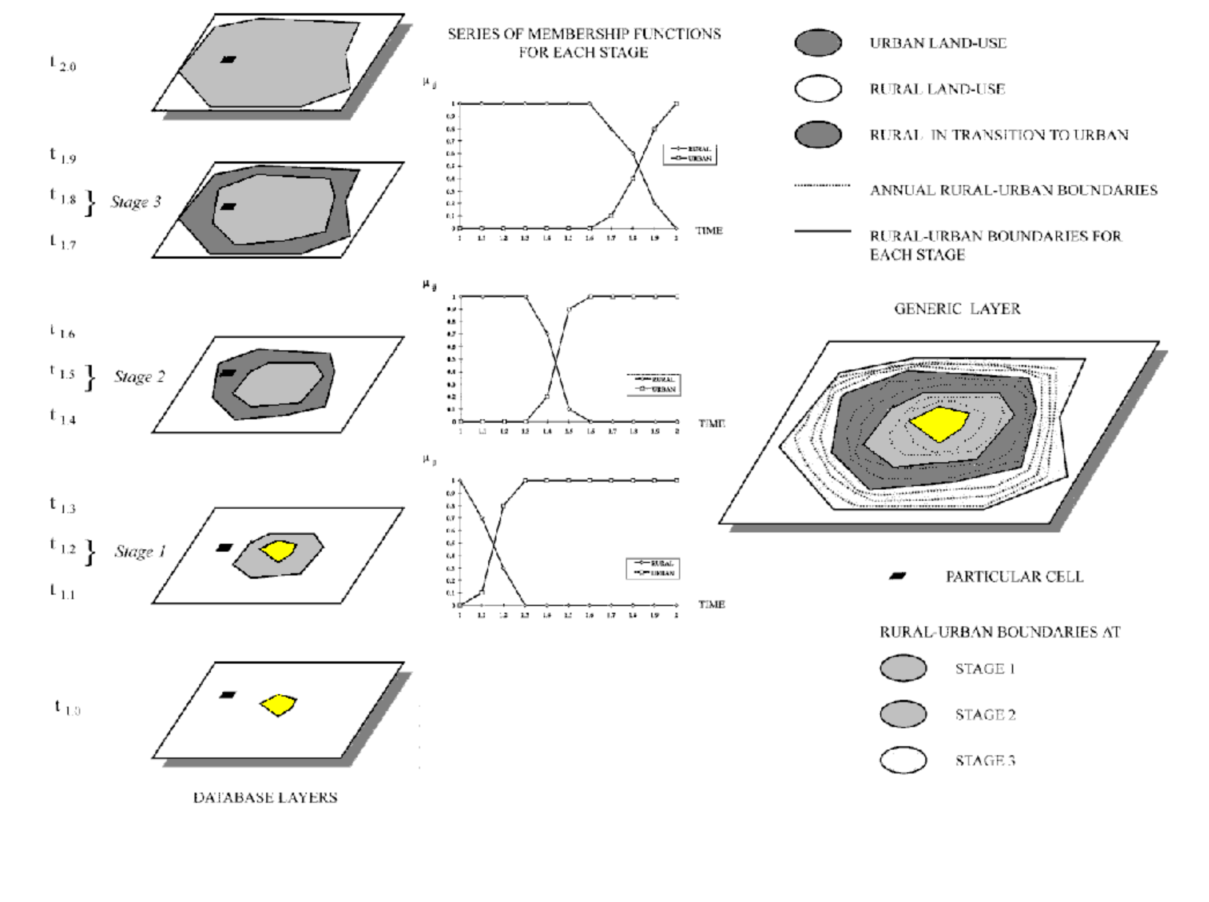

Figure 3

years for the process one part of the city to be completed, three transition zones are created each of one represents one completed phase of the urbanization process. When the cell value is the same between the time interval defined by time points t_i , t_{i+1}, the value of this element, will stay unchanged with the highest degree of belonging to rural or urban land-use class. If the value in the space element examined is different at the time t_i and t_{i+1}, this means that the

geographic entity is in transition. The value of the space element at time t_i indicates 1.0 membership to the class *R* named *Rural land-use* while the value of the same element at the time t_{i+1}, indicates 1.0 degrees of belonging to the class *U* Named *Urban land-use.* The fuzzy transition zone is created using the time interval of 1 year and the membership degree $C(t_i)$ calculated according to the fuzzy functions which model the transition between classes *R* (rural) and *U* (urban) between two known geometries.
Although the results of the above example were satisfactory, a major problem of the described method is that it assumes smooth distribution throughout each zone. However, in reality the hypothesis of smooth distribution is hardly accepted. One of alternatives to overcome the problem is to use ancillary data. If there is relevant ancillary information about uneven distribution, it is possible to utilize in order to make more realistic estimation for the data of each transition zone.

