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Digital Government: Knowledge Management Over Time-Varying Geospatial Datasets

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Digital Government: Knowledge Management Over Time-Varying Geospatial Datasets

Project Participants

Senior Personnel

Name: Agouris, Peggy
Worked for more than 160 Hours: Yes
Contribution to Project:
Principal Investigator, managing research activities.

Name: Beard-Tisdale, Mary-Kate
Worked for more than 160 Hours: Yes
Contribution to Project:
Co-Investigator, contributing research activities.

Name: Stefanidis, Anthony
Worked for more than 160 Hours: Yes
Contribution to Project:
Co-Investigator, managing research activities.

Post-doc

Name: Takatsuka, Masahiro
Worked for more than 160 Hours: Yes
Contribution to Project:
Partially supported by this project, post-doctoral researcher at Penn State.

Name: Doucette, Peter
Worked for more than 160 Hours: Yes
Contribution to Project:
Pete's involvement in this project started when he was a graduate student and continued after his graduation in 2002, when he accepted a post-doctoral position.

Graduate Student

Name: Eickhorst, Kristin
Worked for more than 160 Hours: Yes
Contribution to Project:
Graduate research assistant at UMaine, Ph.D. student. Receives monthly stipend and tuition.

Name: Georgiadis, Harris
Worked for more than 160 Hours: Yes
Contribution to Project:
Graduate research assistant at UMaine, Ph.D. student. Receives monthly stipend and tuition.

Name: Li, Han
Worked for more than 160 Hours: Yes
Contribution to Project:

Graduate research assistant at Penn State, Ph.D. student. Receives monthly stipend and tuition. Partially supported by this project.

Name: Wheeler, Mike
Worked for more than 160 Hours: Yes
Contribution to Project:
Graduate research assistant at Penn State, Ph.D. student. Receives monthly stipend and tuition. Partially supported by this project.

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Worked for more than 160 Hours: Yes
Contribution to Project:
Graduate research assistant at Penn State, Ph.D. student. Receives monthly stipend and tuition. Partially supported by this project.

Name: Tsoukatos, Ilias
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Zhang, Donghui
Worked for more than 160 Hours: Yes
Contribution to Project:
Mr. Zhang received his Ph.D. last year and he is currently an Assistant Professor at Northeastern University in Boston, MA.

Name: Hadjieleftheriou, Marios
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Vlachos, Michalis
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Partsinevelos, Panayotis
Worked for more than 160 Hours: Yes
Contribution to Project:
Mr. Partsinevelos received his Ph.D. in Dec. 2002. His work on modeling spatiotemporal phenomena and objects contributed significantly to this project.

Name: Gyftakis, Sotiris
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: O'Brien, James
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Luo, Junyan
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Vagena, Zografoula
Worked for more than 160 Hours: Yes

Contribution to Project:

Undergraduate Student

Technician, Programmer

Other Participant

Name: Gahegan, Mark
Worked for more than 160 Hours: Yes
Contribution to Project:
Supervises and directs subcontract to Penn State University. Managing research activities.

Name: Tsotras, Vassilis
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Gunopulos, Dimitris
Worked for more than 160 Hours: Yes
Contribution to Project:

Research Experience for Undergraduates

Organizational Partners

National Imagery and Mapping Agency

Department of Agriculture National Agricultural Statisics Serv

BAE SYSTEMS

U.S. Geological Survey

National Academy of Sciences

San Diego Supercomputer Center

Other Collaborators or Contacts

We are working with Milcord LLC, a IT consulting firm based in Boston, to transition some of the research performed in this project into products through SBIR grants.

Activities and Findings

Research and Education Activities:
As reported in our progress reports, in this project we dealt specifically with

four complementary challenging research issues which are keys to realizing the integration and improved access to the information content of heterogeneous time-varying geospatial datasets.

Specifically, we addressed:
1. The development of a geospatial knowledge management framework to provide the syntax, context, and semantics for researching, understanding, and leveraging technical and human behaviors related to spatial understanding and work.
2. The development of novel meta-information concepts to convey summaries of heterogeneous datasets (focusing especially on raster and vector spatial datasets). This is a step towards next generation geospatial metadata, in which we take advantage of modern computer capabilities to convey the actual content of datasets.
3. The development of efficient techniques for discovering sequential patterns in spatio-temporal datasets. Sequential patterns are important as they take into account not only the spatial characteristics of a sequential event but also the time order by which the event components happened.
4. The integration of the above issues to support spatio-temporal reasoning for the extraction of complex information through scene modeling and analysis processes.

