Journal of Visual Languages and Computing 41 (2017) 54–69

Contents lists available at ScienceDirect

Journal of Visual Languages and Computing

journal homepage: www.elsevier.com/locate/jvlc

# Animated chorem-based summaries of geographic data streams from sensors in real time

Zina Bouattou[a,*], Robert Laurini[b], Hafida Belbachir[a]

[a] LSSD Laboratory, Computer Science Department, University of Science and Technology of Oran-USTO, Algeria
[b] LIRIS Laboratory, INSA de Lyon, University of Lyon, 69621, Villeurbanne Cedex, France and Knowledge Systems Institute, Illinois, USA.

ARTICLE INFO

*Article history:*
Received 20 March 2015
Revised 9 March 2017
Accepted 22 March 2017
Available online 7 April 2017

*Keywords:*
Geovisualization
Real-time
Geographic data streams
Sensors
Animated chorems
Spatial analytics

ABSTRACT

This paper describes a new visualization approach for the automatic generation of visual summaries dealing with cartographic visualization methods and modeling of real time data coming from sensors. Indeed the concept of chorems seems an interesting candidate to visualize real time geographic database summaries. Chorems have been defined by Roger Brunet as schematized visual representations of territories. However, the time information is not yet handled in existing chorematic map approaches, that is the issue been discussed in this paper in which geodata are coming regularly from sensors distributed along some territory. Our approach is based on spatial analysis by interpolating the values recorded at the same time, so we have a number of distributed observations on areas of study. To get a better visual overview of the entire sensor geodata at a given time, we use spatial statistics formulas on the fly, and so it is possible to extract important spatiotemporal patterns and detect trends over time as geographic rules. Then, those spatiotemporal patterns are visualized as animated chorems. An example is taken from meteorology.


## 1. Introduction

In today's society, the shared amount of information and data is significantly increasing, requiring a strong need for understanding. A direct projection of the geodata on a display surface does not make sense to mapping viewpoint. For this, methods and techniques for the representation and visualization grew into a new scientific discipline known as "*Visual Analytics*" [28] and more precisely in our case "*Geovisualization*"; this discipline utilizes intelligent tools that can help find needles in a big data haystack, using spatial relationships to filter relevant data. Geovisualization is defined by Kraak [30] and MacEachren and Kraak [39] as it "*Incorporates methods and the development of decision making techniques through spatial thinking, visualization, statistic analytics, analytical reasoning, synthesis and presentation of spatial data*". In addition, when it comes to real time data coming from sensors, here the complexity increases further. As visual presentation and analysis of these data are currently a very promising research topic [3], the scope will be not to determine the mapping once at all, but more especially to calculate it in real time in order to schematize evolution and to understand the structures in space and time. In this paper, our challenge is twofold:

- *Synthesized map*: essential information is displayed in a layout layer, which requires prior analysis to extract relevant information. The solution presented in this paper is called a chorematic map [13] in which both geometry and semantics are generalized; this solution has shown several successes as an efficient communication tool. In addition, for extracting salient features, a novel method based on importance functions is presented.
- *Animated real-time map:* a single map which shows changes discretely over time in accordance with the modification of the data results in motion or perceived changes in the object's appearance. In the presented work, as data streams come from sensors, it is necessary to implement an automatic and efficient solution for chorematic cartography without any expert editing.

In this paper, we are concerned with the concept of chorems as inspiration to propose a new approach for allowing the generation of animated chorematic maps, using the methods able to take into account the spatial and temporal distribution of structured data provided by sensors.

After briefly introducing the related works necessary for the understanding of our research, the proposed approach is detailed, followed by the implementation process. Along the paper, an example is used, based on meteorological data. Then we conclude with

* Corresponding author.
*E-mail addresses:* zina.bouattou@univ-usto.dz, zina.bouattou@hotmail.com (Z. Bouattou), Robert.Laurini@insa-lyon.fr (R. Laurini), h_belbach@yahoo.fr (H. Belbachir).

http://dx.doi.org/10.1016/j.jvlc.2017.03.002

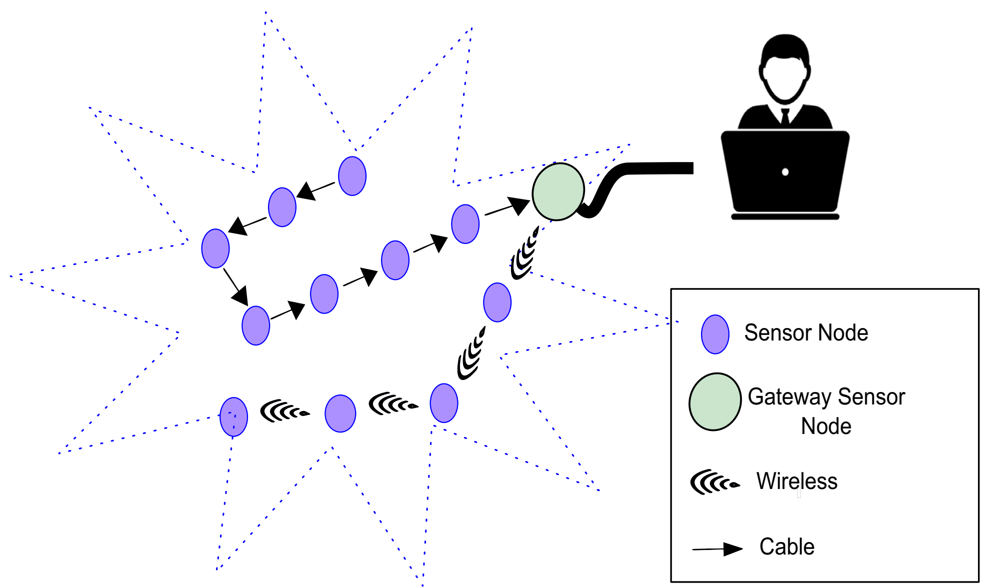


**Fig. 1.** Sensor networks architecture.

a discussion of the results and finally suggest some further perspectives.

## 2. Related works

In this section, we briefly discuss related works required to understand the background of our research, *i.e.* some reminders concerning sensor networks, data streams, geovisualization time, and chorems.

### 2.1. Sensor network and data stream

The specific characteristics of sensor networks and sensor data are going to be described in this sub-section. Sensors are electronic devices which can measure some phenomenon data, and are equipped with a communication system for sending data. Sometimes, there are cables for communication, but more and more wireless systems are used. Usually sensors are geo-referenced.

#### 2.1.1. Sensor network

The sensor network consists of an autonomous node set, battery-powered, randomly distributed in a geographic area that defines the territory of interest for the captured phenomena; each of these nodes has the capability to collect and route data either to other sensors or to some gateways [16,27] (see Fig. 1).

In addition, there are often controlled by a monitoring center. Sensor networks are considered as an intermediary between the physical and digital worlds, they are able to monitor in a continuous manner, a large variety of physical and environmental information such as temperature, humidity, pressure, pollution and even the heart rate of an individual, etc. Some of them are static and others can be mobile; in this case, they also send their variable GPS position. Sensor networks have various applications; for instance, they are used for collecting the information needed by smart environments quickly and easily, such as for weather in buildings, utilities, industries, home, and shipboard or transportation systems automation. Sensor networks are also useful in vehicle traffic monitoring and control, and for infrastructure security in critical buildings and facilities, such as power plants and communication centers [16]. The major challenge of a sensor network is to combine the sensing nodes in computational infrastructure. They are able to produce information from data obtained by the individual sensor nodes and to contribute to the synthesis and communication of spatiotemporal intelligent information.

#### 2.1.2. Big data streams coming from sensor network

Data streams coming from sensor networks are defined as "*sequences of ordered data (usually by arrival time), continuous and real-time*" [10]. They are different from conventional data, characterized by the spatial dimension of data which determine the sensor position, and the time dimension of the data which determines the moment of shared sensors measurement. Both are carriers of information and play a crucial role in the information synthesis. However, the real-time data streams are not easy to retrieve and to process. Few software products and applications dealing with such data due to their continuous nature and volume and all in real-time, manage such data in a workable set of constraints and challenges. While providing data with unparalleled temporal and spatial resolution, sensor networks have overcome the frontiers of traditional geographic information science research into the realms of data analysis. Higher-level spatial and temporal modeling need to be imposed in parallel, so that users can effectively exploit their perspective [44]. Retrieving spatiotemporal information in a sensor network, perhaps with data mining [43] or statistical time series analysis, will bring numerous computational challenges and opportunities [1,30,40] for collection, storage and processing. These challenges arise from both accuracy and scalability perspectives. Statistical analysis of a time series of sensor data can be simply descriptive. It is then to identify synthetic elements that summarize best the observed size or exhibiting certain characteristics (mean, standard deviations, etc.). Indeed for such data, forecasting remains a major objective of the study of a time series. In it, were treated filtering and control aspects related to the study of dynamical systems (trends, derivatives, etc.). This is to assume that the same causes produce the same effects. Thus, one of the features of temporal series is to create links between the acquired variables to make comparisons and autocorrelations in order to detect patterns and seasonal variation or to deduce unusual behavior; this provides additional information necessary in order to refine the seasonal values and to understand their evolution over time. Thus, it is possible to analyze the interactions between different variables in the time series in order to detect possible trends.

In this paper, we exploit the challenges for real-time tasks and dynamic geovisualization. First, the visual analysis of real-time data from sensors is developed in the following sections.

### *2.2. Geovisualization*

In this section we briefly present geovisualization and its background.

#### *2.2.1. Cartography, GIS and geovisualization*

Cartography is an ancient discipline developed from the practice of making maps, combining science, and complex techniques in an effort to portray the world accurately and effectively convey information to the map-reader [22]. Indeed GIS (acronym of Geographic Information Systems), were developed much more recently as software systems designed to perform a wide range of operations on geographic information. The two fields (cartography and GIS) have converged becoming an expanded digital technology; GIS opens up new possibilities that offer to escape many constraints from manual map-making operated. Cartography is both an art and a science, but GIS evolved as a digital analysis approach what is observable and measurable on the surface of the Earth. From decades, it has been recognized that cartographic scales demand data with different accuracies. See the seminal paper written by Douglas and Peucker (now Poiker) [20] on cartographic generalization. Since, many works have been carried out in this domain and comprehensive surveys were written by Spiess [55] and Weibel [12].

Many researchers have found the traditional term cartography too limiting as a description of this new, much richer world, and begin to describe their field as geovisualization. Geovisualization [30,39] is considered as a means of representing spatial information visually in a way that allows people to explore, synthesize, refine, analyze, and communicate conclusions and ideas. Geovisualization is much more than cartography since it includes other methods to represent the geographic reality for decision-makers in the spirit of Visual Analytics [57]. Visualization of geographic data is essential to allow a human analyst or a user understand the data in space, extract relevant and important information, and derive knowledge [21]. It is generally recognized that visual displays facilitate the efficient perception and cognition [41] the promoting of ideas [5] and the support of analytical thinking [57] for efficient decision-making.

#### *2.2.2. Geovisualization and visual analytics*

An existing visualization approach involves the direct representation of each record in a set of data to enable the analyst, to extract remarkable patterns, watching the displays and to interact with them [7,14]. However, these techniques may not be effective when applied at considerable and complex data sets that are increasingly common. Users may also have difficulties in collecting, monitoring and understanding many visual elements that change simultaneously. But the speed in which graphics are displayed and in which responses to user interactions are solicited may become too slow for efficient comprehension and cognition. To overcome these drawbacks, the main goal is not to return exactly some visualization of geographic data with a high level of details, but rather to show the most relevant aspects of the phenomena. Such spatial curiosity led directly to new ideas; other visualization methods emerged known as "*Visual Summaries*" [18,35] of datasets that will help an analyst find what the more important is out of the mass of available information, and to answer queries quickly and efficiently. By facing this challenge, several approaches have been proposed in the literature in which we can note some of them such as: approaches with direct representation using data aggregation methods and summaries before visualization on map [7]. Thus one has to consider approaches that apply more sophisticated computing techniques such as spatial data mining [53] to extract semi-automatically or fully automatically specific patterns from geodata before visualization.

