SOLAP GIS in maritime research

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Multidimensional Geographical Information System is a system especially designed to acquire, distribute, analyze and visualize complicated spatio-temporal data. Modern Geographical Information System technology can provide easy-to-use, near real-time solutions to many problems from different areas of research. In the article, authors summarize recent works on Spatial Online Analytical Processing (SOLAP) and multidimensional Geographical Information System (GIS), discuss its capabilities and data structures used in spatio-temporal datasets, and propose its possible applications in maritime research.

Keywords: spatio-temporal GIS, multidimensional data, fish biomass estimation, AIS, tracking vessel movement

1. Introduction

Spatial data is information describing a location, identifying an object's shape, and other characteristics in a geographical context. It is estimated that about 60% of all the data has a spatial character, or it can be so attributed by using information about geographical coordinates; the address, country of origin, time and place of the observed events etc. Geospatial data in a raster or vector form is commonly used in multiple types of computer systems. It fulfills a wide range of functions, from the representation of geographic regions, visualizing recent trends in population migration, land and sea navigation, to logistic, marketing and biological research [1].

Geographic Information Systems (GIS) provide multiple features, e.g. geospatial data storage, analysis and visualization, that can be helpful in solving various problems. Recent trends in GIS research focus on analysis of time-dependent spatial data, also known as spatio-temporal data. In the article, authors present the idea of temporal, four-dimensional GIS, describe techniques for designing a multidimensional dataset, and propose data structures suitable for its needs. At the end, possible areas of maritime research that could utlize spiato-temporal analysis are proposed [2].

2. Multidimensional GIS

The information system, whose main task is processing, analysis, and presentation of spatial data is a Geographical Information System, GIS. GIS is being used in many areas, from logistics to navigation and meteorology, marketing, or social research. The data in GIS is usually presented in the form of two-dimensional layers, and displayed in an electronic map on the computer screen. Most methods of spatial data analysis operate with 2D data, and, less frequently, 3-D data [1][2].

Classic GIS does not have the power to scrutinize the data with more than three dimensions. Examples of such data are spatio-temporal data (sometimes abbreviated as "4D") that is the data corresponding both to the “where?" and "when?" questions. This kind of GIS can store various layers, mapping the state of reality at a given moment of time, but it does not have consistent tools to track changes over time.

One of the most important functions of a GIS is the analysis of spatial data. The challenge for the modern GIS is to track changes over time, and by knowing the trends, conducting prediction of upcoming events.

In recent years, a number of tools to analyze multidimensional data have been created. In particular, an OLAP (Online analytical processing) technology, in which data is formed into a so-called data cube, having three or more predefined dimensions. In this context, not only time and position in space (eg. position, altitude, depth of immersion) can be used as dimensions. Any hierarchical structure, such as geographic region (city, state, country), the type of fishing (fish family, species) etc. can act as such a dimension[3][4].

The OLAP standard operations (Fig. 1.) include roll-up and roll-down (for example in the context of spatial aggregation), or slicing the data cube. OLAP operates on array data, but with the increasing popularity of this technique, has recently created the so-called SOLAP (Spatial-OLAP), an OLAP tool designed to work on the spatial data. Even though SOLAP provides basic tools for operations on multidimensional data, it is not sufficient enough for a full analysis of 3D data changes over time [5][6].

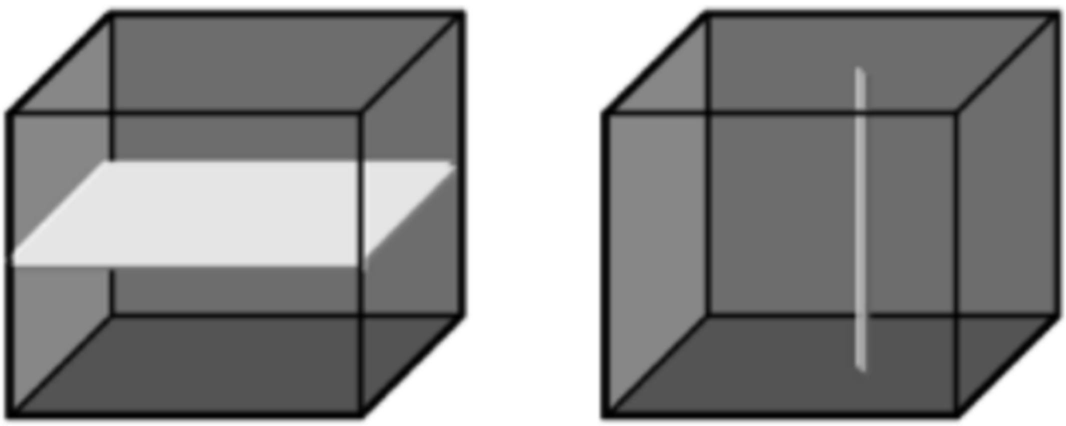


Fig. 1. Data cube section [6].

