Brazilian Journal of Cartography (2016), Nº 68/6, Special Issue GEOINFO 2015: 1079-1086
Brazilian Society of Cartography, Geodesy, Photgrammetry and Remote Sense
ISSN: 1808-0936

TRENDS IN GEOINFORMATICS

Tendências em GeoInformática

Thales Sehn Körting, Karine Reis Ferreira, Lúbia Vinhas, Antônio Miguel Vieira Monteiro & Gilberto Ribeiro de Queiroz

National Institute for Space Research - INPE Brazil
DPI - Image Processing Division at the OBT - General Earth Observation Coordination
Av. dos Astronautas,1758 São José dos Campos, Brazil
{thales.korting, karine.ferreira, lubia.vinhas, miguel.monteiro, gilberto.queiroz}@inpe.br

ABSTRACT

After a thorough review of the past editions of the Brazilian Symposium on GeoInformatics (GEOINFO), from 1999 to 2015, which included more than 300 articles, we have identified some topics pointing to trends in the area of GeoInformatics for the next years of research. As expected, the topics *Data/Information*, *Geographic Information System (GIS)*, *Time* and *Space* were included as the most relevant terms. From this perspective, we understand that research in GeoInformatics for the next years will follow these trends, namely big data, spatiotemporal data analysis, geographical applications for mobile devices, new architectures of Spatial Data Infrastructure (SDI), and spatiotemporal visualisation methods guiding exploratory data analysis.

Keywords: Trends, Big Data, Data Analysis, Mobile Devices, Spatial Data Infrastructure, Visualization.

RESUMO

Após uma revisão minuciosa das edições passadas do GEOINFO (Simpósio Brasileiro de GeoInformática), entre 1999 e 2015, incluindo mais de 300 artigos, foram identificados alguns tópicos que podem apontar para tendências na área de GeoInformática para os próximos anos de pesquisa. Como esperado, termos como D*ados/Informações*, *Sistema de Informação Geográfica (SIG)*, T*empo* e E*spaço* se destacaram como mais relevantes. A partir desta perspectiva, este artigo propõe o que se entende como tendências de pesquisa na área de GeoInformática. Essas tendências incluem *big data*, análise de dados espaço-temporais, aplicativos geográficos para dispositivos móveis, novas arquiteturas de infraestrutura de dados espaciais, e métodos de visualização espaço-temporal para análise exploratória de dados.

Palavras chaves: Tendências, Análise de Dados, Dispositivos Móveis, Infraestrutura de Dados Espaciais, Visualização.

1. INTRODUCTION

In this short paper we discuss some topics which have been highlighted as trends in GeoInformatics, based on a selection of papers presented at the Brazilian Symposium on GeoInformatics (GEOINFO). Since 1999, GEOINFO is an annual conference for exploring ongoing research, development and innovative applications on geographic information science and related areas. At <http://www.geoinfo.info/geoinfo_series.htm> we can find the GEOINFO archive, that provides open access for all presented papers on its past 16 editions. Besides, starting from 2015, the selected full papers presented at GEOINFO are published in a special edition of this Brazilian Journal of Cartography (RBC).

By accessing the GEOINFO archive, composed by 351 articles, the most recurrent topics were related, revealing some of previous and actual trends. In Fig. 1 we provide a visualisation of the 100 most recurrent words in the archive. As expected in this research area, topics such as *data/information*, *spatial*, *model* and *geographic* are at the top of this list. It is worth to say that, the topic *spatial* includes the words *geospatial* and *space*; topic *model* includes *models* and *modelling*, and so on. In the next section we detail some selected trends in GeoInformatics.

2. SELECTED TRENDS IN GEOINFORMATICS

The most frequent topics in all abstracts of GEOINFO archive were collected. In Fig. 2 we provide a time series, composed by all years in which GEOINFO occurred, relating 4 selected topics. They include the following:

- *Data/information*
- Geographic Information System (*GIS*)
- *Time-related* topics (e.g. *time*, *temporal*, *spatiotemporal*)
- *Spatial* (e.g. *geospatial, space*)

By analysing Fig. 2, it is possible to identify different patterns in the topics. *Data/Information* remains, as expected, in the top of the graph. Nowadays, GeoInformatics needs to merge multiple sources of data, and deal with constant updates, following a tendency to work with huge amounts of data, usually known as Big Data. The topic *Spatial* also remains with a constant trend, and it is also expected, since spatial data is the basis for GeoInformatics.