One method that is the subject of this paper is more common in the world of cartographers and recently has been improved in terms of computing and semantic under the name of "*Chorems*" [13] which will be developed in this paper thereafter (Section 2.2.4).

#### *2.2.3. Geovisualization and time*

Spatial analysis and process data are both sustained by the fundamental concept of the spatial dependency, which is often referred to as the first law of geography; "*Tobler's first law: everything is connected to everything else, but near things are more related than distant things*" [58]. According to this law the characteristics of nearer places tend to be correlated. In statistical terms, this is called spatial autocorrelation. Similar concepts of time dependence and temporal autocorrelation exist for relations in time. Integrating the time in Geographic Information Systems has been studied in the research literature since 1990s [47,31]; especially in cartography, several methods have been developed to represent geographic information in space and time [59]. However, the methods used in geovisualization are limited to small amounts of data and some units of time. In the case of a large volume of data that changes frequently over time independently of the presence of a spatial component, the fact that data changes over time is a challenge for many disciplines related to visualization and data analysis. Visual methods were found to be useful in the analysis of time-related data, other interactive techniques and visual analysis tools as statistical analysis and data mining [4,5] for spatiotemporal data have been designed, developed and evaluated mainly in the field of geovisualization [2,6,19]. The preferred output of real-time visualization, among the visualization systems, is the animated map [24]; it is becoming a standard approach to represent data with time and dynamic phenomena [3]. Animated map is considered as a simple way to present the evolution of an object or process in the territory. Especially the animation in real time mapping should be investigated, including:

- Cognitive aspects of decision-making in real time;
- Graphic semiology for the animated mapping;
- Automatic selection of relevant data to synthesize information for policy makers.

Another well-known technique is the Space-time-cube implementation of visualization in time [23], which examined time and space are inseparable and which suggested a three dimensional representation in which two dimensions represent the space and the third dimension represents time. The reader can consult the following references [3] for a comprehensive review of the existing visual analysis methods, tools and concepts of discrete objects emphasizing spatiotemporal data.

#### *2.2.4. Geovisualization with chorems*

In the last few years, much work has been done on the chorem concept and on its exploitation as an appealing visual notation for communicating geographic information, especially for communicating highly synthesized and aggregated concepts. The neologism "*chorem*" composed of the Greek word " $\chi\omega\rho\alpha$ " meaning space, territory, place and the suffix "- $\eta\mu\alpha$ " meaning "*em*", such as in the word "problem". As defined by the French geographer Roger Brunet, who invented chorems, "*a chorem is a schematic representation of the territory*" [13], or in other words, a chorem can be considered as a sort of synthetic vision or a caricature emphasizing salient aspects. More precisely, in this paper, a chorem is

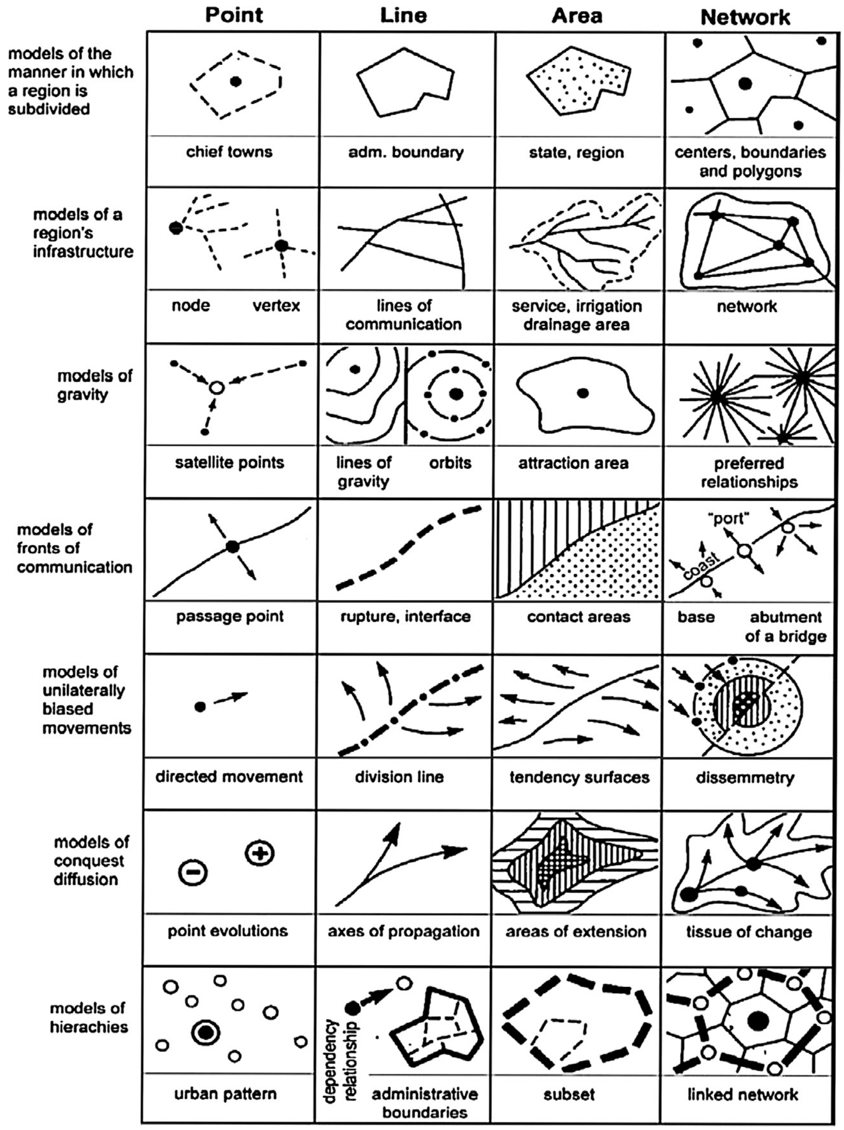


**Fig. 2.** Original chorems proposed by Brunet.

defined as a geometric and semantic generalization [55] of a territory. The main advantage of chorems is to facilitate the comparison of spatial systems thanks to a simple representation of complex organizations. Fig. 2 shows the original table of chorems created by Brunet [13]; he developed classes for spatial structures and processes along with a specific way of rendering them graphically. Brunet differentiates between seven classes of basic spatial configurations that take different forms for point, line, area or network-based embodiments of these configurations. Each one is linked to an associate and indexical sign for the respective structure or process.

In the other hand, only a few works have been interested in the use of chorems in the meteorological context. Only Brunet in his paper, references chorems [13] presented visually in a spatial arrangement as a climatic asymmetry of an *Island* where he highlighted the parts of space where the wind is wet and temperate and/or the wind is cold and dry. Also an example of the *Hokkaido* town for the representation of atmospheric-oceanic flows, and another example is given in which the author showed that chorems can be a gradient or asymmetry in latitude, and represents the sunniest places, the coldest places and mist in the country of *Poland* [13].

Chorems have been used a lot in social geography, a famous example that called “*blue banana*” (see Fig. 3) [50]; this presentation highlighting the main axis of economic and social development in the European Union, and the fact that *Paris* is in danger of being excluded [50]. This shape depicting the major economic growth corridor of the European Union is a very good example to demonstrate the effectiveness of the use of chorems.

In addition, in the IT community, chorems also are used both in terms of applications and semantics as they are extensively discussed in [18] in which the author provides a thorough study about the history of chorems usage, from Brunet’s definition [13] to the more recent applications [29,35,15,17,18,50]. In [29] authors propose chorems that can help in presenting highly generalized route information to better model human navigation, they use the term “*wayfinding choremes*” as established by *Klippel* [29] and is inspired by but does not work with chorems above (see Fig. 2). In [50], authors use the term chorematic schematization to refer to the cartographic generalization processes.

In the more recent years, much work has been carried out about chorems as visual summaries of geographic databases providing a novel definition and classification of chorems, in order both to standardize the construction and use of chorems, and to

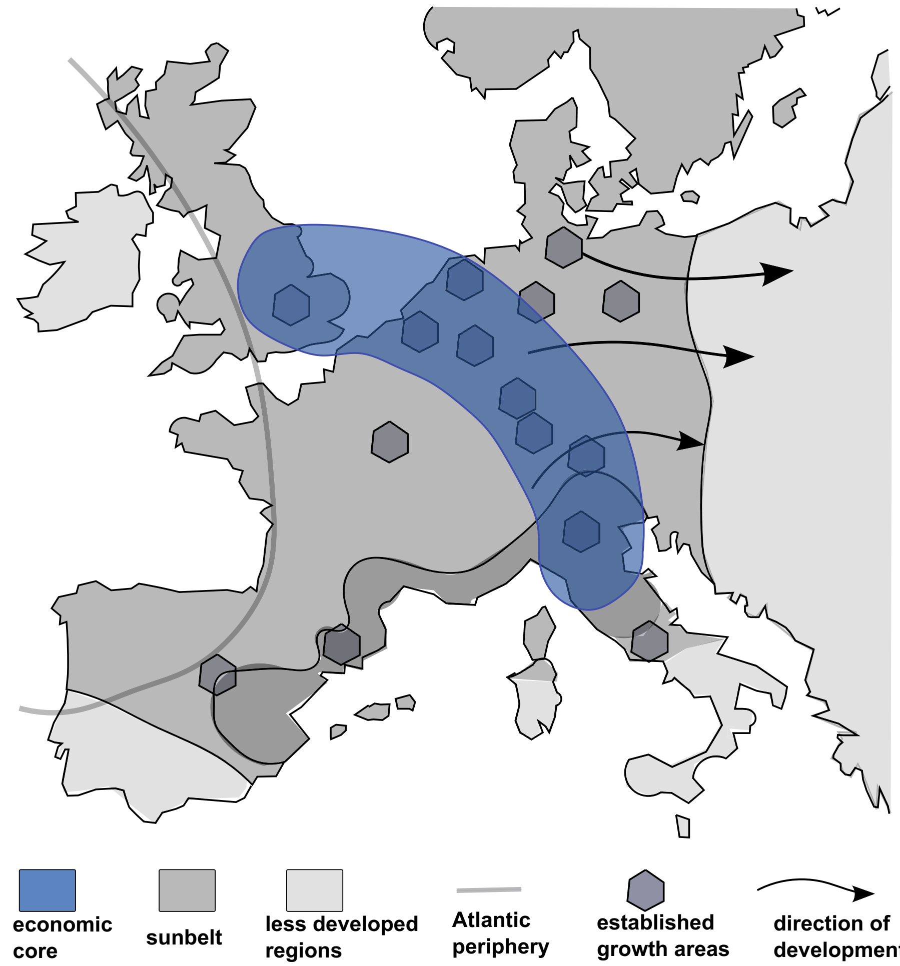


**Fig. 3.** Chorems example: The '*Blue Banana*'.

provide a useful framework computer system [18,35]. In [17] the authors enhance the role that a chorem map may play in geographic domains, by extending the semantics associated with it through a more expressive visual notation.

In particular, by adopting the revisited Shneiderman's mantra, namely "*Overview, zoom and filter, details on demand*" [18], they allow users to acquire information about a single phenomenon by accessing data characterizing it from the underlying database. More recently, Cherni et al. [15] have proposed some methodological aspects to automatically extract chorems. In addition, [32] includes chorems as possible methods to represent visually geographic knowledge. *ChEViS* [18,35] was the system resulting from the project launched between the three international research institutions, (Institut National des Sciences Appliquées of Lyon, France, University of Salerno, Italy and Tecnológico de Monterrey, Campus de Puebla, Mexico). That project aims at defining a novel cartographic solution able to synthesize the content of geographic databases, and represent them in a readable and intuitive map. Fig. 4 shows the resulting chorematic map displayed by the *ChEViS* system [18] where the green arrows represent migrating people flows, and labels represent city and macro-region names. This chorem was the result of two processes, (1) discovering and constructing important region by clustering, (2) taking only the more important flows.