3. Tracking changes over time

Storing information about change in the spatial data over time was researched thoroughly in recent years [7]. In this section, some different approaches used in SOLAP are discussed.

First works on temporal GIS used a technique for preserving information about changes in a sequential structure called a "time-series". In this technique, typically used for raster data, the GIS would store the entire state of a spatial feature in consecutive moments of time. Depending on the approach, new information would be added in fixed time intervals, or only when new data is available. Fig. 2. presents the time-series technique used to store data about a road network development.

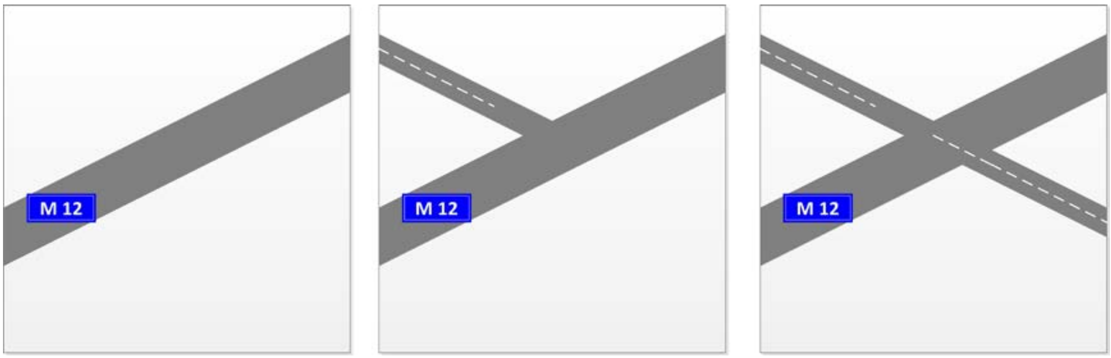


Fig. 2. Using time-series to store information about a road network development.

Time-series technique is easy to implement, but also has a lot of drawbacks. State of the entire data set is saved, even if the change over time was very small; which leads to data redundancy, and considerable requirements for disk space. Moreover, accessing information of changes between numerous sequences depends on data set size; and is, as a result, very time-consuming. One of the possibilities to overcome those issues, is to store information only about differences between consecutive timestamps (Fig. 3.). This approach reduces required disk space, but accessing data for the timestamp requires accumulating information from all previous timestamps.

Fig. 3. Only new elements are stored in the consecutive timestamps.

To accelerate spatio-temporal operations, methods to store data in indexed structures are required. One of the most-often-used is an R-Tree (with variations like R* or B tree). Fig. 4. presents an example of R-tree usage for indexing changes in spatio-temporal features.

Regions R5 and R6 consist of two sub-regions R1, R2 and R3, R4 respectively. Each node in a tree stores aggregated information of its area and pointers to its sub-regions [8].