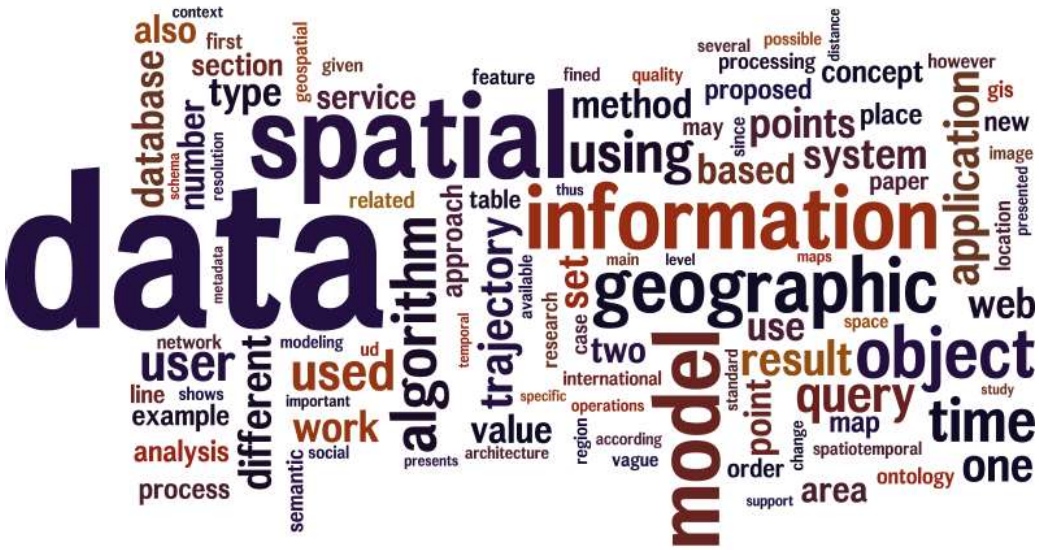

Fig. 1 - The 100 most recurrent words in GEOINFO archive, from 1999 to 2015.

Another analysis is about *GIS* that is reducing its occurrence along the time. One knows that we still need the Geographic Information Systems, however we can infer that the focus of research changed, since researchers of GeoInformatics are developing their own algorithms (or *scripts*) using easy-to-learn programming languages, such as Python or R.

Regarding *Time-related* topic, it is interesting to highlight its increase. More recent research is including effectively the variable time in the analysis of geographic information.

Examples include time series of remote sensing images, or sequences of data obtained by location sensors. Coupled with Spatial analysis, this is also an actual trend in GeoInformatics, which is usually called *Spatiotemporal data analysis*.

We identify trends in GeoInformatics for other areas as well. Although they occurred in some research articles, they were not yet identified as trends in GEOINFO. These topics include *Geographical Applications for mobile devices, New architectures of Spatial Data Infrastructure (SDI),* and *Spatiotemporal Visualisation methods guiding Exploratory Data Analysis*. As follows, we present examples of research related to those trends in GeoInformatics.

2.1 Big Data

The age of big data in the geospatial field has come and researchers are facing critical questions on how to organize and how to provide better tools to take advantage of these data. Both questions are related to the choice of a database technology suited for this task. Although the database technology has succeeded in the business market, it hasn't met the requirements of scientific community yet. The most common related problems range from improper data models and query languages to the lack of a specific data storage mechanism designed for scientific data (MAIER and VANCE, 1993; GRAY *et al.*, 2005).

More recently we are witnessing the emergence of a new family of database systems, the so called Multidimensional Array Databases. They are a mix of a database management system and a platform for data analytics with multidimensional arrays as first class citizens (BAUMANN and HOLSTEN, 2012).

Robust array database implementations are just in the beginning. Rasdaman was one of the pioneers in this field (BAUMANN *et al.*, 1998). Another promising array database is SciDB, that splits a big array into chunks that are distributed among different servers, that control a local data storage in a shared nothing architecture, and can perform array processing in parallel (STONEBRAKER *et al.*, 2011).

New conferences and work groups dedicated to array database technologies proves a renewed interest on the subject of array databases as a promising foundation for new platforms dedicated to scientific data management and analysis in the era of big data (STONEBRAKER *et al.*, 2013).