Visual summaries based on chorems can be considered as a specific type of thematic map with a higher degree of generalization and abstraction. As previously told, generalization is a cartographic process but not the only existing cartographic process [12,55]. Thematic map and visual summaries can usefully be differentiated by examining the detailed level of the map. A thematic map represents phenomenon with details, it is built from precise measurements, in which the contours and thematic characteristics are presented as precisely as possible; usually a thematic map belongs to a set of maps, sometimes an atlas. Whereas a visual summary is a filtering process of weighted elements by the degree of semantic importance over a territory usually coming from different topics and more highly generalized geometries displayed then thematic map to comparable scale. In other words, a summary synthesizes several thematic maps.

But in geographic applications in various domains, the context of continuous fields was not yet explored and must be examined in the next section to see whether the theory of chorems can be useful.

### 2.3. Continuous fields

Continuous fields represent phenomena that influence the normal status of some environment [33]. A field is commonly associated to any phenomenon which can be represented mathematically by a function over space and time. Pressure, temperature, and heat source such as sun exposition are all examples of continuous fields. In GIS applications, continuous fields measure and model a field; we usually first identify the spatial component (the element of the domain) and then associate the field value. A basic requirement is then represented by users' capability to capture some features of a scenario, by selecting an area of interest and summarizing the het-

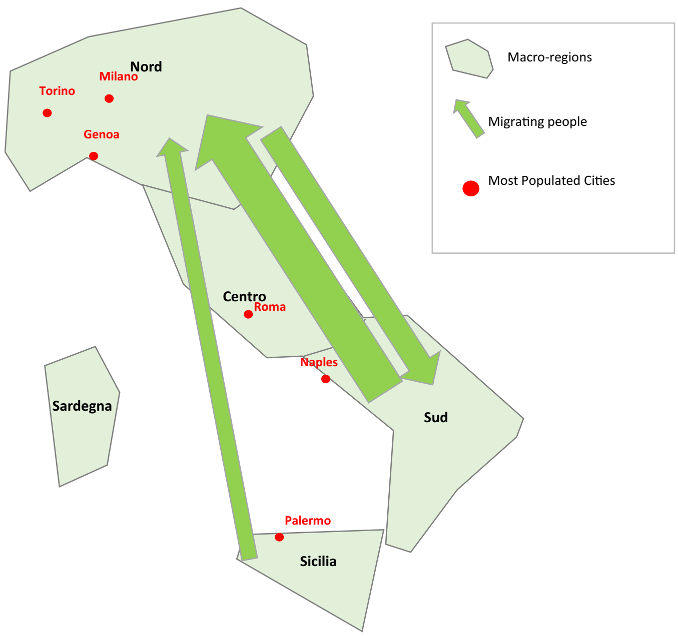


**Fig. 4.** The chorematic map showing the flows of migrating population among macro-regions in Italy.

erogeneous involved events. In order to both derive a functional structure and represent the corresponding phenomenon, an interpolating function is applied to a set of selected samples. Formally, a continuous field *cf* is defined as follows:

$cf = (Df)$ where

$D$ is the continuous field domain (space), and time

$f$ is the function representing the continuous phenomenon.

The geographic phenomena that we choose to model by continuous fields, allow us to focus on fields, where:

$D \subseteq R^3(x, y, t)$ *and*

$(D) \subseteq R^2$

As an example, let $\theta$ represent the temperature field, and $p$ indicate a position in a city (the domain of interest), then $f(p) = v$ corresponds to the temperature value in $p$. But, in the case of winds, $(D) \subseteq R^2$.

In practice, only some samples are known (in our cases, measuring stations). In order to establish a method to evaluate the field values everywhere, some interpolation techniques will be used. Mention that spatial interpolation [9] is a mathematical tool that can be used in the study of a natural phenomenon that unfolds in space. Concerning the spatial interpolation in real time based on the sensor geodata stream, *Nittel* and her colleagues [45] have addressed this topic of research for effective interpolation that was generated in real time; especially when it comes to critical real-time to achieve real-time performance in a sensor from data stream environment. In addition, in [37,38] the authors are based on real-time interpolation method to generate visualization and exploration improvements of precipitation and temperature data in web-cartography. Different univariate and multivariate interpolation techniques are applied to determine the spatial distribution of these data, in space and in time. In our context, one must redesign spatial interpolation methods in order to deal with in a very short time; in any case all must be done before the arrival of new data. In our case, since we work with a soft real-time context [34], these constraints must be easily followed (critical cases corresponding to hard real-time are not addressed in this paper as for example in military or nuclear plant applications).

### 2.4. Visualization for meteorological data

Moreover regarding the visualization of meteorological data, a number of systems have been developed for the visual exploration of meteorological data in both operational and research environments; [48] contains a thorough overview of the state-of-the-art approaches. These systems provide varying levels of user control for selecting which fields to visualize and how to encode them, some dealing solely with gridded information, such as forecasts, while others integrate point-based observational data, as well as real-time satellite and radar data [56]. Alternately, Ware and Plumlee offer a range of design alternatives perception motivated to encode meteorological data [60]. Similarly, the meteorological data visualization is difficult and often involves reducing the size of data as visual summaries that contain important features of the original data, and exclude unnecessary details. Therefore, in [49], the author presents the generation of visual summaries for forecasting that put the focus specifically to probabilistic characteristics of the data set.

### 2.5. Research overview

Until now, in an existing chorematic map, the time usually is a forgotten dimension because few representations of chorems carry information about temporal changes; however, in Brunet's classification, some chorems show some dynamics statically. This led us to investigate the use of chorems in the IT and geographic fields, which highlighted the lack of a rigorous approach to the creation of real-time chorems. The research questions are now: "How to automate the map production process using real-time data? How the dynamics of spatially-extended phenomena can be adequately expressed by means of an animated chorematic map? So can we extract chorems from spatiotemporal data coming from sensors? How can we visualize them in a comprehensive way, according to time?" The challenge in this paper concerns the special case of dynamic spatiotemporal data coming in real time, which requires effective methods based on the previous considerations.

In this paper, the real-time mapping is oriented to meteorological data. The automated mapping process will be implemented in a prototype application based on the synthesized based chorematic mapping modeling, as it can help decision makers in their task to monitor developments and real situations of significant event. To this end, the cartographic update must be synthesized, schematized, and easy to understand. Data visualizations are required with which decision makers can constantly reassess real meteorological situations. With the integrated approach presented here, various processes consist of several steps setting up. These steps include data loading and cleaning; data transformation and pre-processing; extraction and visualization of patterns, mapping to examine the spatial distribution of the discovered important patterns. Remember that usually, weather observation is shown as animated images done mostly off-line and then presented with human supervision. Our goal is not to generate a new type of off-line-generated animated images, but really to compute and show them in real time on the fly and without human intervention.

In the following sections, we will deal with these questions and introduce a new approach for generating automatic visual summaries from located sensor-based data streams with animated chorematic maps.

## 3. Proposed approach for generating real-time chorems

In order to explain our approach, an example will be taken from meteorology. It should have been interesting to work with very time-critical applications such as in the monitoring of nuclear plants, but in geography usually phenomena are slow (it is not

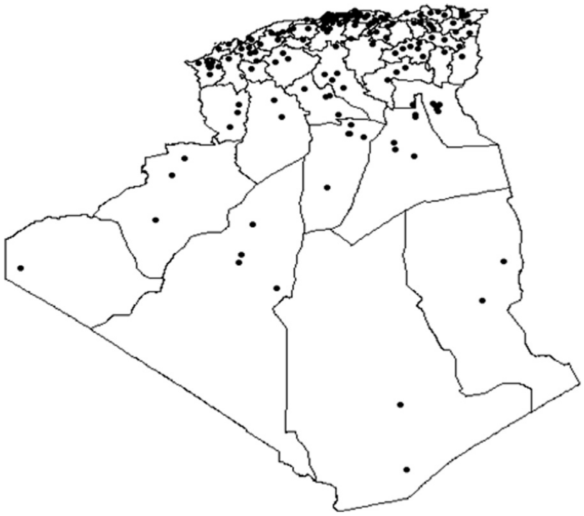

**Fig. 5.** Map of sensor location in *Algeria*. The lines inside Algeria denote administrative subdivisions.

necessary to measure temperature every second!). In other words, processing time is not very decisive, but anyway time constraints must be followed. In this section, first the application domain will be detailed. Then the global methodology of extracting spatiotemporal patterns will be presented and of visualizing them as animated chorems.

### 3.1. Data acquisition, storage and access

The data sets used in this work are coming from *OpenWeatherMap* API [46]. This API provides access to weather sensor stations that are directly connected to the Internet and enables us to collect high frequency updates from potentially hundreds of thousand sensors deployed over a larger area. We used altogether, 180 stations distributed in the region of Algeria (18.97°N, 37.09°N Latitude and −8.66°E, 11.98°E Longitude). Fig. 5 illustrates the provided station point coordinates distributed onto a plane surface using black dots.

The scenario acquisition is described as follows:

1. The sensors $u_i, i = 1, \ldots, C$ are identified by a progressive number within the network within $C$ sensors and are using geo-referenced coordinate points 2-D (latitude and longitude);
2. The number of sensors that acquire data may change over time: a sensor can be temporarily inactive and will not acquire any measure for the time interval corresponding to inactivity; in this paper the anomaly of blocked sensors sending always the same values is not considered since specific methods exist to detect them;
3. The recorded elevation information (altitude) is not yet considered within our approach. It is known that elevation is important to interpolate meteorological phenomena. See for instance [54]. In our case, in *Algeria*, the *Atlas Mountain* is a sort of barrier between the northern (the more populated area) and the southern part of the country (beginning of the Sahara desert). As a consequence, interpolation between North and South must take this barrier into account.
4. Active sensors acquire data stream for each climate variable noted $Z$; which $Z$ may be a few values such as: temperature, humidity, pressure, speed and direction of wind, the presence of clouds and precipitation.

This scenario is used to represent data from sensors that are time-stamped and all geo-referenced, within an interval of time equal to a period $P$ in the time line fixed at 30 days. Hence, data that are acquired from a network of sensors $C$ in the period $P$ produce a geographic data stream.

Each of the stations contributes from the *OpenWeatherMap API* to an *XML* file on current meteorological conditions; this file is updated every time the station sends a new set of observations. There is currently no direct method to retrieve these conditions concerning several weather stations; they are individually accessible via an *URL* that contains the *ID* of the station of interest. To create a complete set of meteorological observations for *Algeria*, which can then be analyzed, a small *Java* program was developed to collect data streams from several stations iteratively and periodically each fifteen minutes, and the observations are then stored in a PostgreSQL/PostGIS database (See Fig. 6).

Before the insertion into the database will occur, data are checked and cleaned (e.g., duplicate measuring time, type of data such as text or number, outliers). If the data fail to meet these conditions, either no data or pre-set values are replaced. So we had to consider a degree of confidence that data in real time when used for filtering, sorting and comparison with the historical data.

In this paper, an Inverse Distance Weighting Interpolation method (IDW) is adapted to estimate the value of the unknown field at any location and at any time. Through the search for an analytical grid by interpolation methods can be detected peaks and holes, we aimed to show the possibilities offered by the static spatial analysis tools for complex interactions in the explicit geographic area. The choice of the method of inverse distance (IDW) is motivated by comparative study in [36]. This study concludes that deterministic methods, in particular the Inverse Distance Weighting method is considered as a relatively quick and precise interpolation. Specifically, simplicity, computational speed, and ease of programming, and acceptable results for many types of geographic data are all elements that led to the approach widely adopted in several geographic applications.

