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# NSF-CNPq Collaborative Research on Integrating Geospatial Information

Max J. Egenhofer

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**Final Report for Period:** 09/1999 - 09/2004

**Submitted on:** 02/01/2006

**Principal Investigator:** Egenhofer, Max J.

**Award ID:** 9970123

**Organization:** University of Maine

**Title:**

NSF-CNPq Collaborative Research on Integrating Geospatial Information

### Project Participants

#### Senior Personnel

**Name:** Egenhofer, Max

**Worked for more than 160 Hours:** Yes

**Contribution to Project:**

**Name:** Camara, Gilberto

**Worked for more than 160 Hours:** No

**Contribution to Project:**

Research partner while visiting the Brazilians at INPE and during his visit to Orono. Jointly conducted research on the ontology of fields.

**Name:** Tillio, Marcello

**Worked for more than 160 Hours:** No

**Contribution to Project:**

Research partner during his visit to Orono.

#### Post-doc

**Name:** Campos, Jorge

**Worked for more than 160 Hours:** No

**Contribution to Project:**

#### Graduate Student

**Name:** Fonseca, Frederico

**Worked for more than 160 Hours:** Yes

**Contribution to Project:**

Conducted research into onotology-based geographic information systems, as a graduate research assistant.

**Name:** Rodriguez, Andrea

**Worked for more than 160 Hours:** No

**Contribution to Project:**

**Name:** Farrugia, Jim

**Worked for more than 160 Hours:** No

**Contribution to Project:**

#### Undergraduate Student

#### Technician, Programmer

**Other Participant****Research Experience for Undergraduates****Organizational Partners****INPE, Brazil****UNICAMP, Brazil****Catholic University Rio de Janeiro, Braz****Other Collaborators or Contacts**

A research project funded by the National Geospatial-Intelligence Agency (formerly NIMA) that fostered collaboration with the Virginia Commonwealth University

Other NSF-funded projects collaboration with UC Santa Barbara and the Univeristy at Buffalo

An NIH-funded project collaboration with the University at Buffalo

A bioinformatics project that included collaboration with Jackson Lab (Bar Harbor)

Collaboration with researchers at the University of M<sup>3</sup>nster (Germany) and the University of Bremen (Germany) during a sabbatical of the PI.

**Activities and Findings****Research and Education Activities:**

Development and implementation of a computational model for semantic similarity based on ontologies.

Development and simulation of a computational model for assessing the potential for information integration.

Development of the concept of ontology-driven GIS as a novel approach to integrate treatment of semantics into GIS.

Development of the concept of the geospatial semantic web as a foundation for semantic spatial search.

**Findings:**

Information retrieval at different levels of granularity inside the framework of information systems based on ontologies.

We introduced a GIS architecture that can enable geographic information integration in a seamless and flexible way based on its semantic value and regardless of its representation. The proposed solution is an ontology-driven geographic information system that acts as a system integrator. In this system, an ontology is a component, such as the database, cooperating to fulfill the system's objectives. By browsing through ontologies the users can be provided with information about the embedded knowledge of the system. Special emphasis is given to the case of remote sensing systems and geographic information systems. The levels of ontologies can be used to guide processes for the extraction of more general or more detailed information. The use of multiple ontologies allows the extraction of information in different stages of classification. The

semantic integration of aerial images and GIS is a crucial step towards better geospatial modeling.

The paper 'Using Ontologies for Integrated Geographic Information Systems' by Fonseca, Egenhofer, Agouris, and Camara, published in Transactions in GIS, has become the second most frequently cited paper in that journal.

See publications with Fonseca for detail.

A method to compare different ontologies for similarity.

We developed a novel approach to computing semantic similarity that relaxes the requirement of a single ontology and accounts for differences in the levels of explicitness and formalization of the different ontology specifications. A similarity function determines similar entity classes by using a matching process over synonym sets, semantic neighborhoods, and distinguishing features that are classified into parts, functions, and attributes. Experimental results with different ontologies indicate that the model gives good results when ontologies have complete and detailed representations of entity classes. While the combination of word matching and semantic neighborhood matching is adequate for detecting equivalent entity classes, feature matching allows us to discriminate among similar, but not necessarily equivalent, entity classes.

The paper 'Determining Semantic Similarity Among Entity Classes from Different Ontologies' by Rodriguez and Egenhofer, published in IEEE Transactions on Knowledge and Data Engineering has already over 110 citations (according to google scholar).

See publications with Rodriguez for further details.

#### **Training and Development:**

Ontology design, ontology construction, and similarity-based ontology alignment.  
Software engineering (prototype development by graduate research assistants).  
Oral and written presentations.

#### **Outreach Activities:**

Participation in the development of the UCGIS emerging research theme on 'Ontological Foundations of Geographic Information Science.'

