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An event-based archive of soft maps for the analysis of glacier changes

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Abstract

This paper aims to describe a system for creating and managing archives of thematic maps obtained by classifying remote sensing images by soft computing techniques. Unlike traditional spatial approaches, the main key feature for query formulation is time, thus improving the investigation on changes occurred in time ranges. Both the functionalities of the system and the data structure on which it is based are described. The system has been tested in the monitoring of Alpine glacier variations: the validation methodology and its results are illustrated as well.

1. Introduction

The study of Earth changes and of the effects of human activities on the environment requires tools to analyze modifications which occur in time ranges and are directly and immediately observable through remote sensed images. The development of such tools, however, depends on the definition of models for storing and retrieving images able to privilege a dynamic and careful representation of the events under study.

To this purpose, we propose a model that, unlike traditional Geographic Information System (GIS) models, is based on time as fundamental key by which spatial information is accessed: in this way, searching of changes through time is more effective and the monitoring activity becomes easier.

With respect to other time-based models (Peuquet 1994, Peuquet/Duan 1995, Yuan 1996, Carrara/Rampini, 1997), our proposal allows to manage remote sensed images classified by soft approaches, that assign more than one value to the pixels of the image to be classified, corresponding to the degrees of membership to more classes; in this way, also minority classes can be described, whereas they are usually lost

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with traditional classification methods based on hard methodologies (Binaghi/Rampini 1996).

The paper describes the proposed data structure and the characteristics of a prototypal system, GeoTemp, developed on its basis; furthermore, the application of GeoTemp to the monitoring of Alpine glacier changes are illustrated.

2. The time-based data structure for soft maps

Traditional GIS models are based on space as fundamental key, while time has a secondary role. Such models do not favour searches based on time which require a speed and easy access to temporal information, without the need of previously visiting associated spatial indexes.

Therefore some data structures propose to store time as first-level information to which the whole spatial data are related (Armstrong 1988). This results in a waste of memory: a good solution is represented by event-based data structures that store only changed information. Their purposes are: to encourage the emergence of time (the timestamps of stored events) as basic information; to record only occurred variations and their types (Yuan 1996).

The data structure we defined has one more new goal, i.e to manage, for each stored event, the information on more images corresponding to the classes of interest.
In fact, it was conceived to create and search archives of images classified with soft classification methods, which result in one thematic map for each considered class.

The structure is composed of four levels (figure 1): the first level is the event vector which stores the temporal information (timestamps) of considered images; each element of the vector points to two other vectors: the first one stores, for each class of interest, the number of pixels whose value of membership to the class itself increased with respect to the previous event (rise-vector), while the second one records the number of pixels whose membership decreased (decrease-vector). The third level hosts the variation table, accessed from the rise- or decrease- vectors: it supplies the coordinate values of the locations changed at given time, rising or decreasing with respect to the various classes; the membership degree of each changed pixel is at last stored in the classified image itself, in correspondance to the coordinates recorded in the variation table.

This data structure allows to archive, without waste of memory, only data regarding changes; furthermore its multi-layer approach is suitable to manage queries referred to variations with different effectiveness: you need only to access to the first level to know if any modification occurred in a given time range. Queries searching for the membership values of pixels to classes, on the other hand, are the heaviest with respect to resources, as they require the access to the deepest level of the structure. Queries about the number of pixels whose membership values increased or

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decreased and queries about coordinates of changed pixels, have an intermediate effectiveness.

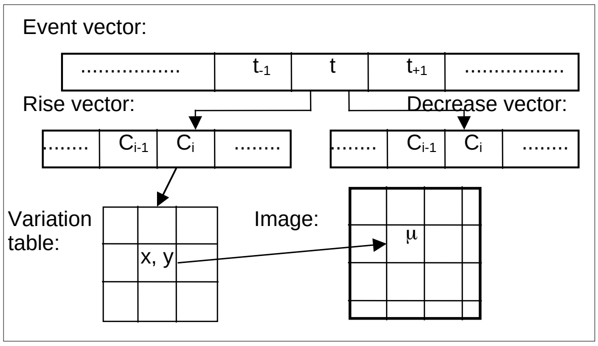

Figure 1
Schema of the proposed data structure; μ is the membership value of the pixel with coordinates x,y to the class C_i, which increased at time t with respect to t_{-1}

3. The system for change monitoring

The proposed data structure has been implemented in the system GeoTemp 3.00, developed under the Windows operating system; GeoTemp allows to create archives of maps classified by soft methods (Binaghi/Showengerdt 1996), and to express various kinds of queries, mainly based on temporal key, guided by a graphic interface; queries can be simple when they are referred to one class only, or composed if they combine investigations on more than one class. The retrieved results can be presented both in table and in image format.