In the first year of the project we worked on areas 1 and 2. During year two, we continued working on areas 1 and 2, but also started working on area 3. During year 4, we worked on areas 1, 2 and 3, and during the past year we worked on area 4.

More specifically, our work under topic 1 has focused on computational and visualization tools to process and extract meaning (or allow users to extract meaning) from complex geospatial datasets. To this end, we have added a number of visualization, analysis and machine learning tools, to the tools we developed over the previous months. These tools leverage additional research underway at Penn State Geography, and more specifically, a software environment within which to construct and experiment with geospatial semantics known as GeoVISTA Studio. The environment, along with some of the tools developed in this research, can be downloaded over the Internet from http://www.geovistastudio.psu.edu/jsp/index.jsp.

In this project we also developed a data model that spans the various tools and techniques described above, providing the basic building blocks for a semantic network that relates these various stages of knowledge discovery together. This model has been extensively tested, refined, and implemented in two phases. In the first phase, core data structures that form the basis of concept discovery, evolution (refinement) deployment and evaluation have been developed. These data structures were integrated with the computational and visual tools described above, to provide the user with several collaborating strategies for extracting content from large datasets. In the second phase, an expert system shell was used to construct a sentinel to arbitrate and monitor the transformations applied to geospatial data, in order to keep track of associated meaning and heritage/lineage.

Overall, major research activities on area 1 have focused around four specific topics:

(1) Development of a conceptual framework within which the process of science, or specifically the discovery, construction, use and validation of new knowledge can be understood.

(2) Design of an agent-based representation of semantic interoperability and exchange between components within a geospatial framework.

(3) Development of suitable data model components with which to describe the process of knowledge discovery and establish meaning in the sense of the process of science that led to the construction of an object, category or relation.

(4) Tools to support the extraction of meaning, or interpretation of complex spatio-temporal datasets.

Our work under topic 2 has focused on spatiotemporal generalization and summarization of time-varying geospatial datasets. We developed an extension of self-organizing maps (SOM) to perform generalization of spatiotemporal (ST) point-based trajectories of events. This allowed us to identify critical nodes along such trajectories. The nodes correspond to instances where the rate of evolution of an event has changed (acceleration/ deceleration), or instances where the event's path has changed in space (e.g. a storm front changing its path). Subsequently, we extended our work beyond point-based trajectories to include spatiotemporal events of full spatial extent (not just point-based), similar to the ones typically encountered by our partner agencies. To accomplish this, we have developed a new concept, the concept of the 'Spatiotemporal Helix'. This novel model of multiresolutional spatiotemporal information integrates our work on self organizing maps (SOM) as well as image-based change detection algorithms we have newly developed, and allows us to perform multimedia summarization. Because of its innovative concept, our novel model is suitable for both metric-quality analysis as well as visualization. As we have previously reported, our work has allowed us to leverage research funds by collaborating with our industrial partner (BAE Systems). In addition, through interactions initiated by this project and based on work performed by the PIs at UMaine, we have received funding from NIMA for additional collaborative efforts. Lastly, we developed novel similarity metrics for our SpatioTemporal Helix model, that allow us to compare events and perform high-level reasoning. We also created algorithms to differentiate multiple overlapping phenomena, solving thus the problem of entangled spatiotemporal trajectories.

Our work on area 3 included three subtasks. During year one, we completed (and published) our work on the first subtask that deals with mining spatiotemporal data for simple spatiotemporal events. The second subtask dealt with identifying trends and correlations among collections of simple spatiotemporal events. For this subtask, we examined efficient techniques for computing temporal and spatial aggregate queries. We then proposed indexing schemes for temporal and spatiotemporal data, and finally, we examined the problem of indexed temporal join queries. We also addressed aggregate computation by proposing efficient techniques for temporal aggregates and examining how to improve spatial aggregate computations and temporal aggregation over data streams. In terms of indexing schemes we have developed efficient indexing techniques for spatiotemporal data with linear moving functions, extended them to objects moving with general functions and worked on temporal hashing methods. We have also examined efficient ways to process temporal join queries. In terms of the third subtask which is to mine complex sequential patterns, we presented a fast algorithm that mines frequent spatiotemporal patterns and we have investigated techniques for analysis and retrieval of object trajectories in 2- and 3-

dimensional space.