7. Fuzzy Interoperable Geographical Object (FIGO) principals

The previous review illustrates that fuzzy set theory can be successfully used in the processing of geographical information. Fuzzy set theory coupled with object oriented modelling, may compose a powerful tool with reasoning capabilities harmonized with the inherent properties of GIS. The basis of the object modelling is that crisp sets of objects can be used to model real-world phenomena. Similar objects are categorized into an object *type*, which is generally called *class*. The term *type* has been selected for the object data model whereas the term *class* has been used to define both object intent (structure and behaviour) and object extent (set of similar objects) (Valerie Cross et al., 2000). Objects have two primarily features: Object identity and object grouping. A real world entity has a unique identifier associated with it. This identifier can be value based, where the identifier is determined by the values of a set of its properties, or it can be independent of any of these values by using a system-generated identifier.
Object grouping refers to the collection of properties that are relevant to one real-world entity. These properties can be either attributes that describe the object itself or relationships between the object and one or more other objects. These attributes and relationships are specified in the definition of the type for the object.

7.1. FIGO Description

The complexity and the dynamic character of the natural environment require appropriate methods for its representation in GIS. A generalized spatio-temporal data model is required to deal with fuzziness and dynamics of objects. This need motivates the development of a spatio-temporal data model for objects with fuzzy spatial extent.
The basic idea of FIGO is to include all the prescribed methodologies as methods of an object with fuzzy spatial extents and to give interaction capabilities with other spatial or external information. Thus, the object may modify its characteristics and change its behaviour, according with the environments the object intends to represent. The results would be more impressive if the object has the capability to automatically generate its behaviour as this instructed from the inference engine of an embedded expert system.
Let $U_M = \{....,O_i,....\}$ be the universe of a map *M*, where the term *map* refers to a spatial database containing a terrain description and O_i ; $i=1,2,3...$ is a discrete spatial object, e.g., a polygon showing arable land. While U_M is the collection of all spatial objects represented in this database, it is possible to distinguish three types of statements with respect to the existence of the spatial objects:

- An existential statement asserting that there are spatial and thematic conditions that imply the existence of an object O_i.
- An extensional statement identifying the geometric elements that describe the spatial extent of the object.

- A geometric statement identifying the actual shape, size and position of the object in a metric sense.

These three types of statements are intimately related. The extensional and geometric statements imply the existential statement. If an object does not exist it cannot have a spatial extent and geometry. The uncertainty whether a specific object O_i exists can be expressed by a function of the form: $Exist(O_i \in [0,1])$. If this function has a value of 1.0 we are sure that the object exists, if it has a value of 0.0 we are sure that the object does not exist. This leads to a dilemma of how can we make existential statements about objects that do not exist, or rather how can we identify non existing objects and refer them as an argument of this function. In this case the existence of an object at a specific moment may be identified using relevant information from other sources, e.g., statistical or historical data that is usually called ancillary data. Thus, the *object type that belongs* to the *class* of FIGO must be a generalization of many different spatial *object types*.

If a real-world entity exists, or if there is information concerning the existence of this object in the past, then the object can be identified and created by adding or modifying the existing type definition.

7.2. A Case study

FIGO appears to be useful in monitoring agricultural activities and in creation of thematic maps. This is the case of the island of Crete in Greece, which has been selected to test the prescribed capabilities of FIGO. The physical problem consist of how to combine geographically statistical data, which is based on Corine Land Cover (CLC) database, along with the census data based on the Farm Structure Survey (FSS) data provided by Eurostat. This has been achieved by the development of a class of objects (FIGO) in order to display on a map accurately, the combined spatial descriptive statistical data along with the geographical information of Crete. Thus, FIGO provides the flexibility to combine statistical information from different sources in an intergraded geographical environment. This allows complicated analysis of potential scenarios to be carried out in a landscape study (Sambrakos et al., 2001).

