Shashi Shekhar

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Shashi Shekhar is currently a Mcknight Distinguished University Professor of Computer Science at the University of Minnesota, Minneapolis, MN, USA. Shashi is a prominent researcher in the area of geographic information systems (GIS), spatial databases, and spatial data mining. For outstanding contributions to these areas, he received the IEEE-CS Technical Achievement Award and was elected an IEEE Fellow as well as an AAAS Fellow. Shashi was also named a key difference-maker for the field of GIS by the most popular GIS textbook[1]. He has a distinguished academic record that includes 250+ refereed papers, a popular textbook on Spatial Databases (Prentice Hall, 2003) and an authoritative Encyclopedia of GIS (Springer, 2008).

Shashi is serving on the *Computing Community Consortium Council* (2012-2015)[2] and *Future Workforce for Geospatial Intelligence Committee* (2011-2012) of the National Research Council (NRC) of the National Academies. Earlier he served on the NRC *Mapping Sciences* committee (2004-2009) and NRC committee on *Priorities for GEOINT Research* (2004-2005). He is also serving as a co-Editor-in-Chief of Geo-Informatica[3]: An International Journal on Advances in Computer Sciences for GIS (Springer), a program co-chair for the Intl. Conference on Geographic Information Science (2012), and as a series editor for the Springer-Briefs on GIS. He served on the Board of Directors of University Consortium on GIS (2003-4), editorial boards of IEEE Transactions on Knowledge and Data Eng. as well as the IEEE-CS Computer Sc. & Eng. Practice Board. He also served as a general co-chair for the Intl. Symposium on Spatial and Temporal Databases (2011), a program co-chair for ACM Intl. Workshop on Advances in GIS (1996) and as a member of the steering committee of this forum (1997-2006).

A major goal of Shashi's research is to understand the computational structure of very large geo-spatial computations (e.g. data analysis via spatial querying and spatial data mining) needed by social, biological and physical sciences as well as engineering disciplines. In early 1990s, his research developed core technologies behind in-vehicle navigation devices as well as web-based routing services, which revolutionized outdoor navigation in urban environment in the last decade. His recent research results played a critical role in evacuation route planning for homeland security and received multiple recognitions including the *CTS Partnership Award*[4] for significant impact on transportation. He pioneered the research area of spatial data mining via pattern families (e.g. collocation, mixed-drove co-occurrence, cascade), keynote speeches, survey papers and workshop organization. He also contributed significantly to the design of CrimeStat 3.0, which is used by many police departments, as well as the UMN map server, which is being used by tens of thousands of web-services publishing geographic data on the Internet. His recent geo-social media white-paper was discussed[5] in major blogs (e.g. readwriteweb), science forums (e.g. science360), tweets and facebook postings.

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[1] P. A. Longley, M. F. Goodchild, et al, Geographic Information Systems and Science, 3rd Ed., Wiley, 2010.
[2] http://cra.org/ccc/bios
[3] GeoInformatica was rated as a top-tier GIS journal in C. Caron et al, G.I. Science Journals Ranking and Evaluation: An International Delphi Study, Transactions in GIS, 12(3), 2008, Blackwell Publishing (Summary in Table 5, pp. 308).
[4] Evacuation project wins award , The CTS Report, Center for Transportation Systems, University of Minnesota, May 2006 (http://www.cts.umn.edu/news/report/2006/05/EvacuationProject.html).
[5] http://www.readwriteweb.com/archives/your_social_graph_researchers_identify_new_opportu.php

SOUNDBYTE

Newsletter of the Department of Computer Science & Engineering
University of Minnesota
Spring/Summer 2001

Mining Spatial Data: The University of Minnesota Leads the Way

Spatial data mining software - code for pattern discovery processes based on geometric structures - is coming soon. When it arrives we will be able to efficiently identify spatial patterns in massive geo-spatial data sets for application domains including public safety (finding crime hot spots), public health (predicting the spread of disease), climatology (effects of El Niño), ecology (protecting endangered species), transportation (detecting local instabilities in traffic), location-based services in the M(mobile)-commerce industry, and national defense (inferring enemy tactics such as flank attacks).