11 keynote addresses related to geo-ontologies and semantic similarity at international conferences

- Interoperating Geographic Information Systems, GeoBrazil, So Paulo, Brazil, June 2000
- Theory-Based Assessment of Semantic Similarity, EURESCO Conference on Ontology and Epistemology for Spatial Data Standard, La Londe-les-Maures, France, September 2000
- Research Directions for Spatial Information SystemsFrom Knowing Your Location to Spatial Forecasting, Twelve Annual Colloquium of the Spatial Information Research Centre, Dunedin, New Zealand, December 2000
- Advances in GIScience Toward Web-Based Arctic GIS, Arctic Geographic Information Systems Workshop, Seattle, WA, January 2001
- Spatial Web, 16th Simpsio Brasileiro de Banco de Dados, Rio de Janeiro, Brazil, October 2001
- Toward the Semantic Geospatial Web, ACM-GIS 200210th ACM International Symposium on Advances in Geographic Information Systems, McLean, VA, November 2002
- Sensors, Sensors Everywhere, GeoSensor Networks 2003, Portland, ME, October 2003

- Spatial Semantics on the Geospatial Semantic Web. GEOPRO 2003: International Workshop on Semantic Processing of Spatial Data, Mexico City, Mexico, November 2003
- Information Systems Fueled with Data from Geo-Sensor Networks, Information Systems in Geomanagement, Aachen, Germany, March 2004
- A Grand Challenge for Geographic Information Science, Geoide Summer School 2004, Ottawa, Canada, May 2004
- Geo-Ontometry: Beyond Geo-Ontologies, First International Workshop on Conceptual Modeling for GIS, Shanghai, China, November 2004

Participation in a meeting of the NRC committee on Intersections between Geospatial Information and Information Technology.

### **Journal Publications**

- F. Fonseca, M. Egenhofer, C. Davis, and K. Borges  
 , "Ontologies and Knowledge Sharing in Urban GIS", Computer, Environment and Urban Systems, p. 251, vol. 24, (2000). Published
- A. Rodriguez and M. Egenhofer, "Determining Semantic Similarity Among Entity Classes from Different Ontologies", IEEE Transactions on Knowledge and Data Engineering, p. 442, vol. 15 (2), (2003). Published
- F. Fonseca, M. Egenhofer, C. Davis, and G. Camara, "Semantic Granularity in Ontology-Driven Geographic Information Systems", Annals of Mathematics and Artificial Intelligence, p. 121, vol. 36 (1), (2002). Published
- F. Fonseca and M. Egenhofer, "Sistemas de Informacao Geograficos Baseados em Ontologias", Informatica Publica, p. 47, vol. 1, (1999). Published
- A Rodriguez and M. Egenhofer, "Comparing Geospatial Entity Classes: An Asymmetric and Context-Dependent Similarity Measure", International Journal of Geographical Information Science, p. 229, vol. 18(3), (2004). Published
- F. Fonseca, M. Egenhofer, P. Agouris, and G. Camara, "Using Ontologies for Integrated Geographic Information Systems", Transactions in GIS, p. 231, vol. 6(3), (2002). Published

### **Books or Other One-time Publications**

- G. Camara, M. Egenhofer,  
 F. Fonseca, A. Monteiro, "What's in an Image?", (2001). Refereed Conference Proceedings, Published  
 Editor(s): D. Montello  
 Collection: COSIT '01-Conference on  
 Spatial Information Theory  
 Bibliography: Lecture Notes in Computer  
 Science, Vol. 2121, pp. 474-488, Springer-Verlag
- F. Fonseca, M. Egenhofer,  
 and C. Davis, "Ontology-Driven Information  
 Integration", (2000). Refereed Conference Proceedings, Published  
 Editor(s): C. Bettini and A. Montanari  
 Collection: AAAI-2000 Workshop on  
 Spatial and Temporal  
 Granularity  
 Bibliography: pp. 61-64

F. Fonseca, M. Egenhofer,  
and C. Borges, "Ontologias e  
Interoperabilidade  
Semantica entre SIGs", (2000). Refereed Conference Proceedings, Published  
Editor(s): C. Davis and G. Camara  
Collection: GeoInfo 2000--Anais do II  
Workshop Brasileiro de  
GeoInformática, São Paulo,  
Brazil  
Bibliography: pp. 45-52

F. Fonseca and M.  
Egenhofer, "Knowledge Sharing in  
Geographic Information  
Systems", (1999). Refereed Conference Proceedings, Published  
Editor(s): P. Scheuermann  
Collection: IEEE Workshop on  
Knowledge and Data  
Engineering Exchange  
Bibliography: pp. 85-90