7.3. Future work

The results and the experience obtained from the pre-mentioned work indicate the design and the development of a generic scheme. The properties and methods of this scheme must be linked with an embedded expert system, which will be based on multi-criteria rules. This scheme will provide a flexible framework to handle the uncertainty and the temporal component of spatial data. The conventional conceptual model of FIGO is summarized in Figure 4. The model assumes, that complexities of the real world can be handled using inherent features of standard GIS capabilities following the abstraction required by the application in which this object is used. Finally the representation of the environment this object intends to represent is influenced by the available data sets stored in one or more databases and by the set of stored rules and inferred conclusions in the Relational Rule Based Expert System (RRBES) (Filis et al., 2002). Each time a result is validated, then the inferred conclusions feed the expert system, as well as, the database with the new data sets. Thus, these data will be available in a new spatial process. The object may represent dynamic processes affecting the spatial and thematic aspects of individual objects and object complexes. Because the object explicitly stores changes with respect to time, procedures for answering queries relating to temporal relationships, as well as analytical tasks for comparing different sequences of changes, are facilitated.

For the validation of results, a six-step procedure must be followed:

1. Use of cencus or sampe data at specific area (Crete Island).

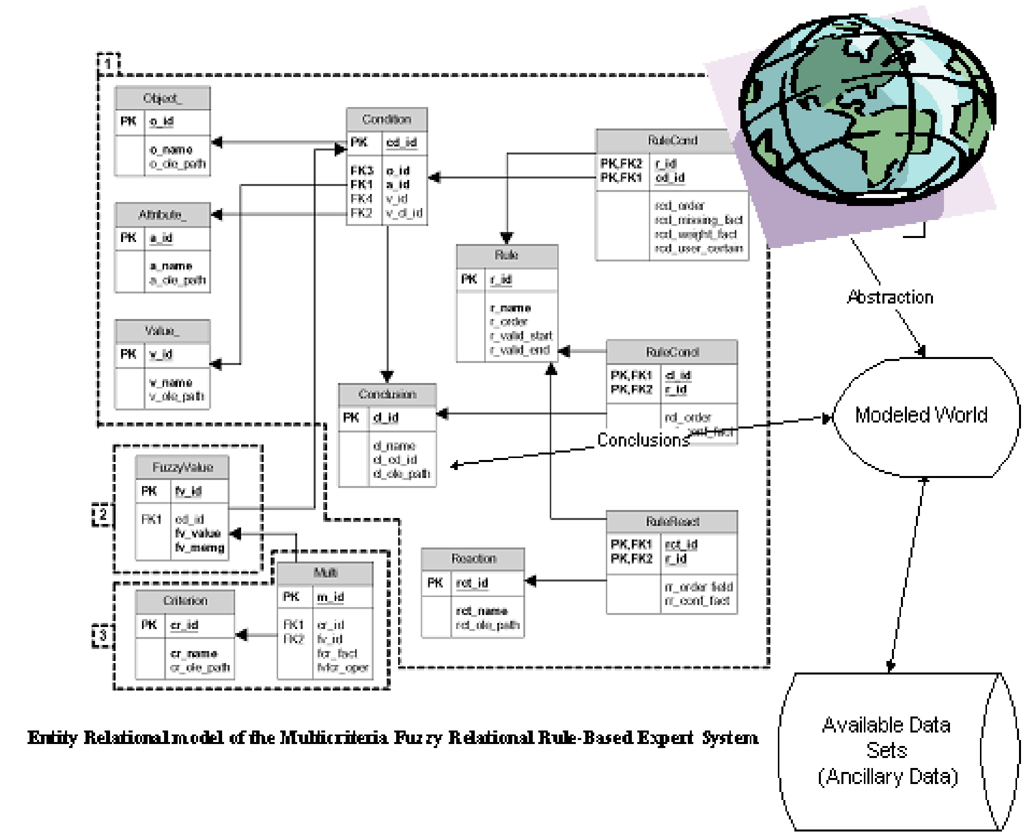

Figure 4. Conceptual model of FIGO

2. Interpolation of the observed data to generate a complete raster or vector covering for the observed area taking into account additional geographical, statistical or historical data.
3. Classification of all grid cells into pre-defined agricultural classes.
4. Aggregation of the classified raster into regions. Each contiguous set of grid cells belonging to one class will form a region that represents the spatial extent of a particular unit.
5. Merging regions that are smaller than a pre-defined minimum mapping unit size with an adjacent region.
6. Identification of objects represented by the regions and comparison with other sources (data from sample cencus) to validate the results.