2.2 Spatiotemporal data analysis

In recent years, researchers on new analysis methods that take into account spatial and temporal features of geographical data have greatly increased. Here we focus on three well-known classes of spatiotemporal data and highlight the following topics: *trajectories of moving objects*, *time series of Earth observation satellite images* and *events*.

Moving objects are entities whose spatial positions or extents change continuously over time (ERWIG *et al.*, 1999). Examples of moving objects are cars, aircrafts, ships, mobile phone users, polar bears, hurricanes, forest fires, and oil spills on the sea. Trajectories are countable journeys associated to objects that are moving over time (SPACCAPIETRA *et al.*, 2008). In this class of spatiotemporal data, most analysis methods aim to discovery patterns. The *stop-move* pattern identifies segments of a trajectory where the object position changes (*moves*) and stays fixed (*stops*) (SPACCAPIETRA *et al.*, 2008; MORENO *et al.*, 2010). *Flock* pattern is defined as a set of moving objects that stay together within a given distance for a continuous period of time (TANAKA *et al.*, 2015). In (FONTES *et al.*, 2013) it is proposed a new algorithm for discovering spatial and spatiotemporal outliers based on trajectories data sets.

Time series of Earth observation satellite images are crucial for studies on land use and cover changes. MODIS (Moderate Resolution Imaging Spectroradiometer) sensor products, such as EVI2 (Enhanced Vegetation Index) and NDVI (Normalized Difference Vegetation Index), as well as LANDSAT images have being widely used for this purpose. Two examples of methods to classify time series of Earth observation satellite images are the time-weighted dynamic time warping (TWDTW) proposed by (MAUS *et al.*, 2016), and a method based on EVI2 time series feature extraction (NEVES *et al.*, 2015).

Events are *occurrents*. An event is an individual episode with a definite beginning and end. It only exists as a whole across the interval over which it occurs. An event does not change over time (GALTON and MIZOGUCHI, 2009).

Spatiotemporal events are associated to spatial locations and their analysis includes detection of spatiotemporal clusters (VELOSO *et al.*, 2013) and geocoding (SALAZAR *et al.*, 2015).

Temporal GIS is used to refer to GIS that can model, access, analyse and visualize spatiotemporal information. In the literature, there are many proposals of conceptual models to represent and handle spatiotemporal data in GIS and database systems. However, there is not yet a full-scale and comprehensive temporal GIS available (YUAN, 2009). Most of the existing temporal GIS technologies either are still in the research phase or are specific for certain application domain. In (FERREIRA *et al.*, 2015) the challenges related to temporal GIS development are highlighted.

2.3 Geographical Applications for mobile devices

The latest advances in GPS, wireless communication networks and portable technologies have motivated the development of mobile applications that deal with geographical information (TSOU, 2004; POORAZIZI *et al.*, 2008). (TSOU, 2004) defines the term mobile Geographical Information System (mobile GIS) as an integrated technological framework for accessing geospatial data and location-based services through mobile devices, such as smartphones and tablets. According to the author, there are two major application areas of mobile GIS, field-based GIS and location-based services.

Many studies have being done on this topic. Examples include a proposal of a framework to be used in the creation of volunteered geographic information (VGI) applications, incorporating both web-based tools and mobile applications (DAVIS *et al.*, 2013) and a proposal of a hybrid architecture for mobile geographical data acquisition and validation systems (BOGOSSIAN *et al.*, 2014).

2.4 New architectures of Spatial Data Infrastructure (SDI)

The term Spatial Data Infrastructure refers to a coordinate arrangement of spatial data, technology, policies and people that allows users to discover and access spatial data in a distributed environment and use it for purposes other than those that the data was created for (RAJABIFARD and WILLIAMSON, 2001). In Brazil the INDE - *Infraestrutura Nacional de Dados Espaciais* is a government initiative started in 2008 with the purpose to catalog, integrate and harmonize existing geospatial data in the institutions of the Brazilian government that are producers and/or maintainers of geographical data, so that the data can be easily located, explored and accessed for various uses and for any customer with Internet access.

From the technological point of view the main component of the SDI's is the use of standard geographic web services proposed by the OGC - Opengeospatial Consortium. GEOINFO community has been publishing articles about SDI implementations, including technological aspects of web services as well as communities of practices.