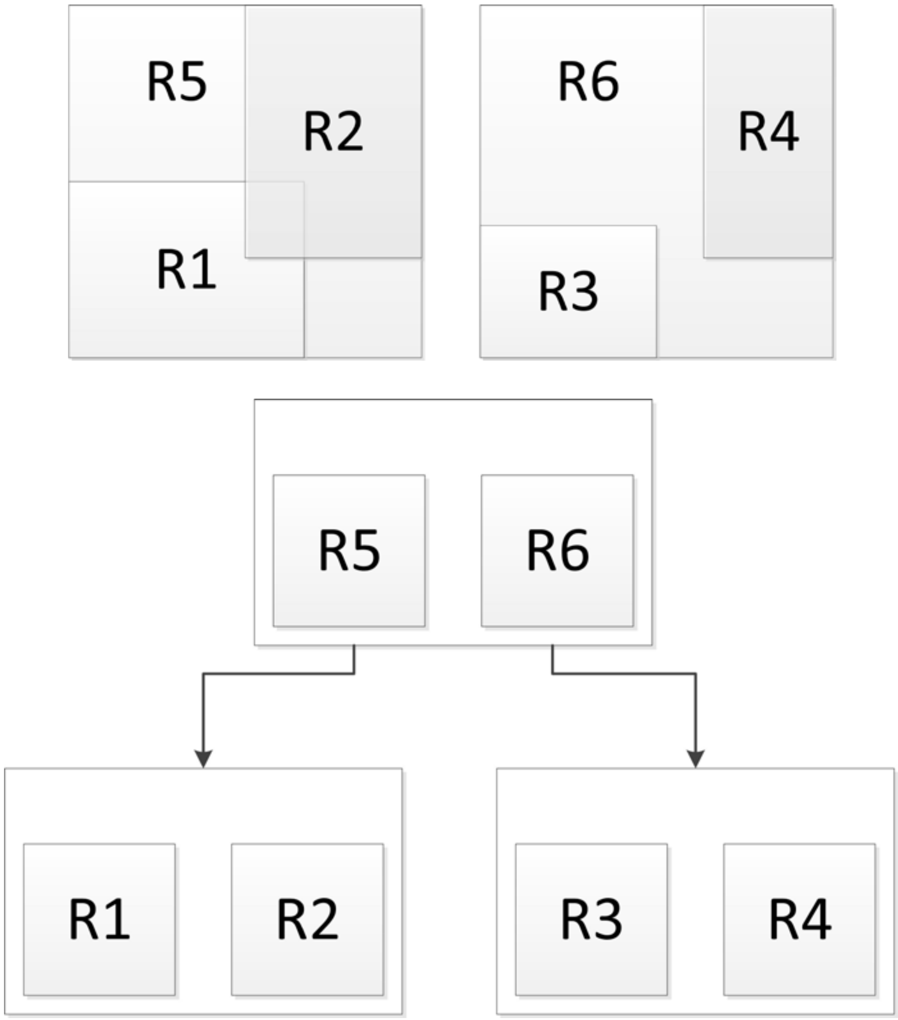


Fig. 4. Regions structure and its R-Tree representation [8].

Simple R-tree methods were created to index non-temporal, static data. Multiple R-trees can be used to store information for different moments in time (in an approach similar to time-series technique), but it would also lead to redundancy. To overcome these problems, historical R-trees (HR) were proposed, in consecutive trees they share common nodes. Fig. 5. presents an example of an HR tree. There is no change in spatial data between timestamps 1-4. In timestamp 5, region R1 changes to R1', which leads to a change in the parent node (R5 to R5'). Since there was no change in R6 (and its children), a new tree for timestamp 5 can point to nodes in tree for timestamps 1-4[8].