Future work is to formalize the object model of FIGO and to validate the results using data from other sources in the agricultural domain. The uncertainty involved in the above steps will be investigated and their effect on the mapped objects will be analysed. The concepts of conditional spatial extent, conditional boundary and transition zones of fuzzy objects will also be examined. Using ancillary data results the *existential* uncertainty to be converted to *extensional* uncertainty. The proposed object class is a general one, from which other objects can be derived. It can support analysis and queries of time series data from varying perspectives through location-oriented, time-oriented, feature-oriented and process-oriented queries, in order to understand the behaviour of spatial features.

8. Conclusions

The work presented so far concerns the design and the development of the FIGO, which is an object model with spatial characteristics and fuzzy spatio-temporal extent. FIGO provides a standard way to handle spatio-temporal uncertainty using consecutive snapshots, ancillary data and rules stored in a multi-criteria knowledge base. The integration of fuzzy set theory and object data modelling provide many advantages such as transition zones between spatial

boundaries, generation of spatial data, dynamic control of the behaviour of spatial objects and monitoring of spatial changes over the time. An example of spatio-temporal interpolation and a geo-statistical application also has been presented.
Future work is to formalize the object model of FIGO and to validate the results using ancillary data as well as the conclusions inferred from a multi-criteria expert system, in the agricultural domain.

References

Baudinet M., Chomili J., Wopler P., 1993 *Temporal Databases, Theory, Design and Implementation*. Benjamin / Cummings, chapter 13

Burrough P. A., 1989 *Fuzzy mathematical methods for soil survey and land evaluation*. Journal of Soil Science 40, 477-492 pp

Couclelis H., 1992 *People manipulate objects (but cultivate fields)*: Beyond the raster-vector debate In: U. Frank, I. Campari and U. Formentini, editors, Theories and Methods of Spatio-Temporal Reasoning in Geographic Space (Lecture Notes in Computer Science Vol. 639). Berlin-Heidelberg:Springer-Verlag, 65-77 pp

Dragicevic V., Marceau D., 2000 *An application of fuzzy logic reasoning for GIS temporal modeling of dynamic processes*. Fuzzy sets and Systems 113, Elsevier, 69-80 pp

Duckham M., Mason K., Stell J., Worboys M., 2001 *A formal approach to imperfection in geographic information.* Journal of Computers, Environment and Urban Systems, no, 25, 89-103 pp

Dyreson C.E., and Snobgrass, 1993 *Valid Time Indeterminacy* Proceedings of the 9th International Conference on Data Engineering, 335-343 pp.

Filis I., Yialouris C., Sideridis A., 2002 *Rule-Based Valid-Time Expert Systems using Fuzzy Logic and Multicriteria Approaches*. Informatics Lab. Agricultural University of Athens. Submitted I-KOMAT2002.

Lorentzos N.A., Sideridis A.B, Yialouris C.P, et al 1999a *An integrated spatio-temporal system*. Elsevier, Computers and Electronics in Agriculture, 22 pp 233-242.

Lorentzos N., Yialouris C., Sideridis A., 1999 *Time-evolving rule-based knowledge bases*. Data and Knowledge Engineering 29 (3), 313-335 pp

Molenaar M, Tao Cheng, 2000 *Fuzzy spatial objects and their dynamics*, Journal of Photogrammetry & Remote Sensing, no, 55, 164-175 pp.

Sambrakos M., Fillis I., Tsiligiridis T. 2001 *Integration of Spatial Descriptive Statistical Data and Geographic Information*. Proceedings of 8th Pan-Hellenic Conference on Informatics, paper 91C, Nov 2001, Nicosia, Cyprus.

Valerie Cross, Aykut Firat, 2000 *Fuzzy objects for geographical information systems*. Fuzzy sets and Systems 113, 19-36 pp

Wang F. and G.B. Hall, 1996 *Fuzzy representation of geographical boundaries in GIS*, International Journal of Geographic Information Systems, Vol. 10, no, 5, 573-590 pp.