Arguably the concepts of SDI's have not been fully adopted by Brazilian institutions and the INDE is very modest considering the size of the country. This can be seen in the VINDE - *Visualizador da INDE* <http://www.visualizador.inde.gov.br/>, the portal that aggregates the data provided by institutions that are members of INDE. The limitations of OGC services and the difficulty to deploy and maintain standardized web services operationally is one of factors that contributes to the modest size of INDE. But it has been seen also as a research opportunity. The design and development of *ad-hoc* web services that complement those that are already part of OGC repertoire but with a simpler implementation and use is a topic of interest in the GEOINFO community, for example, how to disseminate large datasets of remote sensing imagery. Another promising research topic is the proposal of web services that deal with spatial and temporal data and not snapshots in time.

And finally, the possibility of having server side processing in an open environment is an interesting trend topic for research. Platforms such as the Google Earth Engine have been receiving a lot of attention and good reviews. We consider the proposition of alternatives to commercial solutions, including the use of server side processing based on web services and integrated to scientific environments such as R as trend topics.

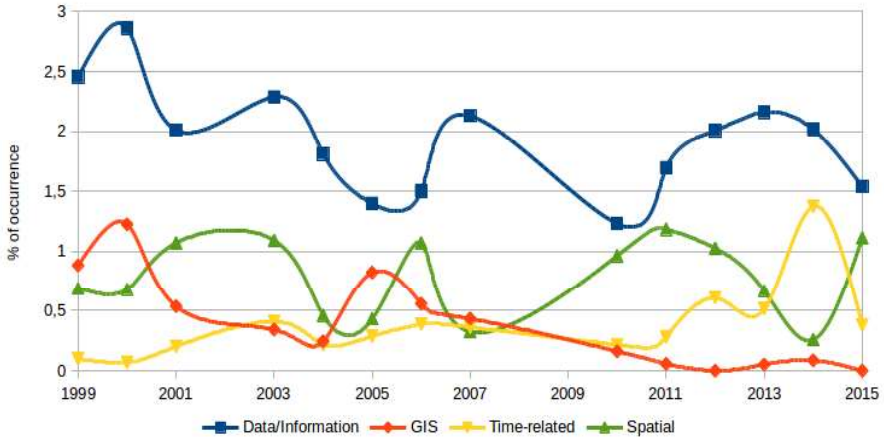

Fig. 2 - The percentage of occurrence of 4 selected topics in all GEOINFO abstracts, from 1999 to 2015.

2.5 Spatiotemporal Visualisation methods guiding Exploratory Data Analysis

Since the 1992 Anselin and Getis "Spatial statistical analysis and GIS" paper published in the *Annals of Regional Science* (ANSELIN and GETIS, 1992) it became clear that a full integration of computational spatial statistics and computational geography methods and concepts in the evolving GIS field would have no way back. Particularly all over the 90's up to the middle 2000's the GIS field saw a good number of fine papers on new methods and on integration models for analysing geographical phenomena modeled and represented using a GIS environment (BURROUGH, 1990; FOTHERINGHAM and ROGERSON, 1994; FOTHERINGHAM *et al.*, 2002; GOODCHILD *et al.*, 1992; OPENSHAW, 1990; OPENSHAW and ABRAHART, 1996; BAILEY and GATRELL, 1995). The GEOINFO series started at 1999 since its first Symposium up to the last one hold in 2015 have presented, every year, at least one paper making advances on this agenda. (FELGUEIRAS *et al.*, 1999; FEITOSA *et al.*, 2015).

However, the promised fully analytical integrated GIS environment have not developed at the same rate of advances that the computational statistics and the computational geography fields in separate, have gone through. But the world of spatial data have changed a lot. Over the last 12 years a whole lot of devices were put in the market that were capable of producing positional data always time tagged, and they did indeed! Associated with new Internet infrastructures and a completely new web-based applications world, these devices, public and/or private, have been producing an enormous and varied quantity of space-time (spatiotemporal) data acquired at different rates, different quality, different storage capabilities, different licenses of use and different institutional arrangements, gathered all over the planet. Although, the GIS field had great advances in methods and techniques developed to deal with complex geographical phenomena, we have to acknowledge that the GIS technology still have as central to its representational core a static, two-dimensional Euclidean support and a view of all these data variety oriented to be assembled as a 'collection of maps' as its central metaphor, constraining new developments due to this heavy legacy of the past.