### 3.2. Proposed architecture: methods and realization

According to the scenario of the architecture of our proposed system (Fig. 7). It is important to note that the chorem structure is handled by both major process, namely the extraction process and the visualization process. So, the user sends a request via a user interface asking for the animated chorematic map of the current time. The second step concerns the extraction of spatiotemporal patterns from a large set of sensor data coming in real time, this process concern semantic aspect. For this reason a system of procedural data filtering, sorting, aggregating, to reduce the number of significant patterns from a large set of sensor data coming in real time in the form “summaries” that contain important characteristics of the original data, and exclude unnecessary detail (semantic process). The former is meant to derive and manipulate the information from available data sets on the fly; the latter handles such information by attributing it visualized in terms of animated chorematic maps (geometric process).

#### 3.2.1. Definitions

First, let us give some definitions:

a) *A geographic data stream* is the sequence of data that arrive sequentially from the $C$ sensors, almost instantly, in consecutive time instant $k$ to geographically describe the values of $Z$ [8]. The flow of acquired geographic data cannot be fully recorded for later analysis, because of their huge volume, or the keeping of seasonal trend over time; an approach to deal with this kind of measurement is based on the use of sliding temporal windows.
b) *A model of Sliding Temporal Window* is the simplest model to consider the more recent data of the stream, and run queries

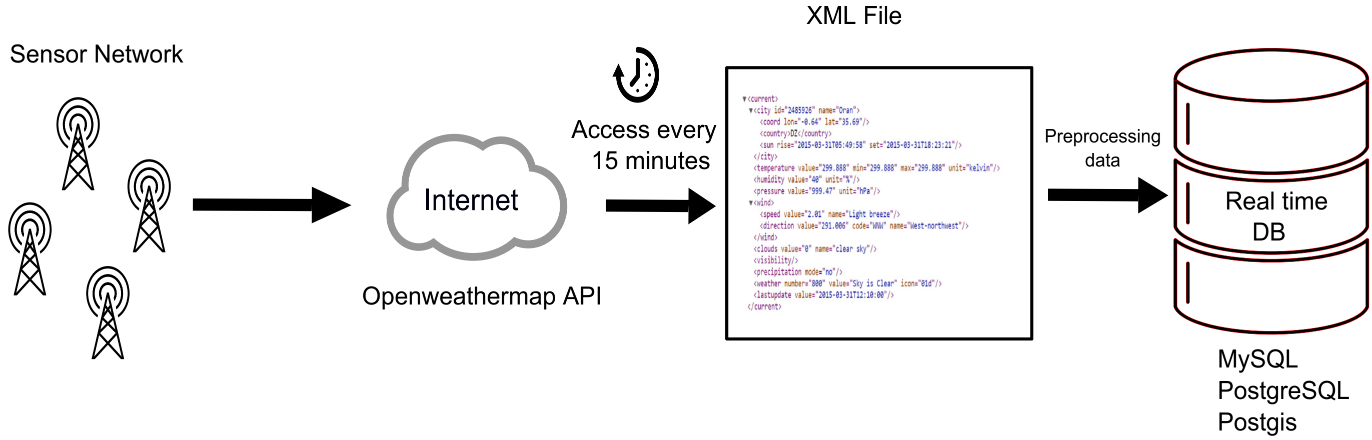


**Fig. 6.** Real time acquisition data process.

against them. This type of window is similar to that of the first-in first-out data [8]. When a given instant is inserted into a new window, another window with instant *k-p* is cast, where *p* is the size of the model window. Let us call snapshot all the data used in a sliding window (see Fig. 8).

c) *Spatiotemporal patterns*: according to [26], Temporal and Spatial Patterns are temporal relationships and spatial patterns that may be revealed through timelines and maps. Changes in pattern, surprising events, coincidences, and anomalous timing may all lead to evidence recognition.
d) *Important Spatiotemporal patterns*: in any domain of the reality, many patterns can be discovered. But in order to schematize a territory, only a reduced number of patterns must be considered. So, important patterns will be defined as interesting patterns which are either very rare or the background (cause) of other patterns.
e) *Rule defining the important patterns:* this rule aims at discovering important spatiotemporal phenomena. In our case, those rules will be specialized to discover important patterns in continuous fields stored in very large databases.

Once prerequisites are established, we can specify how chorems are extracted (Section 3.2.2) and visualized (Section 3.2.3).

### 3.2.2. Chorems extraction process

The whole process starts by taking into account data streams coming from sensors networks in real time. In order to extract chorems we begin to define the function of "*Importance*". Importance function is based on filtering data between ranges of values. The first step of our summarization framework applies data reduction operations, filtering and sorting important parts only. Indeed the distribution of meteorological parameters on the long term is following some statistical distribution that is to say that we can reach a long-term average. In a statistical distribution, the various measures are distributed according to a *Gaussian* function. The objective of our approach is therefore to describe the data by calculating descriptive statistics (*e.g.* average, variance) and more precisely moving average and variance from sensor time series. The moving average is applied in the time series data analysis, allowing the suppression of fluctuations in order to highlight trends in the long term. This approach tends to smooth the studied phenomenon by drowning extreme values in a mass of data more representative of an average trend. Fig. 9 describes the extraction chorems process.

In order to avoid expensive calculations, among others a solution must be found taking into account the contribution of what goes in and out without having to recalculate these parameters (mobile means and variances) at each iteration; in other words, for each snapshot these parameters will not be recalculated completely at every arrival of a new observation, but incrementally and online. Thus, we take care of seasonal effects by limiting research data passed to a window (±30 days) from the date of the test. For example, if one wants to visualize chorems of the date of February 1st, 2016, one will limit the flow of data to be analyzed during 30 days, meaning that the statistical calculations begin with the date of January 2nd, 2016.

Let a time series $S$ coming from sensors $C$ over a period $p$, between $k$ and $k+p-1$, $k \in T$

$$S = x_k, \ldots, x_{k+p-1} \tag{1}$$

Suppose a new value $x_{k+p}$ arrives at a moment $p+k$ from sensor $u_i, i = 1, \ldots, C$

For the filtering process, firstly, one needs to calculate the moving average $\mu_{k+1}$ at time $p+k$ depending to $\mu_k$ at time $p+k-1$:

$$\mu_{k+1} = \mu_k + \frac{1}{p}\left(x_{p+k} - x_k\right) \tag{2}$$

Then we calculate the moving variance $\sigma^2_{k+1}$ depending of $\mu_{k+1}$, $\mu_k$, and the new arrival values $x_{p+k}$ :

$$\sigma^2_{k+1} = \frac{1}{p-1}\left(\left(x_{p+k} - \mu_{k+1}\right)^2 - \left(x_k - \mu_{k+1}\right)^2\right) + \sigma^2_k + \frac{p}{p-1}\left(\mu_k - \mu_{k+1}\right)^2 \tag{3}$$

Remember that we only want to display salient features or important aspects. For that, we need to define a criterion to identify whether a feature is important or not. A discussion with a specialist in meteorology led us to adopt the following considerations[1] (See Fig. 10):

Based on this consideration, we define an importance function $\beta = f(x_{p+k}, \mu_{k+1}, \sigma_{k+1})$ as follows:

$$\beta = \left|\frac{x_{p+k} - \mu_{k+1}}{\sigma_{t+1}}\right| \tag{4}$$

According to $\beta$ we can define the following set of rules to decide what the salient phenomena are:

1. If $0 \leq \beta < 1$ Then the phenomenon $x_{p+k}$ is of a trivial importance;

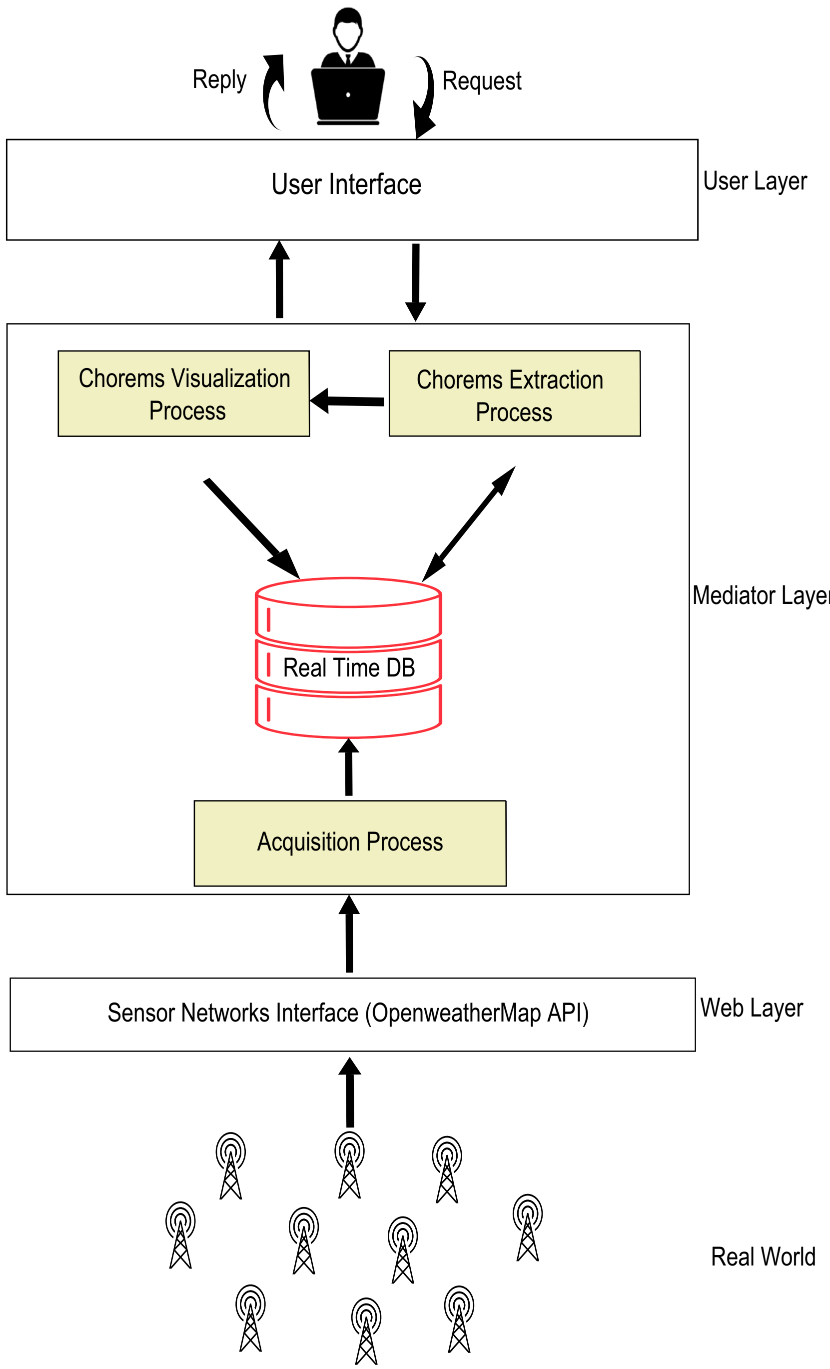


**Fig. 7.** The proposed system structure.

2. If $1 \leq \beta < 2$ Then the phenomenon $x_{p+k}$ is of moderate importance;
3. If $2 \leq \beta < 3$ Then the phenomenon $x_{p+k}$ is of remarkable importance;
4. If $3 \leq \beta < 4$ Then the phenomenon $x_{p+k}$ is of exceptional importance;
5. If $\beta \leq 5$ Then the phenomenon $x_{p+k}$ is of historical importance and very rare.