It is possible to generate more than one archive, each one corresponding to a specific geographic area. Created archives can be updated or modified by introducing new data.

Seven kinds of queries can be expressed by the users, specifying parameters such as the first and last timestamps, the class to be considered (for each simpe query), the type of variation (increasing or decreasing membership), the minimum and/or maximum variation, the aspect, slope, and elevation.

The first six query types produce alphanumeric results (i.e. numeric scores, dates or tables); the last kind of query produces an image result.

The query elaboration requires the access to one or more of the levels of the defined data structure:

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- at the event vector level it is possible to know which dates are stored and, for each date, if it corresponds to any variation
- at the rise/decrease vector level, it is possible to know which classes varied and the sign of the variation
- at the variation table level, we know the number of pixels submitted to the variation
- at the image level, we know both memberships to each class and data regarding slope, aspect, elevation.

4. The analysis of glacier changes

An important application of the system is the analysis of annual Alpine glacier variations by means of archived soft maps from remote sensed images.

The hydrology of glaciated basins is controlled by the mass balance of the glaciers which act as regolators in the river regime. During the hot summers, rainfall and snow melting from glaciers supply water to the system, while, during the cooler summers, part of the remaining winter snow contributes to the accretion of the glacial mass.

The boundary between snow-free area (ablation basin) and snow-covered (accumulation basin) area is the snow transient line; at the end of the ablation season, this limit on the Alpine chain coincides with the equilibrium line, the height of which is directly related to the mass balance of the glacier. Investigating on a regional scale the annual changes of glacier areas and the position of equilibrium lines is extremely important not only for scientific purposes but also for short- and long-term planning of water resources.

The use of remote sensing techniques demonstrated to provide good estimates of accumulation and ablation basins. Several image classification techniques have been experimented and particularly accurate results have been obtained by using soft classification techniques, such as neural network and fuzzy statistical based approaches. Moreover, the degrees of membership to classes produced by this kind of classifiers, represent the percentage of presence of cover classes in the pixel (Wang 1990, Binaghi/Zilioli 1999).

In this context, a tool for the analysis of changes by comparing different percentage of covers may improve the accuracy in the evaluations of the glaciological and hydrological parameters.

In this application the interest lies in the evaluation of the amount of snow-covered and ice-covered areas, and their variations through the years. In particular it is important to know the amount of the glacier changed from snow to ice or from ice to rock or viceversa.

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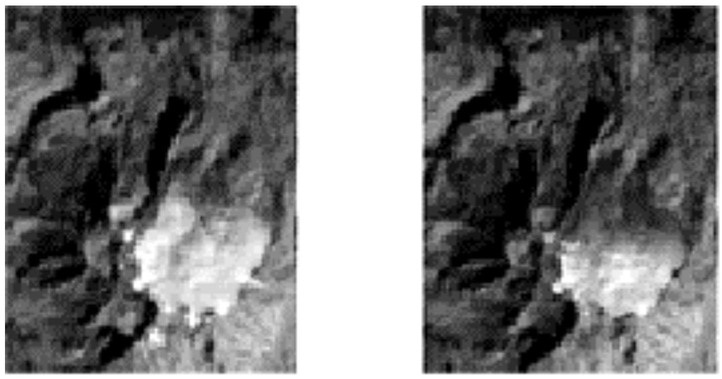
The GeoTemp system has been applied on glaciers of the Vedrette di Ries Group in the southern flank of the Eastern Italian Alps. In figure 2 images acquired on September 13, 1989 and September 24, 1991 are shown. The false color composition (band 5, 4 and 3 /red, blu and green) enhances snow-covered areas in white tone and ice areas in light grey tone; snow- and ice-free areas are in darker grey and black tones and will be considered here as a unique residual class named "Other". Variations occurred have been analysed with the following described methodology.



a b

Figure 2
The "Gigante Occidentale" glacier in Landsat TM images
of September 1989 (a) and 1991 (b).