F. Fonseca and M.  
Egenhofer, "Ontology-Driven  
Geographic Information  
Systems", (1999). Refereed Conference Proceedings, Published  
Editor(s): C. Bauzer Medeiros  
Collection: 7th ACM Symposium on  
Advances in Geographic  
Information Systems  
Bibliography: pp. 14-19

A. Rodríguez and M.  
Egenhofer, "Putting Similarity  
Assessments into Context:  
Matching Functions with the  
User's Intended Operations", (1999). Refereed Conference Proceedings, Published  
Editor(s): P. Bouquet, L. Serafini, P.  
Brezillon, and F. Castellani  
Collection: Modeling and Using  
Context, CONTEXT-99  
Bibliography: Lecture Notes in Artificial  
Intelligence, Vol. 1688, pp. 310-323,  
Springer-Verlag,

Frederico Fonseca, "Ontology-Driven  
Geographic Information  
Systems", (2001). Thesis, Published  
Bibliography: Ph.D. in Spatial Information  
Science and Engineering

A. Rodriguez, "Assessing Semantic  
Similarity Among Spatial  
Entity Classes", (2000). Thesis, Published  
Bibliography: Ph.D. in Spatial Information  
Science and Engineering

A. Rodriguez, M. Egenhofer, and A. Blaser, "Query Pre-Processing of Topological Constraints: Comparing a Composition-Based with a Neighborhood-Based Approach", (2003). Fully refereed conference proceedings, Published Editor(s): T. Hadzilacos, Y. Manolopoulos, J. Roddick, and Y. Theodoridis  
Collection: SSTD 2003: Eighth International Symposium on Spatial and Temporal Databases  
Bibliography: Lecture Notes in Computer Science, Vol. 2750, pp. 362-379, Springer.

M. Egenhofer, "Towards the geospatial semantic web", (2002). Fully refereed conference proceedings, Published  
Collection: ACM-GIS 2002  
Bibliography: ACM Press, pp. 1-4

J. Farrugia and M. Egenhofer, "Presentations and Bearers of Semantics on the Web", (2002). Fully refereed conference proceedings, Published  
Collection: Semantic Web Track at FLAIRS 2002  
Bibliography: pp. 408-412

C. Bauzer Medeiros, M. Egenhofer, and E. Bertino (eds.), "Advances in Spatial and Temporal Databases, 9th International Symposium, SSTD 2005, Angra dos Reis, Brazil, August 2005, Proceedings", (2005). Book, Published  
Editor(s): C. Bauzer Medeiros, M. Egenhofer, and E. Bertino  
Collection: Lecture Notes in Computer Science, Vol. 3633  
Bibliography: Springer

A. Rodriguez, I. Cruz, M. Egenhofer, and S. Levashkin (eds.), "GeoSpatial Semantics, First International Conference, GeoS 2005, Mexico City, Mexico, November 2005, Proceedings", (2005). Book, Published  
Editor(s): A. Rodriguez, I. Cruz, M. Egenhofer, and S. Levashkin  
Collection: Lecture Notes in Computer Science  
Bibliography: Lecture Notes in Computer Science, Vol. 3799

### Web/Internet Site

**URL(s):**

<http://www.spatial.maine.edu/~max/CNPq.html>

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**Description:**

### Other Specific Products

## Contributions

### **Contributions within Discipline:**

The newly developed concepts of ontology-driven GISs and the geospatial semantic web have had a profound impact on the research domain in geographic information science. The University Consortium for Geographic Information Science selected as one of its emerging research themes 'Geospatial Semantic Web' (<http://www.personal.psu.edu/faculty/f/u/fuf1/Fonseca-Sheth.pdf>), founding this research challenge explicitly on the work that came out of this research award.

The Brazilian collaborators at INPE have integrated these research results into their master's and GIS programs.

Several doctoral dissertations are under way at the University of M<sup>3</sup>nster that are extensions of the work on semantic similarity comparisons, the development of which was also funded by this award.

### **Contributions to Other Disciplines:**

In a cross-disciplinary effort, the PI co-organized a workshop on Semantic Web Technologies for Searching and Retrieving Scientific Data (Sanibel Island, FL, October 2003), which addressed research issues related to the geospatial semantic web to a broad audience.

PI also initiated the GeoS conference on geospatial semantics, bringing together researchers from computer science, geography, and engineering working.

### **Contributions to Human Resource Development:**

Two PhD students who were partially funded under this grant completed their doctoral degrees (Andrea Rodriguez, 2000; Fred Fonseca, 2001), who are now faculty (Computer Science, University of Concepcion, Chile; and Information Science, PennState, respectively).

One post-doc (Jorge Campos) funded on this project is faculty at the University of Salvador, Brazil.

One doctoral dissertation (Jim Farrugia) is still ongoing.