Case 1 is eliminated; then for other values of $\beta$ (Fig. 10), we make a decreasing sort according to $\beta$ extended to for all types of meteorological data $Z$; once this sort is done, we keep only the 7–10 higher group values density (by aggregation): these values will be referred to important patterns (chorems). This will identify the elements and critical values of detection of important phenomena which are used to generate summaries values to help users understand and guide the synthesis process, now we can examine how to visualize them as chorems.

### 3.2.3. Chorems visualization process

After extracting interesting patterns, the following question must be asked: How salient aspects can be depicted within a chorematic map? Originally, Brunet [13] established a table to set a completely defined vocabulary (by means of icons) which could

[1] http://forums.infoclimat.fr/topic/85358-detection-anomalie-de-temperature-a-court-terme/.

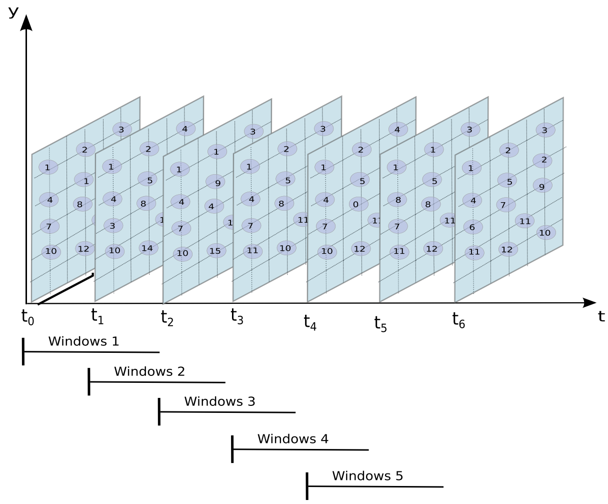


**Fig. 8.** Model snapshots on sliding temporal windows.

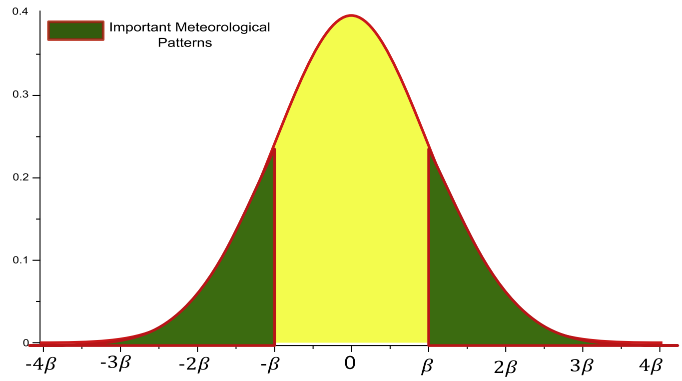


**Fig. 10.** Definition of importance $\beta$ based on Gauss probability function.

be used in any situation (see Fig. 1). In practice, a study [35] that surveyed 50 manually-made chorem maps gave the following results: (1) even if the chorem concept is said to be used by a lot of geographers and cartographers, the Brunet's vocabulary is not very used; (2) generally the users define their own chorem vocabulary (ad hoc chorem vocabulary) by providing a legend; (3) usually less than 10 chorems are used in a single chorematic map; (4) the more used patterns can be lumped into main categories such as main cities, main regions and main flows. Users seem to prefer to define their own vocabulary by providing an ad-hoc caption. In our case, we took the Brunet's chorems as an inspiration in order to represent automatically a map with only the salient aspects and it is represented by significant way. In other words, chorems include some cartographic symbols which are integrated to generate a chorematic map. Fig. 11 describes the chorems visualization process, we obtained from the previous process the important patterns characterized by the position of the initial density and more important phenomena.

a) *Generalized basemap*

A general strategy for the automated construction of chorematic maps is to first create the territorial outline of the region of interest, for that highly generalized territorial outline used as "basemap", or rather "spatial container" by using the point removal techniques with Douglas-Peucker algorithms [20] (Fig. 12, operation #1), then we define the major cities and certain attributes which can be retrieved by Structured Query Language (SQL Selects) (Fig. 12 operation #2).

Even if we do not take elevation into account, the Atlas Mountains are really a barrier to interpolate meteorological phenomena. In order to schematize this aspect, a wide dotted line will be added to symbolize this barrier.

b) *The visual vocabulary and its operations*

According to [35] chorems can be classified into three main categories, namely; geographic chorems; phenomenal chorems and annotation chorems. For geographic chorems, we choose some chorems proposed by Brunet as the point representing the important cities, the polygon to represent administrative boundaries, and thematic areas, and lines represent the geographic barriers.

For geographic phenomena, in addition of some *Brunet's* chorems, we define our own chorems based on *Bertin's* graphic semiology [11], some of them being adopted to represent an important phenomenon within a continuous field; two kinds of representation are deemed suitable in our case:

- Area-polygonization: domains of meteorological parameters can be represented by polygons, such as temperature and humidity, the generalization of the contour of the territorial area of interest; generalizing contours were made using several algorithms, such raster-based modeling [25] (Fig. 13, operation #a), and smoothing polygons with Bezier-tube [52] (Fig. 12, operation #b), and aggregation operation. Regarding the aggregation step, it may be invoked to group meteorological objects that share common properties, both geometric and semantic, and generate a unique geometric representation of relevant elements.

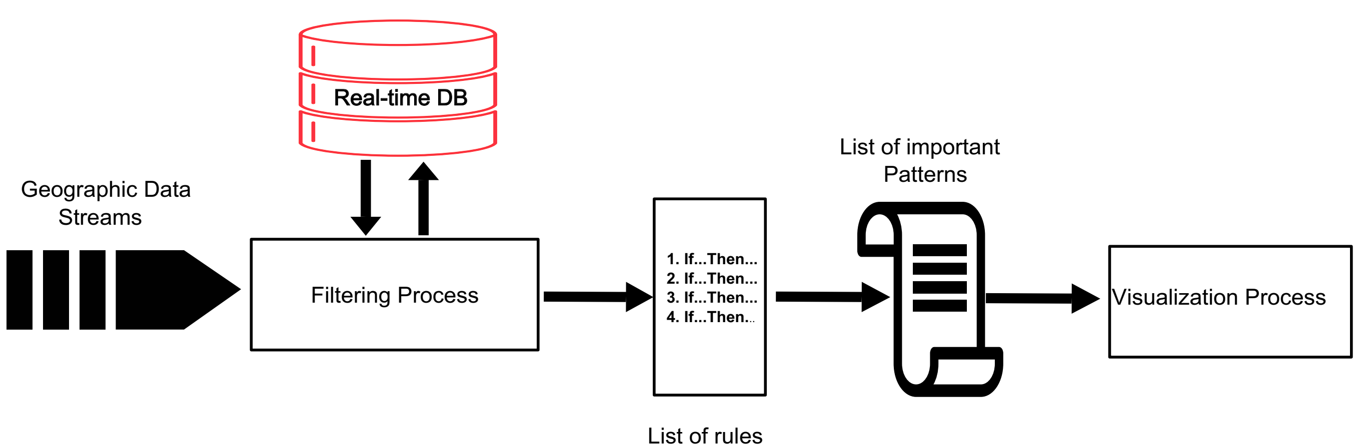


**Fig. 9.** Extraction chorems process.

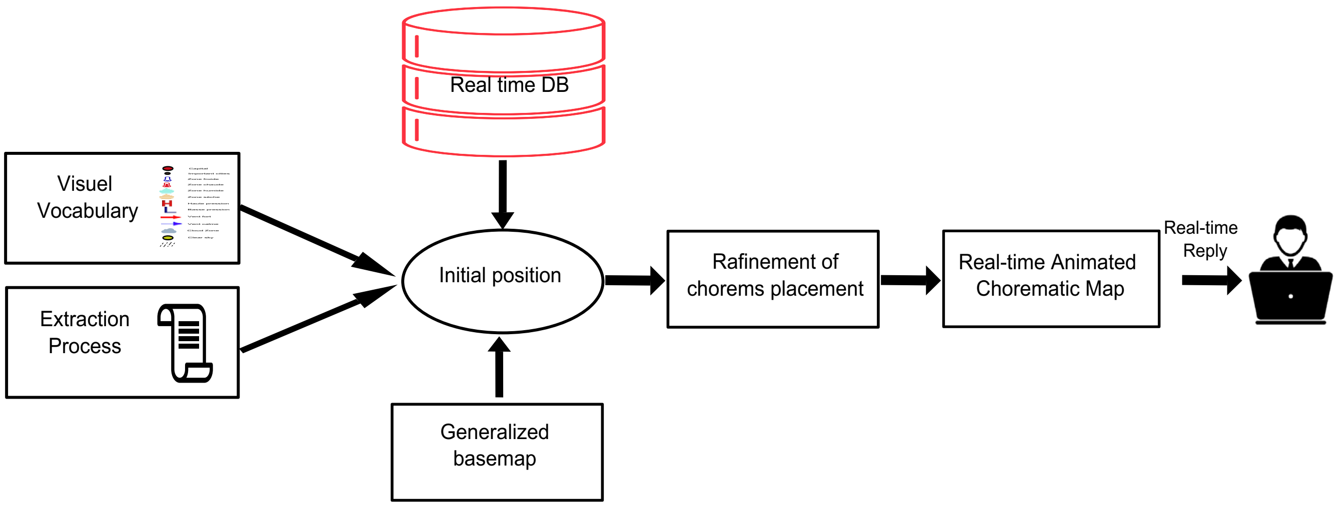


**Fig. 11.** Chorematic map visualization process.

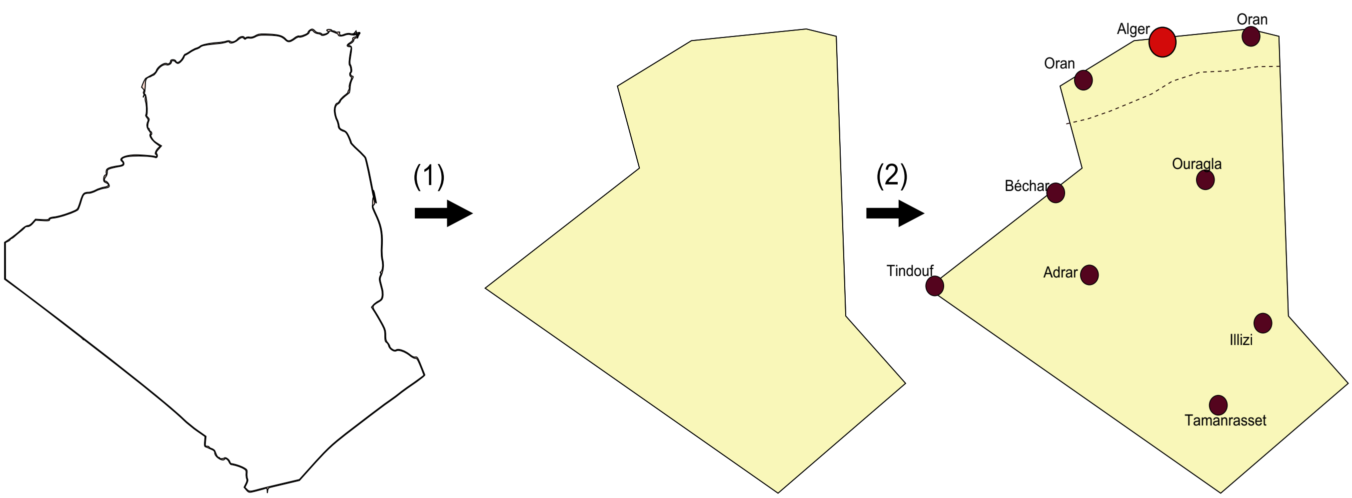


**Fig. 12.** The process of the generalization steps.

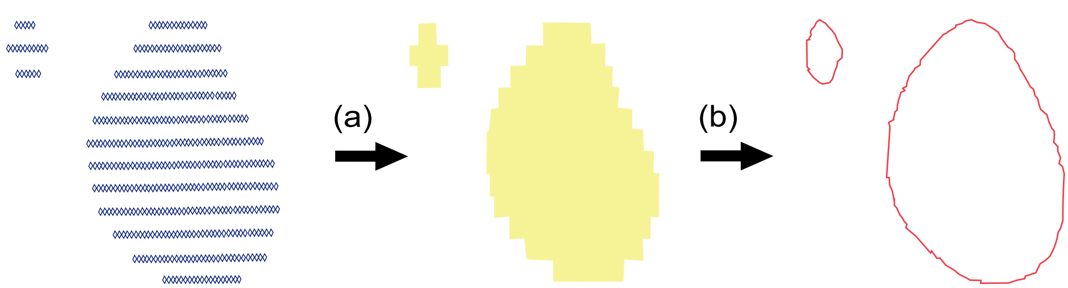


**Fig. 13.** The process of the generalization steps.

- Area-symbolization: once the meteorological parameters that can be viewed by symbols from a region (fields) are detected by the extraction process described above, this region can be called "symbolized area" leading to the use of "*symbols*" or "*glyphs*" for representing wind, cloud, precipitation, and air pressure; the glyph is shown in the centroids to indicate a phenomenon summarized in the concerned region.