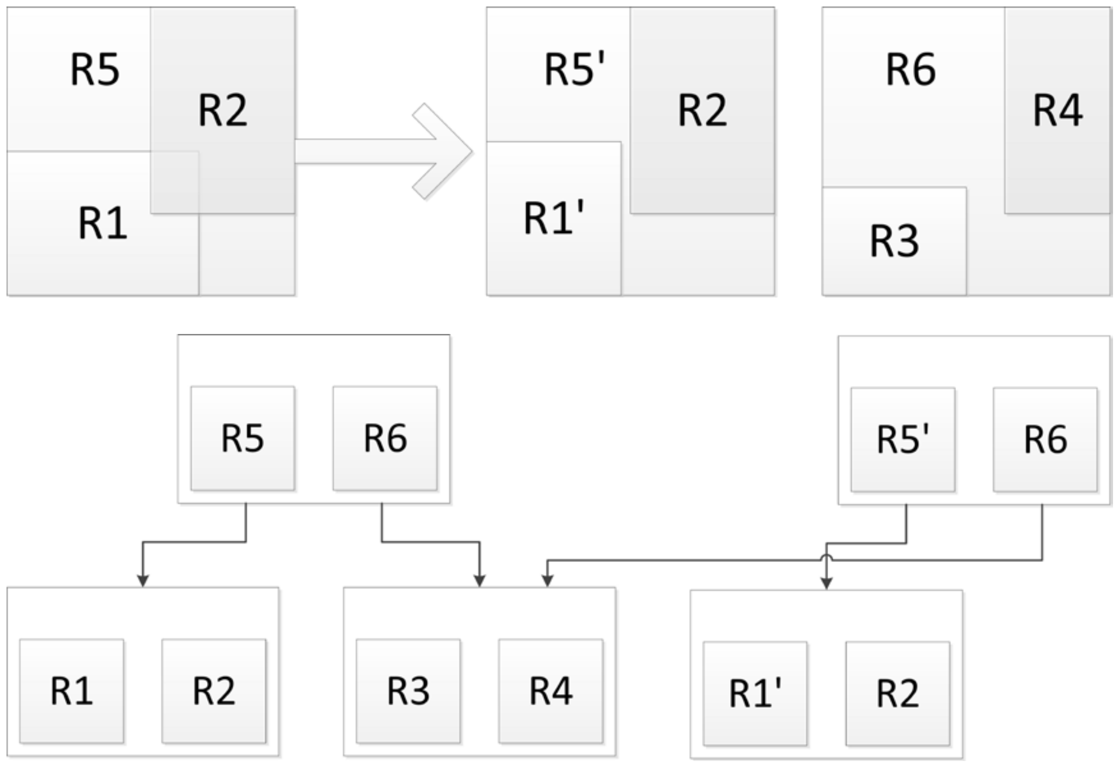


Fig. 5. HR-Tree for timestamps 1-4 (left) and timestamp 5 (right) [8].

4. Tracking vessel movement

Automatic Identification System (AIS) is a system used to locate, track and identify ships and vessels. AIS messages are exchanged between vessels, base stations, and recently, satellites. AIS system that uses satellite receivers to obtain positioning data is known as Satellite AIS or S-AIS. The main aim of AIS is to provide collision avoidance by providing information about nearby vessels; their characteristics such as speed, course, unique identifier (MMSI - Maritime Mobile Service Identity) etc.[9]

Vessel movement data is a classical type of spatio-temporal information. Spatio-temporal GIS can be used to gather information for input to sea risk-management, assessment and decision-making applications. Due to SOLAP warehousing capabilities enabled by temporal indexing, it can be easily used to store vessels' movement history. In composition with position interpolation algorithms, it can be used to obtain ship localisation (Fig. 6.) in any defined point in time. Moreover, ship movement history can be used to evaluate maritime risk, and detect abnormal maritime behavior according not only to safety (collision, grounding etc.) but also according to security (piracy, illicit goods, etc.). Risk-detection capabilities can be increased by integrating spatio-temporal data with vessel characteristics and environment data (weather, oceanographic context).

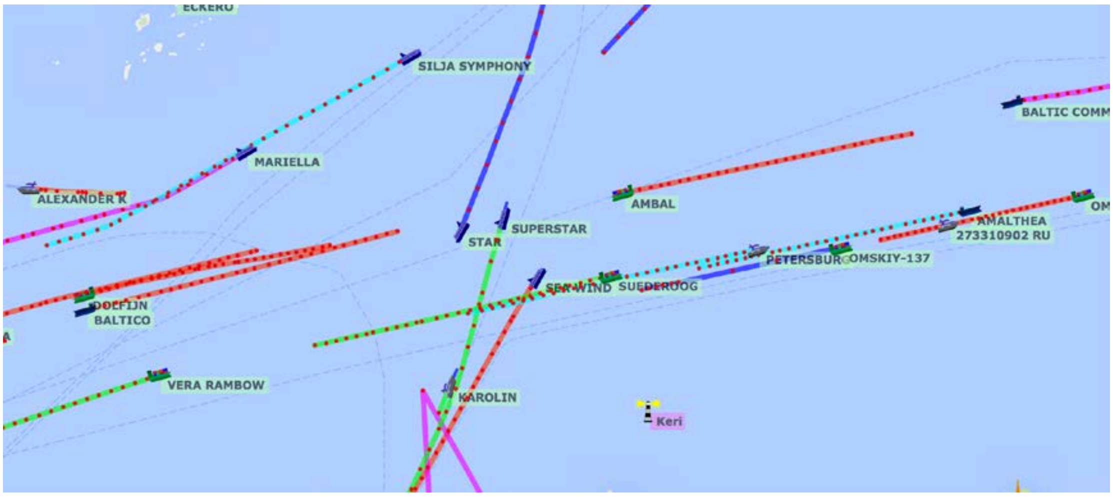


Fig. 6. Vessels movement history [source: aprs.fi].