Before these spatiotemporal data flood it was possible, although unnecessary, to keep the map metaphor and provide some advances in visualisation, but this is no possible any longer. As it happened over the 90's we need to advance the breed between visualisation techniques and the GIS environment. These new datasets bring about a higher dimensional and complex set of data for interpreting multi-scale spatiotemporal dynamics in geographical problems and, as such, they are in need of visualisation strategies capable of mapping these dimension into a visual interpretable space.

Inside the GIS field and related ones, as the cartography, we are seeing a movement in certain way similar to the developments the field has seen in the 90's over the analytical tools incorporated from the computational statistics and computational geography. As the geographical world is complex, dynamic, multi-dimensional and multi-scale over time it does

not fit a flat paper neither a computer screen. The GIS field is in need of new metaphors for dealing with the representation of mechanism and motion, process and dynamics, causes and effects, in order to help geographers and other interpreters of the space in building explanations and narratives for very complex interweaved spatiotemporal phenomena. The works of the Andrienko's group, Mitasova and Mitas, Yuan and Horsnby and the Peuquet's group show an entire way ahead (ANDRIENKO *et al.*, 2013; ANDRIENKO and ANDRIENKO, 2005, 2006; MITASOVA *et al.*, 2006; YUAN and HORSNBY, 2007; SWEDBERG *et al.*, 2014).

In Brazil, some groups, not historically involved into the GIS field, have a consistently production on new computational visualisation strategies for dealing with high-dimensional datasets as the Visualisation, Imaging and Computer Graphics Lab - VICG at the ICMS-USP/São Carlos and other groups, traditionally working on scientific visualisation techniques, could find a profitable dialogue with the GIS visualisations needs. The GEOINFO series has presented along the years some works on visualisation, they have appeared since 1999, although more focused on 3D visualisation and, more recently, on trajectory data visualisation strategies.

This is a necessary research agenda for the next years if we can advance the GIS field. We should do so by looking around and picking other experiences of the display of spatiotemporal analytical data to inspire our field in producing the innovative visualisation methods and technologies we are in need to make sense of this data deluge we are living in. Open our minds and looking through new ideas outside the strictly disciplinar field, for instance, works like those from Edward Tuft, Emeritus Professor of Political Science, Statistics and Computation at the Political Science Department at Yale, illustrated by his books *The Envisioning Information* from 1990 and, particularly, *Visual Explanation* from 1997, could be inspiring and a source for innovation.

3. FINAL REMARKS

In this short paper we pointed out what we consider as actual trends in GeoInformatics, based on a selection of papers presented at the Brazilian Symposium on GeoInformatics (GEOINFO), since 1999. By analysing the evolution of terms used in GEOINFO papers, we highlighted the following main topics: *Data/ Information, Geographic Information System (GIS), Time* and *Space*.

Some of these terms are growing, and some of them are reducing in terms of occurrence in articles. Based on them, and also relating other research areas, we understand that research in GeoInformatics for the next years should increase in at least five areas, namely Big Data, Spatiotemporal data analysis, Geographical Applications for mobile devices, New architectures of Spatial Data Infrastructure (SDI), and Spatiotemporal Visualisation methods guiding Exploratory Data Analysis.

REFERENCES

ANDRIENKO, G.; ANDRIENKO, N. Multimodal analytical visualisation of spatio-temporal data. **In: Cartwright, W. Multimedia Cartography,** Berlin, Germany. 2006.

ANDRIENKO, G.; ANDRIENKO, N.; BAK, P.; KEIM, D.; WROBEL, S. **Visual Analytics of Movement**. Springer-Verlag Berlin Heidelberg, 2013.

ANDRIENKO, N.; ANDRIENKO, G. **Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach**. Springer-Verlag Berlin Heidelberg, 2005.

ANSELIN, L.; GETIS, A. Spatial statistical analysis and geographic information systems. **In: Annals of Regional Science,** p. 19-33, 1992.

BAILEY, T.C.; GATRELL, A.C. **Interactive Spatial Data Analysis**, Harlow, Essex, Uk, Longman Scientific and Technical, 1995.

BAUMANN, P.; DEHMEL, A.; FURTADO, P.; RITSCH, R. and WIDMANN, N. The multidimensional database system RasDaMan. **In: Proceedings of the ACM SIGMOD international conference on Management of data (SIGMOD '98)**. New York, NY, USA, p. 575-577, 1998.