We also worked on subtasks 2 and 3 (outlined in the previous paragraph). In particular we addressed:

- Joins in a spatiotemporal setting (subtask 2);
- Spatiotemporal aggregate computation (subtask 2);
- Correlation of spatiotemporal data streams (subtask 2);
- Mine for sequential patterns that may occur at different spatial positions (subtask 3);
- Understanding pattern change in spatiotemporal data sets (subtask 3).

As usual, our publications (listed in a subsequent section) reflect our work in all project areas. In terms of educational activities, we have been integrating our research findings in the relevant courses taught by the PIs and have developed new selected studies course offerings that are based on our project work.

Findings:

Our research findings are described in detail in our project-related publications. Based on our research work we developed novel software prototypes like the Spatiotemporal Helix tool and GeoVISTA Studio environment. We have also been able to leverage more mature software from other on-going efforts to enhance our current project products.

In addition to funded research activities, this collaboration resulted in the donation of valuable digital image analysis software. Beyond research, this software is used in relevant courses at UMaine. The project has also enabled us to form closer ties with additional researchers from complementary fields and personnel from agencies other than our initial partners.

Training and Development:

The project supported (partially or fully) post-doctoral researchers and several graduate students as research assistants at all three academic sites (UMaine, Penn State, and UC-Riverside). It should be noted that during their involvement in this project, some of the supported students have received NSF fellowships, awards by the American Society for Photogrammetry and Remote Sensing, and fellowships by NASA. All supported students were directly involved in research training through the development of research concepts and novel algorithms and tools for their theses.

Some of the project's activities are presented to students enrolled in the graduate and undergraduate programs of the Departments that are involved in this project as parts of the courses offered by the PIs.

Outreach Activities:

With respect to outreach activities, and in addition to the fact that our research findings were incorporated in the courses offered by the PIs, we also participated in the following:

-Dept. of Spatial Information Engineering's 'Spatial Horizons' high school outreach program, and
- University of Maine's 'Expanding your Horizons' program that is geared towards female high school students in an effort to increase their participation

in science and engineering.

The GeoVISTA Studio software system, which was developed in part through this project, has a growing list of users that includes (among others) several government agencies (e.g. Census, NCI). Studio is also being used by another Digital Government group (Quality Graphics--DGQG) and by a large NSF ITR project (the GEON network hosted by SDSC). We plan to leverage additional resources to improve online training and documentation to make these tools available to a wider community of scientists.

Studio is also being used by Pacific Northwest National Labs, with whom we are now collaborating on various aspects of software development. Several universities throughout the world are also now using this system for a variety of tasks, ranging from marine biology to social anthropology.

Studio was used to train participates in the NSF-sponsored workshop series Center for Spatially Integrated Social Science (CSISS) in the use of visualization and knowledge discovery methods.

Last but not least, several NSF-related meetings (e.g. the DG Statistics workshop in 2001, a biodiversity workshop that took place in Florida in 2002, a workshop on Geo-Sensors that took place last fall, and other similar events) have provided us with the perfect forum to present our work to interested federal and state agencies and expand the visibility of our efforts.

Journal Publications

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D. Zhang, V.J. Tsotras, "Improving Min/Max Aggregation Over Spatial Objects", Proceedings, 9th ACM International Symposium on Advances in Geographic Information Systems
, p. -, vol. , (2001). Published,

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D. Zhang, V.J. Tsotras, B. Seeger, "Efficient Temporal Join Processing Using Indices", Proceedings, 18th International Conference on Data Engineering (ICDE)
, p. -, vol. , (2002). Published,

M. Hadjieleftheriou, G. Kollios, V.J. Tsotras, D. Gunopulos, "Efficient Indexing of Spatiotemporal Objects", Proceedings, 8th International Conference on Extending Database Technology (EDBT), p. -, vol. , (2002). Published,

MacEachren, A. M., Hardisty, F., Gahegan, M., Dai, X., Guo, D., and Takatsuka, M., "Supporting visual integration and analysis of geospatially-referenced statistics through web-deployable, cross-platform tools", Digital Government Conference, p. -, vol. , (2001). Published,

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M. Hadjieleftheriou, G. Kollios, V.J. Tsotras, "Performance Evaluation of Spatio-temporal Selectivity Estimation Techniques", 15th International Conference on Scientific and Statistical Database Management
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Gahegan, M., "Is inductive inference just another wild goose (or might it lay the golden egg)?", International Journal of Geographical Information Science, p. 69, vol. 17(1), (2003). Published,