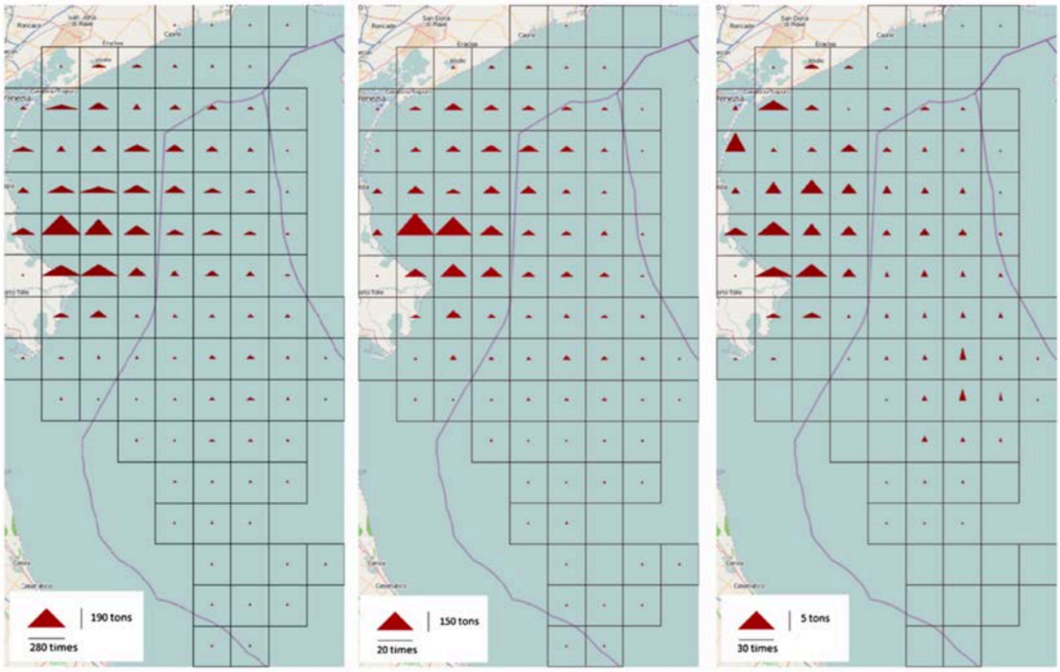
5. Fish biomass estimation and fishery planning

In the last four decades, the research into the food resource provided by pelagic fish, has become significantly more important. The problem of its exploration, and utilization, is now an issue of world–wide importance. Development of modern methods of catching and detecting fish, and raising the number of fishing vessels, brought about the catch volumes to the millions of tonnes in live weight. Even though FAO (Food and Agriculture Organization of the United Nations) experts decided that current catches are below the acceptable level, extensive fishery exploitation, performed by many countries, infringed local biological balances. In many traditional fishery locations, overfishing, and even extermination of fish population, was observed. The basic condition for rational sea fish resource-management is to have information on the size of the resources, and the dynamics of its change. This is achieved by both fish stock assessment, and fish abundance population estimation. Fish assessment is, in general, based on determining the total fish biomass in a basin, divided by species [10].

The main objective of fish stock assessment is to provide data for its optimal exploitation. Since the fish stock size is both limited, and renewable, it can be considered as a search for a level of exploitation that allows maximal catch in a long time-span, the so-called "maximum sustainable yield". Several types of fish stock assessment methods are being used nowadays; beginning with traditional fishing bio-statistical methods that analyze population and its dynamics, to indirect methods based on the concentration of dissolved and suspended matter, variations in primary production levels, distribution of surface isotherms, location of frontal boundaries, regions of upwelling, currents and water circulation patterns [11].

Spatio-temporal analysis methods could be used to fuse results from both direct and indirect methods, compare them, and possibly provide more accurate results. SOLAP could also perform the role of interface for more advanced algorithms, such as those using data from satellite sensors. Moreover, analysis of the consequent assessment for the same area over extended periods of time, could help in explaining the changes occurring in the environment, like migration, or changes in population.

Moreover, pelagic fish biomass estimation compared with fishing data can be helpful in effective fishery planning. By combining catches and effort data, it is possible to obtain information related to the CPUE (Catch Per Unit Effort), an index of efficiency of a given fishing technique in a certain environment. As an example Fig. 7. uses triangular diagrams for indicating the relation between the amount of catch in a given cell (height of the triangle) and the fishing effort for that cell (base of the triangle). [7]



(a) Any fish (b) *Anchovies* (c) *Cuttlefishes*

Fig. 7. Correlation between catches (height) and fishing effort (base) [7].

6. Conclusions

Spatio-temporal GIS is able to gather multidimensional data from different sources and then store, fuse, manipulate and visualize it. Advanced indexing algorithms with appropriate data structures used in SOLAP provide near real-time analysis capabilities, and the possibility to easily access the state of spatial data for a given point in time. Especially important is an ability to track changes occurring in an environment over a long time span [12].

Many problems faced by the maritime research community are very similar to those faced by the spatial community. Multidimensional GIS and SOLAP can provide solutions, tools and methods, to overcome, speed, simplify or enhance works in those fields. Spatio-temporal GIS can be used in many areas of maritime research like vessel tracking, ship movement history analysis, fish biomass estimation, abnormal behavior at sea etc.

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