BAUMANN, P.; HOLSTEN, S. A Comparative Analysis of Array Models for Databases . **International Journal of Database Theory and Application**, v 5, p. 89-120, 2012.

BOGOSSIAN, C. H.; FERREIRA, K. R.; MONTEIRO, A. M. V.; VINHAS, L. A Hybrid Architecture for Mobile Geographical Data Acquisition and Validation Systems. **In: Proceedings of XV Brazilian Symposium on GeoInformatics (GEOINFO)**. Campos do Jordão, Brazil. 2014.

BURROUGH, P. A. Methods of spatial analysis and GIS. **International Journal of Geographical Information Systems**, v 4, p. 221-223, 1990.

DAVIS JR., C. A.; VELLOZO, H. S.; PINHEIRO, M. B. A Framework for Web and Mobile Volunteered Geographic Information Applications. **In: Proceedings of XIV Brazilian Symposium on GeoInformatics (GEOINFO).** Campos do Jordão, Brazil. 2013.

ERWIG, M.; GUTING, R. H.; SCHNEIDER, M.; VAZIRGIANNIS, M. Spatio-Temporal Data Types: An Approach to Modeling and Querying Moving Objects in Databases. **GeoInformatica**. v. 3, p. 265-291. 1999.

FEITOSA, F.; ROSEMBACK, R. G.; JACOVINE, T. C. Small area housing deficit estimation: a spatial microsimulation approach. **In: Proceedings of XIV Brazilian Symposium on GeoInformatics (GEOINFO)**, Campos do Jordão, Brazil. 2015.

FELGUEIRAS, C. A.; MONTEIRO, A. M. V.; CAMARGO, E. C. G.; CAMARA, G. FUKS, S. D. Integrating geostatistical tools in Geographical Information Systems. **In: Proceedings of I Brazilian Symposium on GeoInformatics (GEOINFO)**, Campos do Jordão, Brazil. 1999.

FERREIRA, K. R.; OLIVEIRA, A. G.; MONTEIRO, A. M. V.; ALMEIDA, D. B. F. C. Temporal GIS and Spatiotemporal Data Sources. **In: Proceedings of XVI Brazilian Symposium on GeoInformatics (GEOINFO)**, Campos do Jordão, Brazil. 2015.

FONTES, V. C.; ALENCAR, L. A.; RENSO C.; BOGORNY, V. Discovering Trajectory Outliers between Regions of Interest. **In: Proceedings of XIV Brazilian Symposium on GeoInformatics (GEOINFO)**, Campos do Jordão, Brazil. 2013.

FOTHERINGHAM, A. S.; BRUNSDON, C.; CHARLTON, M. **Geographically Weighted Regression: The Analysis of Spatially Varying Relationships**. Hoboken, NJ: Wiley. 2002.

FOTHERINGHAM, A. S.; ROGERSON, P. **Spatial Analysis and GIS**. London: Taylor and Francis, 1994.

GALTON, A.; MIZOGUCHI, R. The water falls but the waterfall does not fall: New perspectives on objects, processes and events. **Applied Ontology**, v. 4(2), p. 71-107. 2009.

Brazilian Symposium on GeoInformatics (GEOINFO) series of proceedings. Available at <http://www.geoinfo.info/geoinfo_series.htm>. ISSN 2179-4847. Visited in March, 15. 2016.

GOODCHILD, M. F.; HAINING, R. P.; WISE, S. Integrating GIS and spatial analysis: problems and possibilities. **International Journal of Geographical Information Systems**, v 6, p. 407-23, 1992.

GRAY, J.; LIU, D. T.; NIETO-SANTISTEBAN, M.; SZALAY, A.; DEWITT, D. J.; HEBER, G. **Scientific data management in the coming decade**. SIGMOD Rec. 34, v 4, p. 34-41. 2005.

MAIER, D.; VANCE, B. A call to order. **In: Proceedings of the 12th ACM SIGACT-SIGMOD-SIGART symposium on Principles of database systems (PODS)**. New York, USA, 1993.

MAUS, V.; CAMARA, G.; CARTAXO, R,; SANCHEZ, A.; RAMOS, F.; QUEIROZ, G. A time-weighted dynamic time warping method for land use and land cover mapping. Accepted for publication on **IEEE Journal of Selected Topics In Applied Earth Observations And Remote Sensing**. DOI: 10.1109/JSTARS.2016.2517118. 2016.