Not forgetting that the choice of the color is a very important step for constructing chorems. In our case we represent a decrease and an increase in the blue and red scales. Blue for the reduction and red for the increase. Annotation chorems represent the names of important cities and legend (that contains a description of each chorem). In addition to this category, we can include exterior names, *i.e.* the names outside the territory under study (neighboring countries, adjacent seas, etc.). Finally, the output of the results is shown on a real-time animated map display.

### 3.3. Algorithm

To synthesize those ideas, we give an algorithm to automatically generating an animated chorematic map according to the steps as previously described:

***Input:*** $\{S = x_1, x_2, \ldots, x_{p+k-1}$, for $C$ sensors $u_i, i = 1, \ldots, C\}$
***Output:*** *{Find feature points: 7–10 as the number of important selected density patterns}*
***Begin***
*1: For (Z in {temperature, humidity, pressure, speed wind, direction wind, clouds, precipitation})*
***Begin***
*Arrival of a new value $x_{p+k}$ at a moment p+k of type Z;*
*1: Estimation of values from missing sensor value stations with the IDW method;*
*2: Calculate $\mu_{k+1}$ with Eq. (2);*
*3: Calculate $\sigma^2_{k+1}$ with Eq. (3);*
*4: Calculate $\beta = f(x_{p+k}, \mu_{k+1}, \sigma_{k+1})$ with Eq. (4);*
***End***
*2: Decreasing sort according to $\beta$ for all Z values;*
*3: Aggregation: Keeping only the 7–10 groups characterized by the most important density values of $\beta$;*
*4: Define the visual vocabulary (points, lines, polygons, glyphs);*
*5: Improvement: deleting the overlapping chorems;*
*6: Showing the resulting animated chorematic map.*
***End***

## 4. Design of a prototype and discussions

We underline our idea and in order to check the validity of our approach, a prototype was made with an application example, describing the whole process; the system accomplishes the construction of one of the animated chorematic maps necessary to represent the important situations meteorological of *Algeria.* In particular, details about the different steps and the modules involved are described as follows.

### 4.1. About data

Starting from data streams coming from sensors, storage of data and access to large time series data are identified as potential problems, and updating rapidly in a GIS is still a challenge to date. Since a spatiotemporal data model which takes into account all the data in real time and the historical data from sensor network in a way that allows quick recovery, data must be immediately accessed, compared, selected, sorted and filtered so that decision making can be improved especially in terms of maintaining the flexibility of the system. The selected data model is a relational database model, including spatial extension for spatial data; it allows storing large amounts of immediate and simultaneous spatial and temporal data to ensure concurrent operations such as querying and updating data. Faulty data are rarely available and if not, they are corrected quickly. In consequence, the system must be robust enough and able to automatically check and maintain spatial and temporal integrity in case of system or sensor failure.

### 4.2. Semantic generalization

First, city chorems of the largest cities are retrieved (an appropriate threshold defined by the user is used to determine the say 9 most populated cities by an SQL query). From the extraction process, a limited set of chorems is identified, Table 1 shows an excerpt of the real-time interesting patterns summarizing the density number; in consequence, this table contains the interesting patterns described, by their position (latitude, longitude), date, $\beta$ (importance index) and the natural phenomenon *Z*, by sorting according to $\beta$ among others.

Patterns extracted by the extraction process as density points (Table 1) are then aggregate for obtaining important patterns to avoid cluttering of the map, they will become chorems and they appear in order of importance (10 only) (Table 2):

This step concludes the phase of semantic generalization. Now, we have to perform the geometric generalization. So, chorems obtained are then sent to the visualization process to generate a representation of all views of the animated sequence and present them in real-time maps in a chorematic style to convey the essential information the more quickly as possible.

**Table 1**
Example of real-time extraction of interesting patterns ordered by phenomenon (excerpt).

| ID | Date | Long | Lat | $\beta$ | Z |
|---|---|---|---|---|---|
| 23274 | 61629 | −8.1 | 27.7 | 2.653 | Temperature |
| 23275 | 61629 | −8 | 27.7 | 2.654 | Temperature |
| 23276 | 61629 | −7.9 | 27.7 | 2.655 | Temperature |
| 23277 | 61629 | −7.8 | 27.7 | 2.654 | Temperature |
| … | 61629 | … | … | … | … |
| 34269 | 61629 | 2.8 | 36.5 | 2.621 | Humidity |
| 34270 | 61629 | 2.9 | 36.5 | 2.620 | Humidity |
| 34271 | 61629 | 3 | 36.5 | 2.620 | Humidity |
| … | 61629 | … | … | … | … |
| 46219 | 61629 | −0.6 | 35.7 | 1.956 | Wind |
| 46220 | 61629 | −0.5 | 35.7 | 1.956 | Wind |
| 46221 | 61629 | −0.4 | 35.7 | 1.956 | Wind |
| … | 61629 | … | … | … | … |
| 68851 | 61629 | 6.7 | 21.3 | 1.211 | Pressure |
| 68852 | 61629 | 6.8 | 21.3 | 1.210 | Pressure |
| … | 61629 | … | … | … | … |

**Table 2**
Example of 10 important patterns obtained by sorting the interesting patterns according to $\beta$ and additional attributes.

| Chorems numbers | Z | Shape | Color | Dotted line |
|---|---|---|---|---|
| 1 | Temperature | Polygons | Blue | False |
| 2 | Humidity | Polygons | Red | True |
| 3 | Wind | Glyphs | Red | False |
| 4 | Temperature | Polygons | Red | False |
| 5 | Pressure | Glyphs | Blue | False |
| 6 | Wind | Glyphs | Blue | False |
| 7 | Humidity | Polygons | Blue | True |
| 8 | Cloud | Glyphs | Grey | False |
| 9 | Cloud | Glyphs | Null | False |
| 10 | Pressure | Glyphs | Red | False |

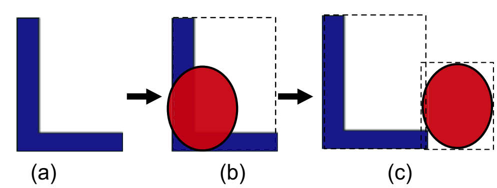


**Fig. 14.** Principles of overlaps elimination. (a) A possible configuration. (b) With minimum bounding rectangles. (c) Displacement.

### 4.3. Geometric generalization

A key task in the visualization is to choose the visual vocabulary. Glyphs, color, graphical structure and data density are all aspects to be considered in generating the layout of the chorematic visual representations. In contrast, our application demands a caricature that minimizes details to enhance perceptual tasks. Several operations are need and necessary for the automatic generation of chorematic map (see Section 3.2.3). For color, a discrete system was used to indicate a decrease and an increase in the blue and red scales.

However some glyph overlays may exist as depicted in Fig. 14(a); to resolve this conflict, we propose a refinement algorithm to avoid overlapping symbols for increasing the quality of visual information on the resulting map in real time. To solve spatial conflicts in map generalization, different generalization operators are applied. McMaster and Shea [42] presented a topology for generalization called operators, such as simplification, displacement,

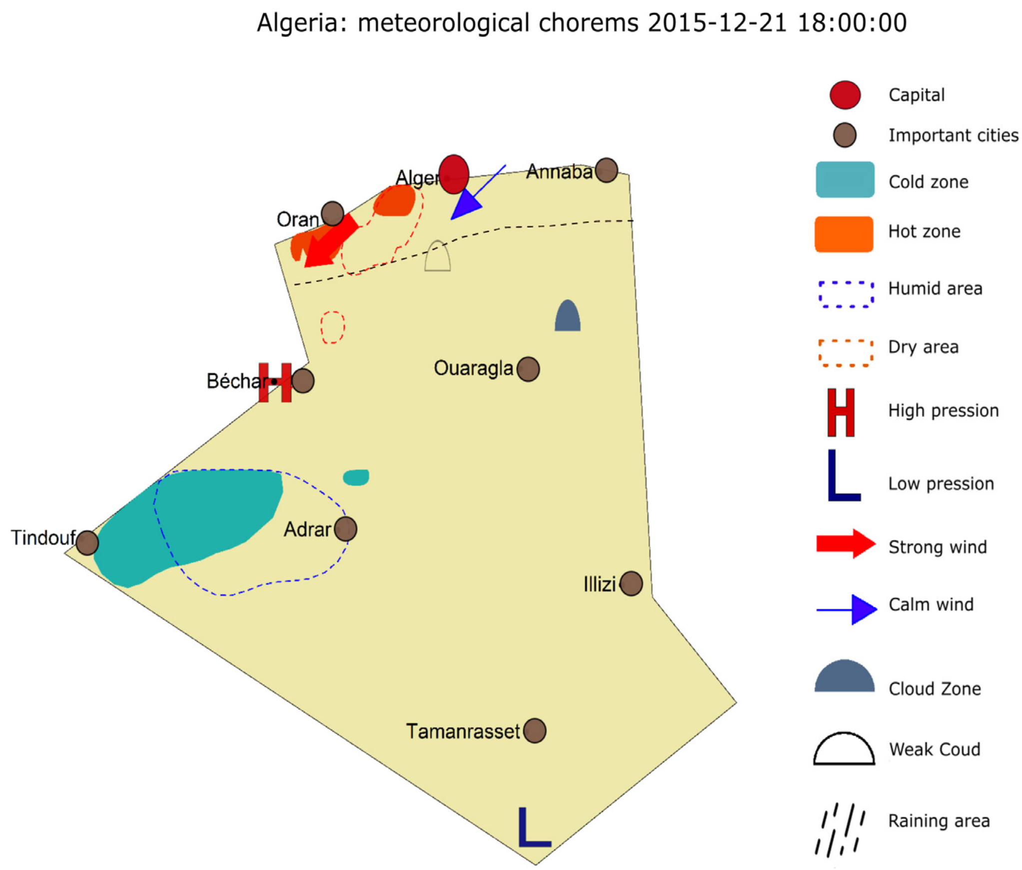


**Fig. 15.** A chorematic maps example showing real-time meteorological phenomena.

etc. Each operator defines a transformation that can be applied to a single spatial object, or to a group of spatial objects. Concerning generalization operators in cartography, please refer to [51]. In our case and for that purpose, the basic idea is that each chorem glyphs will be assigned their minimum bounding rectangles as in Fig. 14(b) to ease the determination of possible overlaps. When an overlap is detected, the both concerned glyphs must be moved until there is no more overlap as illustrated Fig. 14(c).