Images have been classified by a fuzzy-statistical classifier (Binaghi/Rampini 1993) which provide for each pixel the degrees of membership to all three classes. These values can be interpreted as the percentages of coverage within the pixel.
Classified maps toghether with topographic data (elevation, slope and aspect) have been stored in the GeoTemp archive.

Simple queries have been formulated to search for variations of single classes in the time range from 1989 and 1991: in figure 3 graphic results of the search for variations of class Snow (a), Ice (b) and Other (c) are shown. It can be perceived that Snow decreased where Ice increased (in the boundary between ablation and accumulation basin) and the class Other increased where Ice decreased (in the lower front of the ablation basin).

By analysing numeric results of the previous simple queries (table 1) it can be noticed that both Snow and Ice decreased, i.e. the glacier decreased both in the accumulation and in the ablation areas; furthermore, the strong increase of Ice (583 pi-

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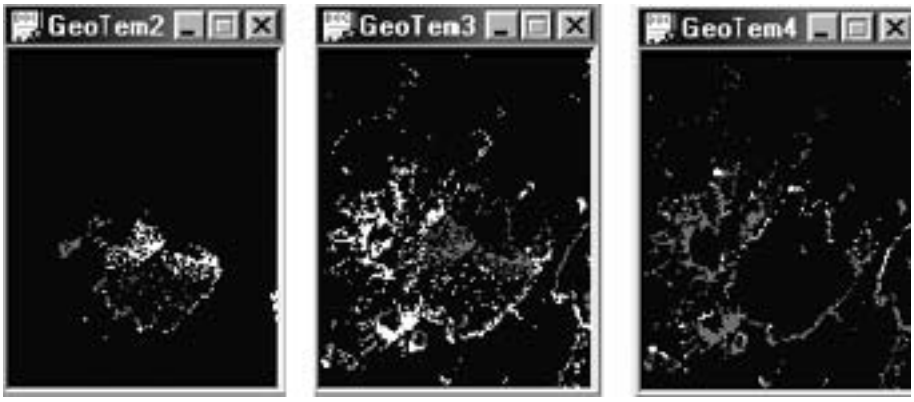
xels corresponding to about 0.52 Km^2) could be balanced by the retreat of the Snow (338 pixels corresponding to 0.30 Km^2) which causes the appearance of the underlying ice.



a b c

Figure 3
Graphic results of the search of Snow (a), Ice (b) and Other (c) variations (white=decreaseing, grey= increasing)

A composed query to search pixels in which the percentage of Snow decreased of the 50% and contemporary the Ice increased of 50% confirmed the analysis: the result is of 332 pixels on a total of 338 pixels in which Snow decreased, in accordance with the hypothesis that a part of the accumulation basin was transformed in ablation basin. The result of the composed query in image format is presented in figure 4.

Table 1 Numeric results of the queries

Class	Number of increased pixels	Number of decreased pixels	Prevailing expusure of increasing	Prevailing expusure of decreasing	Mean elevation of increasing	Mean elevation of decreasing
Snow	189	338	N	N-E	3076 m	2901 m
Ice	583	1247	N-E	N	2853 m	2887 m

Another composed query shown that, on a total of 1247 pixels in which Ice decreased, in 1056 pixels the class Ice decreased of the 50% with a gain of the class Other.

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Further composed queries using topographic data allowed to compute the elevation of the changes occurred, giving as results the location of the equilibrium line at 2900 m. according to the data measured by glaciologists during on field campaigns.

Figure 4
Result of the query showing pixels in which the percentage
of snow decreased of the 50% and contemporary the ice increased of 50%

5. Conclusions

The monitoring of variations by means of remote sensing images usually requires the use of different software packages and the production of an amount of intermediate results (of transformations, data exchanges, intermediate mask operations, etc.). Furthermore, new collected data or new analysis approaches, require a complete re-elaboration. The described experience shown that a time-based searching tool, like GeoTemp, improves the analysis of changes as it allows to flexibly inspect from various points of view the same set of maps with very easy tools and quickness, without generating intermediate data. Furthermore, it easily manages updating as new data are automatically accomodated in the corresponding archive, and are immediately ready for investigations.

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