Guo, D. Gahegan, M. and Peuquet, D., "ICEAGE: Interactive Clustering and Exploration of Large and High-dimensional Geodata", GeoInformatica, p. , vol. , ( ). Accepted,

Gahegan, M. and Brodaric, B., "Computational and Visual Support for Geographical Knowledge Construction: Filling in the Gaps Between Exploration and Explanation", 10th International Symposium on Spatial Data Handling, p. 11, vol. , (2002). Published,

Gahegan M. and Brodaric, "Examining Uncertainty in the Definition and Meaning of Geographical Categories", 5th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, p. 0, vol. , (2002). Published,

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A. Stefanidis, P. Agouris, M. Bertolotto, J. Carswell, Ch. Georgiadis, "Scale and Orientation-Invariant Scene Similarity Metrics for Image Queries", International Journal of Geographical Information Science, p. 749, vol. 16(8), (2002). Published,

G. Mountrakis, P. Agouris, A. Stefanidis, "Multitemporal Geospatial Query Grouping Using Correlation Signatures", International Conference on Image Processing (ICIP), p. , vol. , (2003). Accepted,

G. Mountrakis & P. Agouris, "Learning Similarity with Fuzzy Functions of Adaptable Complexity", Proceedings Symposium on Spatio-Temporal Databases (SSTDó03), Springer-Verlag, p. , vol. , (2003). Accepted,

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G. Mountrakis, P. Agouris, A. Stefanidis, "A Differential Spatiotemporal Model: Primitives and Operators", Advances in Spatial Data Handling, Springer Verlag, p. 255, vol. , (2002). Published,

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K. Eickhorst & P. Agouris, "On the Use of Hierarchies and Feedback for Intelligent Video Query Systems", Int. Archives of Photogrammetry & Remote Sensing, p. 412, vol. 34(4), (2002). Published,

Books or Other One-time Publications

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Open Systems GIS and
Semantics", (2000). Proceedings, Published
Collection: GeoCanada 2000: The
Millennium Geoscience Summit
Bibliography: Proceedings

Gahegan, M., "Exploratory Geographic Visualization: Analysis with Light", (2001). Book, Published
Editor(s): Miller, H. and Han, J.
Collection: Knowledge Discovery with Geographic Information
Bibliography: Taylor & Francis, London

P. Agouris, P. Doucette & A.
Stefanidis, "Automation and Digital
Photogrammetric Workstations", ( ). Book, Accepted
Editor(s): E. Mikhail, C. McGlone
Collection: Manual of Photogrammetry (5th
Edition)
Bibliography: ISPRS Book Series

Web/Internet Site

URL(s):

http://www.geovistastudio.psu.edu/jsp/index.jsp

Description:

The GeoVISTA Studio environment (partially supported by this project), along with some of the tools developed in this research, can be downloaded over the Internet from the above web site.

Other Specific Products

Contributions

Contributions within Discipline:

This project advanced science in geospatial data processing and analysis, and spatial databases. We developed new algorithms to support the metric analysis of such information. We also developed new multimedia summaries to communicate the content of large dataset collections to expert users and general audience alike.

Contributions to Other Disciplines:

As reflected by the multidisciplinary academic group working on this project, the work performed here addressed issues relevant to several fields: geospatial information systems, digital image analysis, geography, and databases. Our efforts complemented and were complemented by parallel advancements in a variety of related disciplines, most notably digital libraries.

Contributions to Human Resource Development:

This project supported the graduate studies of several students at three academic sites (UMaine, Penn State, UC-Riverside). All supported students worked as Graduate Research Assistants. Most of them were Ph.D. candidates and their research work performed for this project formed the core of their dissertation (or thesis) research.

Furthermore, educational developments resulting from this work affected graduate and undergraduate courses at all 3 sites.

Contributions to Resources for Research and Education:

Our work in this project has been instrumental in enabling the PIs at UMaine to attract funding for complementary collaborative efforts from NGA and NRO, as well as several SBIR grants where some of the PIs are participating.

In addition, the GeoVISTA Studio software environment has a significant user-base. Studio is also being used by another Digital Government group (Quality Graphics--DGQG), and by a number of federal agencies and universities. We plan to leverage additional resources beyond this project to improve online training and documentation and make these tools available to a wider community of scientists.

Contributions Beyond Science and Engineering:

No direct such contributions were expected to be made through this project. However, indirectly, we expect that work in this project will facilitate the availability of and access to more reliable, accurate, and timely spatiotemporal information.

Categories for which nothing is reported:

Any Product