However due to overlaps of two objects, the artifact of displacement may generate a visual drawback: indeed if in the successive map, there is no overlap of these objects, the reader may by led to see a wrong movement. The final map result is depicted in Fig. 15 and meets the basic principles of readability and comprehension in terms of color and chorems elements. So, the raw output of our visualization method contains chorems referring to the region of *Algeria* country with generalized geometric shape, where some aspects are highlighted in order to allow fast detection of the positions of extreme values, such as the most important cities and the Atlas barrier; various meteorological phenomena are represented by polygons and glyphs by synthesizing and compiling especially hot and/or cold phenomena.

The geometric glyphs in textual form represent air pressure levels, the arrows obviously represent the speed and direction of wind; and the temperature is represented by filled polygons and humidity by unfilled polygons with dotted lines. In addition, the size represented by geometric symbols is proportional to their importance values, indicating various important meteorological phenomena, as a given moment, and colors clearly indicate the difference between the various periods. However, in the whole country, certain meteorological phenomena are not important, so not displayed. Chorematic maps highlight the relationships between data values associated with a region. In Fig. 15, South West region with cold zone is indicated by chorems as blue polygons present in this region. Thus, following the same principle, the dry area is important in the northern part of the country, and so a caption is added to the chorematic map to help users interpret the meaning of chorems.

As the final output is animation, a single map is shown that discretely changes over time. Fig. 16 shows four images taken from an animation, obviously the important points cannot only move, but also change their nature. Changing data results in perceived movements or changes in the appearance of objects. Animation allows the user to track the changes of meteorological phenomena on the event scale (a few hours or days) from a time period. Animated real time chorematic map aims to the direct observation of the phenomenon, it allows a direct comparison of the variation of data values and the spatial and temporal pattern, and allows one direction of the order. They are postulated to be a good practice to show the temporal dynamics, although they have known weaknesses by allowing comparisons between the constituent states.

### 4.4. Discussion

Usually the accuracy is not always necessary and sometimes it is not desirable to visualize geographic phenomena over a territory with a high level of details; indeed for some analysts, this type of accuracy overloads their cognitive mind, and can complicate their vision. Specifically, in our case, we use our technique to extract, filter, sort, compare weather data simultaneously coming from sensors in real-time; these steps are essential during the construction phase of chorematic maps, as they help the analyst to identify and extract interesting information over the territory. With our prototype, we want to make available an application that

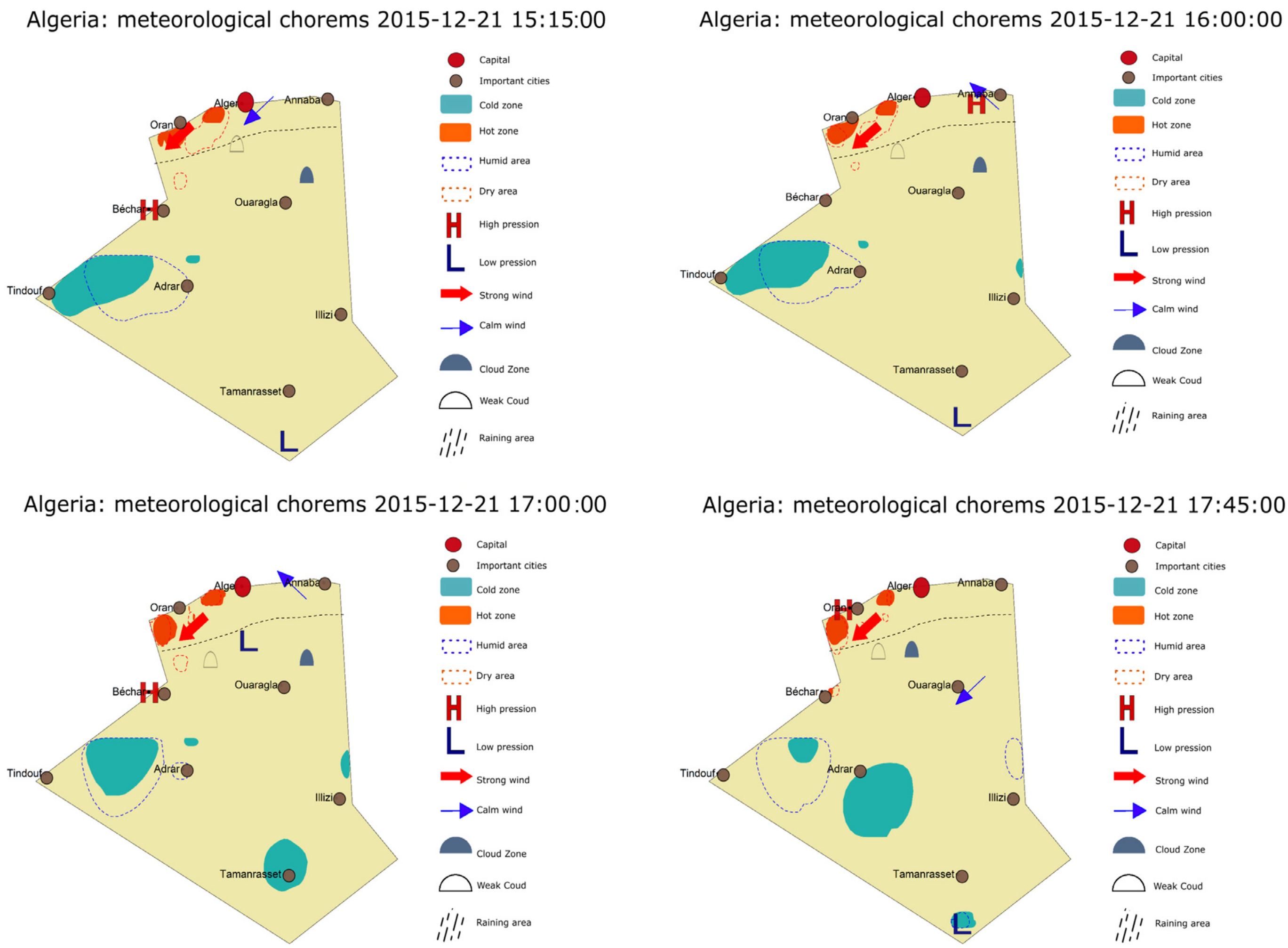


**Fig. 16.** Four images taken from an animation.

automates much of the cartographic design process. We also wish to make available a tool by increasing the temporal aspects of thematic geodata so that the temporal dynamics can be clearly visualized and examined. In terms of weather event management, information can be entered quickly as the peaks and/or holes of the event, namely, the time available to take against measures to make other decisions.

Our first reflection on this animated chorematic map indicates that visualization by chorems is helpful for getting an overview of phenomena in contrast with usual atlases of maps giving all details. This is the starting point for further analysis for the decision makers. In addition, thanks to the intuitive representation of geo-spatial context, the visual representation by chorems in real-time is a precious basis to communicate and discuss modeling results among scientists. This visualization is necessary to ensure that decision-makers:

- are able to enter and explore the overall picture of the weather situation in real time quickly;
- can track the short-term evolution of the state of the weather system;
- can clearly and quickly identify and discuss peaks and holes areas on both spatial and temporal dimension;
- can understand how the values in same places vary over time;
- could learn from past events by comparing real-time data during an animation.

In this research, we do not claim to have proved that our chorematic display is the best that can be done, but we do claim to have created a map that shows several weather phenomenon automatically, synthetically, animatedly and easily understood by the public with important trends and anomalies that may exist through time and without human intervention. Except the weather map is often seen on television (but realized off-line with human intervention), we know of no other example that has been empirically tested to meet that kind of characteristics.

## 5. Conclusion and future works

In this paper, we have presented our early efforts for a new approach to define mapping solutions that adequately represent information from a geographic database in real time based on animated chorematic maps defined as cartographic and semantic generalization of a map.

Because our primary interest was not to represent the entire available information, but rather a general overview of a visual summary, a novel solution was proposed based on the concept of the animated chorematic map and its ability to synthesize scenes that contain geographic objects and real time spatiotemporal phenomena by associating them with schematized visual notations. So, we have studied a solution when decision makers must deal with issues related to the problem of viewing time, and a great effort is needed to detect and represent the dynamics, movements and changes that underlie possible problems in a map or a lot of data is displayed. Thanks to visual analysis, methods and geographic data analysis tools that change with time were developed for geovisualization. The dynamic visual maps are often combined with data processing for analyzing large amounts of data that would be possible with purely visual methods. The visual analysis takes advantage of tools and methods developed in other areas related to data analysis, in particular geostatistics, data mining and knowledge of geographic information. The work so far indicates that the concept of animated chorematic map representations, offers the user the ability to view and track spatial and temporal data types and it provides a better understanding of the mapped phenomena in space and time. In an exploratory environment, animated chorems will be a strong alternative output of data supporting knowledge discovery.

Finally, our main research contributions are

- defining a novel importance function to order phenomena to be present in a chorem;
- demonstrating that chorems can be determined in real time without any human intervention;
- and automatically generating visual summaries from geodata coming regularly from sensors.

Designed with a component-based framework, the developed software environment is open to additions of new components. The integration of new components to extend the capability of the current system is relatively easy, imagine, not a single summary at the highest level (countries), but also the intermediate summaries (regions, departments) to gradually get to basic information, to form a hierarchy, or better an abstract hierarchy. Therefore, more chorems will be used as a system of access to geographic databases. Furthermore, interactive methods can be integrated into the real-time visualization system, such as time sliders or clickable calendars in order to offer the user a temporal navigation to rewind more rapidly.

Concerning meteorology, a perspective will be to modify the way interpolations are made by taking altitude into account. The preliminary step should be to store a digital terrain model for the whole country. Another perspective could be the use of chorem mapping, for instance for weather forecast; in this case, animation is not governed by sensors but by the results of a simulation model.

Since it is common to use basemap from Google Maps, a possible development is to create a special mashup dedicated to a chorem-based system for real-time mapping of meteorological phenomena. The only advantage of this choice is to skip the first step, *i.e.* basemap generalization; but also other steps are not modified.

Brunet proposed a few chorems to represent the dynamics (gradients, etc.). This approach supposes to estimate gradients everywhere for each phenomenon governed by continuous fields, and then to detect the salient issues of those gradients. Three consequences must be studied, (*i*) this process is very time-consuming (*ii*) special glyphs must be selected. The third one (*iii*) will generate another other new interesting patterns, but since their number of important patterns is limited, the visual layout must be carefully examined (understanding, overlap removal, etc.).

The framework has been tested using a meteorological example using sensor-streaming environment. Therefore, a planned future work would be to deal with more time-critical phenomena, for instance by showing the salient features for nuclear plant or disaster management. The framework could also be integrated with decision making systems within road traffic monitoring will surely need to consider different characteristics (for example, to allow to visualize the evolution of the traffic on some road segments), in this application, as some visual summary can be automatically generated showing places with high traffic congestion, this kind of visual summary will be more useful.

In addition, it will carry out extensive research on the acceptance of chorems, understanding by users; for this purpose psychological cognitive tests should be developed, measures will be developed in order to establish rules of best practice in this area. Facing this objective, a psycho-cognitive test can be presented as a questionnaire to validate both the choice of the visual vocabulary and the concept of animated chorems in order to interpret the results of the application with a simple and correct way.

Another aspect will concern the maximum number of chorems to be selected (presently 10). So the question will be: "what the maximum number of chorems to be visualized together while keeping a high degree of understanding and readability, taking the size of the territory and the scale of maps into account?"