MITASOVA, H.; MITAS, L.; RATTI, C.; ISHII, H.; ALONSO, J.; HARMON, R. S. Real-Time landscape model interaction using a tangible Geospatial Modeling Environment. **IEEE Computer Graphics and Applications**, v 26, p. 55-63. 2006.

MORENO B. N.; TIMES V. C.; RENSO C.; BOGORNY V. Looking inside the stops of trajectories of moving objects. **In: Proceedings of XI Brazilian Symposium on GeoInformatics (GEOINFO)**, Campos do Jordão, Brazil. 2010.

NEVES, A. K.; BENDINI, H. N.; KÖRTING, T. S.; FONSECA, L. M. G. Combining Time Series Features and Data Mining to Detect Land Cover patterns: a Case Study in Northern Mato Grosso State, Brazil. **In: Proceedings of XVI Brazilian Symposium on GeoInformatics (GEOINFO)**, Campos do Jordão, Brazil. 2015.

OPENSHAW, S. Spatial analysis and geographical information systems: a review of progress and possibilities. **In: Geographical Information Systems for Urban and Regional Planning**. Dordrecht: Kluwer, p. 153-163. 1990.

OPENSHAW, S.; ABRAHART, R. J. Geocomputation. **In: Proceedings of the 1st International Conference on GeoComputation**, University of Leeds, UK, p. 665-666. 1996.

POORAZIZI, E.; ALESHEIKH, A. A.; BEHZADI, S. Developing a Mobile GIS for Field Geospatial Data Acquisition. **Journal of Applied Sciences**. 8(18), 3279-3283. 2008.

RAJABIFARD, A.; WILLIAMSON, I. P. Spatial data infrastructures: concept, SDI hierarchy and future directions, **In: Proceedings of GEOMATICS'80 Conference**, Tehran, Iran. 2001.

SALAZAR, C, J. C.; TORRES-RUIZ, M.; DAVIS-JR, C. A.; MORENO-IBARRA, M. Geocoding of traffic-related events from Twitter. **In: Proceedings of XVI Brazilian Symposium on GeoInformatics (GEOINFO)**, Campos do Jordão, Brazil. 2015.

SPACCAPIETRA, S.; PARENT, C.; DAMIANI, M.; MACEDO, J. A. F.; PORTO, F.; VANGENOT, C. A conceptual view on trajectories. **Data & Knowledge Engineering**. v. 65, p. 126-146, 2008.

STONEBRAKER, M.; BROWN, P.; POLIAKOV, A.; RAMAN, S. The architecture of SciDB. **In: Proceedings of the 23rd international conference on Scientific and statistical database management (SSDBM)**, Springer-Verlag, Berlin, Heidelberg, 2011.

STONEBRAKER, M.; DUGGAN, J.; BATTLE, L.; PAPAEMMANOUIL, O. SciDB DBMS Research at M.I.T. **IEEE Data Engineering Bulletin**, v 36, pp. 21-30, 2013.

SWEDBERG, B.; ROBINSON, A.; HARDISTY, F.; PEUQUET, D. Geovisualization of spatio-temporal events in STempo. **In: GIScience conference**. Vienna, Austria, 2014.

TANAKA, P. S.; VIEIRA, M. R.; KASTER, D. S. Efficient Algorithms to Discover Flock Patterns in Trajectories. **In: Proceedings of XVI Brazilian Symposium on GeoInformatics (GEOINFO)**, Campos do Jordão, Brazil. 2015.

TSOU, M. H. Integrated mobile GIS and wireless internet map servers for environmental monitoring and management. **In: Special issue on Mobile Mapping and Geographic Information Systems, Cartography and Geographic Information Science**, v 31, p. 153-165. 2004.

VELOSO, B.; IABRUDI, A.; CORREA T. Towards efficient prospective detection of multiple spatio-temporal clusters. **In: Proceedings of XIV Brazilian Symposium on GeoInformatics (GEOINFO)**, Campos do Jordão, Brazil. 2013.

YUAN, M. Challenges and Critical Issues for Temporal GIS Research and Technologies. **In: Handbook of Research on GeoInformatics**, IGI Global, Hershey, p. 144-153. 2009.

YUAN, M.; HORNSBY, K. S. **Computation and Visualization for Understanding Dynamics in Geographic Domains: A Research Agenda**. CRC Press, 2007.