The spatial data mining software results from the research work of Professor Shashi Shekhar and his students. Their research has demonstrated that key assumptions of classical data mining techniques are invalid for geo-spatial data sets. Though classical data mining and spatial data mining share goals, their domains have different characteristics. First, spatial data is embedded in a continuous space, whereas classical data sets are often discrete. Second, spatial patterns are often local whereas classical data mining techniques often focus on global patterns. Finally, one of the common assumptions in classical statistical analysis is that data samples are independently generated. When it comes to the analysis of spatial data, however, the assumption about the independence of samples is generally false because spatial data tends to be highly self-correlated. For example, people with similar characteristics, occupation and background tend to cluster together in the same neighborhoods. In spatial statistics this tendency is called spatial auto-correlation. Ignoring spatial auto-correlation when analyzing data with spatial characteristics may produce hypotheses or models that are inaccurate or inconsistent with the data set. Thus classical data mining algorithms often perform poorly when applied to spatial data sets. New methods are needed to analyze spatial data to detect spatial patterns.

Roots of spatial data mining lie in spatial statistics, spatial analysis, geographic information systems, machine learning, image analysis, and data mining. Several other departments at the University of Minnesota such as Biostatistics, Forest Resources, Electrical and Computer Engineering, Epidemiology, Geography and

Front Row (left to right): Yan Huang, Wei-Hsin Fu, Shashi Shekhar, Wei-Li Wu; Middle row : Xiaobin Ma, Hui Xiong, Chang-Tien Lu; Back row: Ru-Lin (Alan) Liu, Pusheng (Alex) Zhang, Vatsavai Ranga Raju; Not pictured: Caroline Peterson, Svetoslav Stoykov, Judy Djugash.

Psychology as well as research centers such as the Army High Performance Computing Research Center, the Center for Transportation Studies, the Institute for Mathematics and Its Applications (IMA), the Center for Urban and Regional Affairs, Precision Agriculture, and the Cancer Center are contributing to the field. In fact, the IMA is organizing a workshop on spatio-temporal patterns in the geosciences during the last week of September 2001, and a

continued on page 2

INSIDE THIS ISSUE

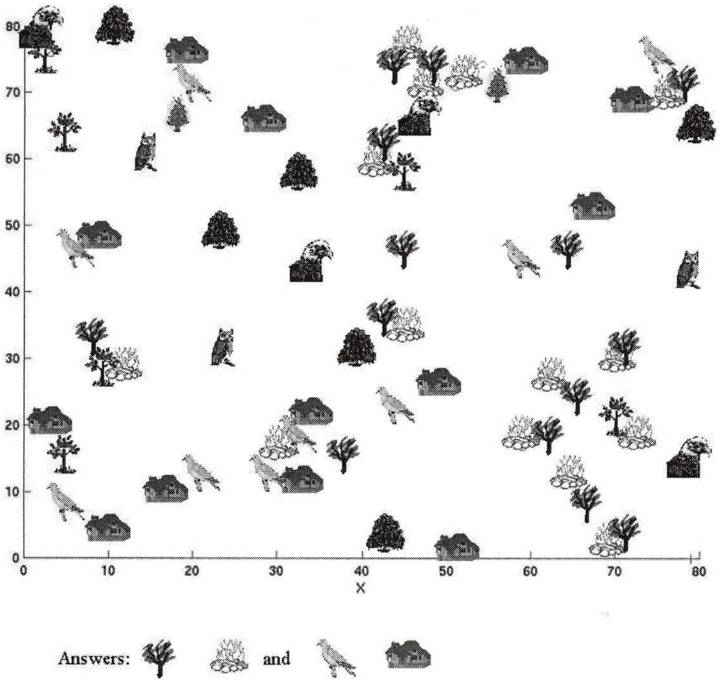


Figure 1.

series of workshops related to the mathematics of geoscience in 2001-2002.