## References


[1] C.C. Aggarwal, An introduction to sensor data analytics, in: Managing and Mining Sensor Data, Springer US, 2013, pp. 1–8.
[2] N. Andrienko, G. Andrienko, in: Exploratory Analysis of Spatial and Temporal data: a Systematic Approach, Springer Science & Business Media, 2006, pp. 1–15.
[3] N. Andrienko, G. Andrienko, Visual analytics of movement: an overview of methods, Tools Proced., Inf. Visualization 12 (1) (2013) 3–24.
[4] G. Andrienko, N. Andrienko, U. Demšar, D. Dransch, J. Dykes, S. Fabrikant, M. Jern, M. Kraak, H. Schumann, C. Tominski, Space, time, and visual analytics, Int. J. Geogr. Inf. Sci. 24 (10) (2010) 1577–1600.
[5] G. Andrienko, N. Andrienko, J. Dykes, S. Fabrikant, M. Wachowicz, Geovisualization of dynamics, movement and change: key issues and developing approaches in visualization research, Inf. Visualization 7 (3-4) (2008) 173–180.
[6] N. Andrienko, G. Andrienko, P. Gatalsky, Exploratory spatiotemporal visualization: an analytical review, J. Visual Lang. Comput., Spec. Issue Visual Data Mining 14 (6) (2003) 503–541.
[7] E.M. Aoidh, M. Bertolotto, D.C. Wilson, Understanding geospatial interests by visualizing map interaction behavior, Inf. Visualization 7 (2008) 275–286.
[8] A. Appice, A. Ciampi, P. Fumarola, D. Malerba, Data mining techniques in sensor networks summarization, in: Interpolation and Surveillance, Book, Computer Science Springer, 2014, pp. 1–105.
[9] M. Arnaud, X. Emery, in: Estimation Et Interpolation Spatiale, Méthodes Déterministes Et Méthodes Géostatistiques, Editions Hermès Sciences Publications, Paris, 2000, p. 221.
[10] B. Babcock, S. Babu, M. Datar, R. Motwani, J. Widom, Models and issues in data stream systems, in: Proceedings of the Twenty-first ACM SIGMO D-SIGACT-SIGART Symposium on Principles of Database Systems, Madison, WI, USA, 2002, pp. 1–16.
[11] J. Bertin, Semiology of Graphics, University of Wisconsin Press, 1983 ISBN: 0299090604.
[12] K.E. Brassel, R. Weibel, A review and conceptual framework of automated map generalization, Int. J. Geogr. Inf. Syst. 2 (3) (1988) 229–244.
[13] R. Brunet, La Carte-Modèle et les chorèmes, Mappemonde 4 (46) (1986) 2–6.
[14] A. Carvalho, AA. De Sousa, C. Ribeiro, Temporal focus plus context visualization model for handling valid-time spatial information, Inf. Visualization 7 (3–4) (2008) 265–274.
[15] I. Cherni, F. Sami, R. Laurini, M. Warghi, ChoreMAP: extracting and displaying visual database summaries tool, ThinkMind eKNOW 2015, The Seventh International Conference on Information, Process, and Knowledge Management, 2015.
[16] D. Culler, D. Estrin, M. Srivastava, Guest editors' introduction: overview of sensor networks, Computer 37 (8) (2004) 41–49.
[17] D. De Chiara, V. Del Fatto, R. Laurini, M. Sebillo, G. Vitiello, A chorem-based approach for visually analyzing spatial data, Academic Press: J. Visual Lang. Comput. 22 (3) (2011) 173–193.
[18] V. Del Fatto, R. Laurini, K. Lopez, M. Sebillo, G. Vitiello, A chorem–based method for visualizing evolutionary scenarios, Inf. Visual. 7 (3) (2008).
[19] U. Demšar, K. Virrantaus, Space-time Density of Trajectories: exploring spatio-temporal patterns in movement data, Int. J. Geogr. Inf. Sci. 24 (10) (2010) 1527–1542.
[20] D. Douglas, T. Peucker, Algorithms for the reduction of the number of points required to represent a digitized line or its caricature, Cartographica 10 (2) (1973) 112–122.
[21] M. Egenhofer, J. Richards, Exploratory access to geographic data based on the map overlay metaphor, J. Visual Lang. Comput. 4 (2) (1993) 105–125.
[22] GIS and Cartography, R. Kitchin, M. Thrift, International Encyclopedia of Human Geography, in: M.F. Goodchild (Ed.), Springer, New York, 2009.
[23] T. Hägerstrand, What about people in regional science? Reg. Sci. Assoc. 24 (1970) 7–21.
[24] M. Harrower, A look at the history and future of animated maps, Cartographica 39 (3) (2004) 33–42.

[25] R.J. Hijmans, V.J. Etten, Raster: geographic analysis and modeling with raster data, 2012. Available at: http://cran.r-project.org/web/packages/raster/index.html (last access: 08-02-2016, R package version R-3.1.1 2013).
[26] J.T. James, A.C. Kristin, A visual analytics agenda, IEEE Comput. Graphics Appl. 26 (1) (2006) 10–13.
[27] A.P. Jayasumana, Sensor networks: technologies, Protocols and Algorithms, Industrial Electronics, ISIE 2009, 2009 IEEE International-ISBN: 978-1-4244-4349-9.
[28] D. Keim, G. Andrienko, J.D. Fekete, C. Görg, J. Kohlhammer, G. Melancon, in: Visual Analytics: Definition, Process, and Challenges, Information Visualization, Springer, 2008, pp. 154–175.
[29] A. Klippel, H. Tappeb, L. Kulikc, P. Leed, Wayfinding choremes a language for modeling conceptual route knowledge, J. Visual Lang. Comput. 16 (4) (2005) 311–329.
[30] M.J. Kraak, Geovisualization illustrated, ISPRS 57 (10) (2003) 5–6.
[31] G. Langran, Time in Geographic Information Systems, Taylor & Francis, London, 1992.
[32] R. Laurini, A conceptual framework for geographic knowledge engineering, J. Visual Lang. Comput. 25 (1) (2014) 2–19.
[33] R. Laurini, L. Paolino, M. Sebillo, G. Tortora, G. Vitiello, Phenomena: a visual query language for continuous fields, in: Procs of ACMGIS, on Association for Computing Machinery, New Orleans, Louisiana, USA, 2003, pp. 147–153.
[34] R. Laurini, S. Servigne, G. Noël, Soft, real-time GIS for disaster monitoring, in: International Symposium on Geo-information for Disaster Management, Springer-Verlag, ISBN 978-3-540-24988, 2005, pp. 465–480.
[35] K. Lopez, R. laurini, V. del fatto, D. Sol, R. Loreto, M. Sebillo, G. Vitiello, Visualizing geographical analysis results from spatial databases based on the chorems, in: Proceedings of the International Conference on Modeling, Simulation and Visualization Methods (MSV'09: July 13–16, 2009), USA, 2009, pp. 29–35.
[36] L. Li, P. Revesz, A comparison of spatio-temporal interpolation methods, in: M. Egenhofer, D. Mark (Eds.), Proceedings of the GIScience, Lecture Notes in Computer Science, vol. 2478, Springer, 2002, pp. 145–160.
[37] C. Lienert, M. Kunz, R. Weingartner, L. Hurni, Methods for real-time visualization and exploration improvements of precipitation radar and temperature data in web-cartography, in: Proceedings of the 24th International Cartography Conference, Santiago, Chile, 2009.
[38] C. Lienert, R. Weingartner, L. Hurni, Real-time cartography in operational hydrology, in: Proceedings of the 23rd International Cartography Conference, Moscow, Russia, 2007.
[39] A.M. MacEachren, M. Kraak, Research challenges in geovisualization, Cartogr. Geog. Inf. Sci. 22 (1) (2001) 3–12.
[40] A.M. MacEachren, M. Wachowicz, R. Edsall, D. Haug, R. Masters, Constructing knowledge from multivariate spatiotemporal data: integrating geographical visualization with knowledge discovery in database methods, Int. J. Geog. Inf. Sci. 13 (4) (1999) 311–334.
[41] B. McCormick, T. DeFanti, M. Brown, Definition of visualization, ACM SIGGRAPH Comput. Graphics 21 (6) (1987) 3.
[42] B. McMaster, S. Shea, Generalization in Digital Cartography, Association of American Geographers, Wahington D.C., 1992.
[43] M. Nanni, B. Kuijpers, C. Körner, M. May, D. Pedreschi, Spatiotemporal data mining, in: F Giannotti, D. Pedreschi (Eds.), Mobility, Data Mining and Privacy: Geographic Knowledge Discovery, Springer-Verlag, 2008, pp. 267–296.
[44] S. Nittel, A Survey of geosensor networks: advances, dynamic environmental monitoring, Sens. J. 9 (7) (2009) 5664–5678.
[45] S. Nittel, Q. Liang, J.C. Whittier, Real-time spatial interpolation of continuous phenomena using mobile sensor data streams, in: Proceedings of the 20th International Conference on Advances in Geographic Information Systems -SIGSPATIAL'12, New n York, NY, USA, 2012, pp. 530–534.
[46] OpenWeatherMap, Free weather data and forecast API. Retrieved 22-12-2014, from Open Weather Map: http://openweathermap.org, (last access: 08-02-2016).
[47] D.J. Peuquet, It's About Time: a conceptual framework for the representation of temporal dynamics in geographic information systems, Ann. Assoc. Am. Geogr. 84 (3) (1994) 441–461.
[48] K. Potter, A. Wilson, P.T. Bremer, D. Williams, C. Doutriaux, V. Pascucci, C.R. Johnson, Ensemble-Vis: a framework for the statistical visualization of ensemble data, in: IEEE International Conference on Data Mining Workshops, 2009, pp. 233–240.
[49] P.S. Quinan, M. Meyer, Visually comparing weather features in forecasts, IEEE Trans. Visual. Comput. Graphics 22 (1) (2015) 389–398.
[50] A. Reimer, Understanding chorematic diagrams: towards a taxonomy, Cartographic J. 47 (4) (2010) 330–350.
[51] A. Ruas, C. Plazanet, Strategies for automated generalization, in: Proceedings of the 7th International Symposium on Spatial Data Handling, Advances in GIS Research, vol. II, 1996, pp. 1–6.
[52] L. Shao, H. Zhou, Curve fitting with Bezier cubics, Graphical Models Image Process. 58 (3) (1996) 223–232.
[53] S. Shekhar, P. Zhang, VR. Raju, Y. Huang, Trends in spatial data mining, in: Data Mining: Next Generation Challenges and Future Directions, MIT Press, Cambridge, MA, 2004, pp. 357–380.
[54] R. Sluiter, Interpolation Methods for Climate Data-Literature Review, KNMI Royal Netherlands Meteorological Institute, De Bilt, The Netherlands, 2009 Intern rapport.
[55] E. Spiess, The need for generalisation in a GIS environment, in: J.C. Müller, J.-P. Lagrange, R. Weibel (Eds.), GIS and Generalisation, Gisdata 1, Taylor and Francis, United Kingdom, 1995, pp. 31–46.
[56] The AWIPS CAVE-D2D User's Manual, OB 13.4.1. NOAA National Weather Service and Raytheon, July 2013, https://www.unidata.ucar.edu/software/awips2/doc/CAVE_D2D_Manual.pdf (last access: 09-04-2017).
[57] J.J. Thomas, K.A. Cook, Illuminating the path, research and development agenda for visual analytics, National Visualization and Analytics Center TM. IEEE 2005, 2005.
[58] W.R. Tobler, A computer movie simulating urban growth in the detroit region, Econ. Geogr. 46 (2) (1970) 234–240.
[59] I.R. Vassiliev, Mapping time, Cartographica 34 (2) (1997) 1–51.
[60] C. Ware, M.D. Plumlee, Designing a better weather display, Inf. Visual. 12 (3-4) (2013) 221–239.