### **Contributions to Resources for Research and Education:**

#### **Contributions Beyond Science and Engineering:**

The similarity measures have become the foundation for an intelligent spatial search mechanism that Lockheed Martin developed in collaboration with our research group.

A significant new development was the creation of a spin-off company from our research group (Intelligent Spatial Technologies, [www.i-spatialtech.com](http://www.i-spatialtech.com)), which focuses on mobile devices. Some parts of the semantic search methods are being incorporated into their iPointer product.

### Categories for which nothing is reported:

Any Product

Contributions: To Resources for Research and Education



Principle Investigator: Max Egenhofer  
Award ID: 9970123  
Organization: University of Maine  
Title: NSF-CNPq Collaborative Research on Integrating Geospatial Information

### **Project Participants**

#### **Senior Personnel:**

Name: Max Egenhofer  
Worked More than 160 hours: Yes

Name: Gilberto Camara  
Worked More than 160 hours: No

Name: Marcello Tillio  
Worked More than 160 hours: No

Name: Peggy Agouris  
Worked More than 160 hours: No

#### **Graduate Student**

Name: Frederico Fonseca  
Worked More than 160 hours: No

Name: Andrea Rodriguez  
Worked More than 160 hours: No

Name: Markus Wuersch  
Worked More than 160 hours: No

Name: Dominik Wilmsen  
Worked More than 160 hours: No

Name: Kostas Nedas  
Worked More than 160 hours: No

### **Organizational Partners**

INPE, Brazil  
UNICAMP, Brazil  
Catholic University Rio De Janeiro, Brazil

## **Activities and Findings**

Development and implementation of computation models for semantic similarity based on entity classes

Development and implementation of computation models for semantic similarity based on entity attributes

### **Outreach Activities**

Program Committee Member, Semantic Web and Databases, Berlin, Germany September 2003.

Program Committee Member, Ontologies for Business Information Systems- OntoBIS, Special Session at 6<sup>th</sup> International Conference on Business Information Systems BIS 2003, Colorado Springs, CO June 2003.

Program Committee Member, Semantic Web and Artificial Intelligence, Special track on Semantic Web at FLAIRS 2003. St Augustine FL. May 2003

Program Committee Member, IV Brazilian Symposium on Geoinformatics-GeoInfo 2002, Caxambu, Brazil, December 2002.

Frederico Fonseca and Amit Sheth authored a research agenda for the Geospatial Semantic Web. Research Priority Series for the University Consortium for Geographic Information Science. <http://www/personal.psu.edu/faculty/f/u/fufl/Fonseca-Sheth.pdf>

### **Journal Publications**

Rodríguez, A. and M. Egenhofer. 2004 Comparing Geospatial Entity Classes: An Asymmetric and Context-Dependent Similarity Measure *International Journal of Geographical Information Science*, 18 (3): 229-256.

Rodríguez, A. and M. Egenhofer. 2003. Determining Semantic Similarity Among Entity Classes from Different Ontologies *IEEE Transactions on Knowledge and Data Engineering*, 15 (2): 442-456.

Fonseca, F. M. Egenhofer, P. Agouris, and G. C. mara. 2002. Using Ontologies for Integrated Geographic Information Systems *Transactions in GIS*, 6(3): 231-257.

Fonseca, F. M. Egenhofer, C. Davis, and G. C, mara 2002. Semantic Granularity in Ontology-Driven Geographic Information Systems. *Annals of Mathematics and Artificial Intelligence*, 36 (1-2): 121-151.

### **Book Chapters**

Fonseca, F. martin, J. and Rodriguez, A. 2002 From geo to eco-ontolgies. In Geogrpahic Information Science 2002. Lecture Notes in Computer Science. Vol. 2478 ( Berlin: Springer) pp. 93-107.

### **Refereed Conference Proceeding Papers and Presentations**

Egenhofer, M. 2002. Toward the Semantic Geospatial Web, ACM-GIS 2002, McLean, VA. A. Voisard, and S.C. Chen (eds) pp. 1-4.

Nedas, K. and M. Egenhofer, 2003. Spatial Similarity Queries with Logical Operators *Advances in Spatial and Temporal Databases, Eighth International Symposium, SSTD 2003*, Santorini, Greece T. Hadzilacos, Y. Manolopoulos, J. Roddick, and Y. Theodoridis (eds.), *Lecture Notes in Computer Science*, Vol. 2750, Springer, pp. 430-448, July 2003.

C, mara, G. M. Egenhofer, F. Fonseca, A. Monteiro  
What's in an Image? *COSIT '01-Conference on Spatial Information Theory*, Morro Bay, CA. D. Montello (ed.), *Lecture Notes in Computer Science*, Vol. 2121, Springer-Verlag, pp. 474-488, September 2001.