In addition to Shekhar, Computer Science and Engineering faculty members interested in spatial data mining include Professors Dan Boley, Ravi Janardan, George Karypis, Vipin Kumar, Nikos Papanikolopoulos and Paul Schrater. Prominent alumni in this field include Jack Dangermond (President, Environmental Systems Research Institute), Dr. Raju Namburu (Army Research Lab), and Dr. Siva Ravada (Manager, Spatial Data Group, Oracle Corporation).

The main contributions made by Shekhar and his students to spatial data mining include algorithms and data structures that can scale up to massive (terabytes to petabytes) data sets and formalization of new spatio-temporal patterns (e.g. co-locations) which were not explored by other research communities due to high computational complexity. Specific contributions include discovering spatial co-locations, detecting spatial outliers and location prediction.

The co-location pattern discovery process finds frequently co-located subsets of spatial event types given a map of their locations (see Figure1). For example, analysis of habitats of animals and plants may identify co-location of predator-prey species, symbiotic species, and fire events with ignition sources. Readers may find it interesting to analyze the map in Figure 1 to find co-location patterns. There are two co-location patterns of size 2 in this map. Shekhar's group has provided one of the most natural formulations as well as the first algorithms for discovering co-location patterns from large spatial data sets and applying it to climatology data from NASA.

Spatial outliers are significantly different from their neighborhood even though they may not be significantly different from the entire population. For example, a brand new house in an old neighborhood of a growing metropolitan area is a spatial outlier. Figure 2 shows another use of spatial outliers in traffic measurements for sensors on I-35W (north bound) in the Twin Cities metro area for a 24 hour time period. Sensor 9 seems to be a spatial outlier and may be a bad sensor. Note that the figure also shows three clusters of sensor behaviors, morning rush hour, busy daytime, and evening rush hour. Spatial statistics tests for detecting spatial outliers do not scale up to massive data sets such as the Twin Cities traffic data set measured at thousands of locations in 30-second intervals and archived for years. Shekhar's group generalized spatial statistics tests to spatio-temporal data sets and developed scalable algorithms for detecting spatial outliers in massive traffic data sets. This work built on the traditional strength in designing scalable hierarchical routing algorithms and efficient storage methods for roadmaps.

Location prediction is concerned with discovering a model to infer locations of a Boolean spatial phenomenon from the maps of other spatial features. For example, ecologists build models to predict habitats for endangered species using maps of vegetation, water bodies, climate and other related species. Maps of nest location, vegetation and water were used to build a location prediction model for nests of red-winged blackbirds in wetlands on the shores of Lake Erie in Ohio. Classical data mining techniques yield weak prediction models as they do not capture the auto-correlation in spatial data sets. Shekhar's group provided a formal comparison of diverse techniques from spatial statistics (e.g. spatial auto-regression) as well as image classification (e.g. Markov random field based Bayesian classifiers) and developed scalable algorithms for those.

Courses on Scientific Databases (CSci 8705, Fall 2001), Data Mining (a CSci seminar), and Spatial Biostatistics (PubH 8436) are wonderful opportunities to learn more about these topics. Professor Shekhar's upcoming book on Spatial Databases (publisher Prentice Hall, 2002) as well as web sites (*www.cs.umn.edu/research/shashi-group and db.cs.sfu.ca/GeoMiner/*) archiving recent research publications on the topic are additional resources.

-Shashi Shekhar & Bobbie Othmer

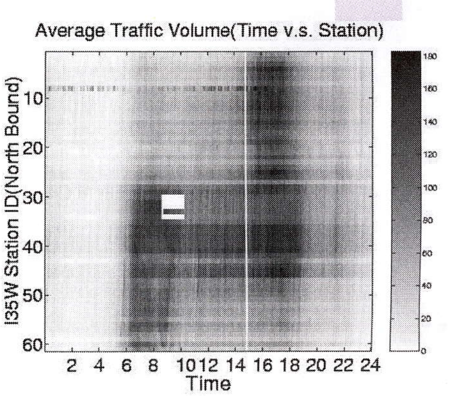
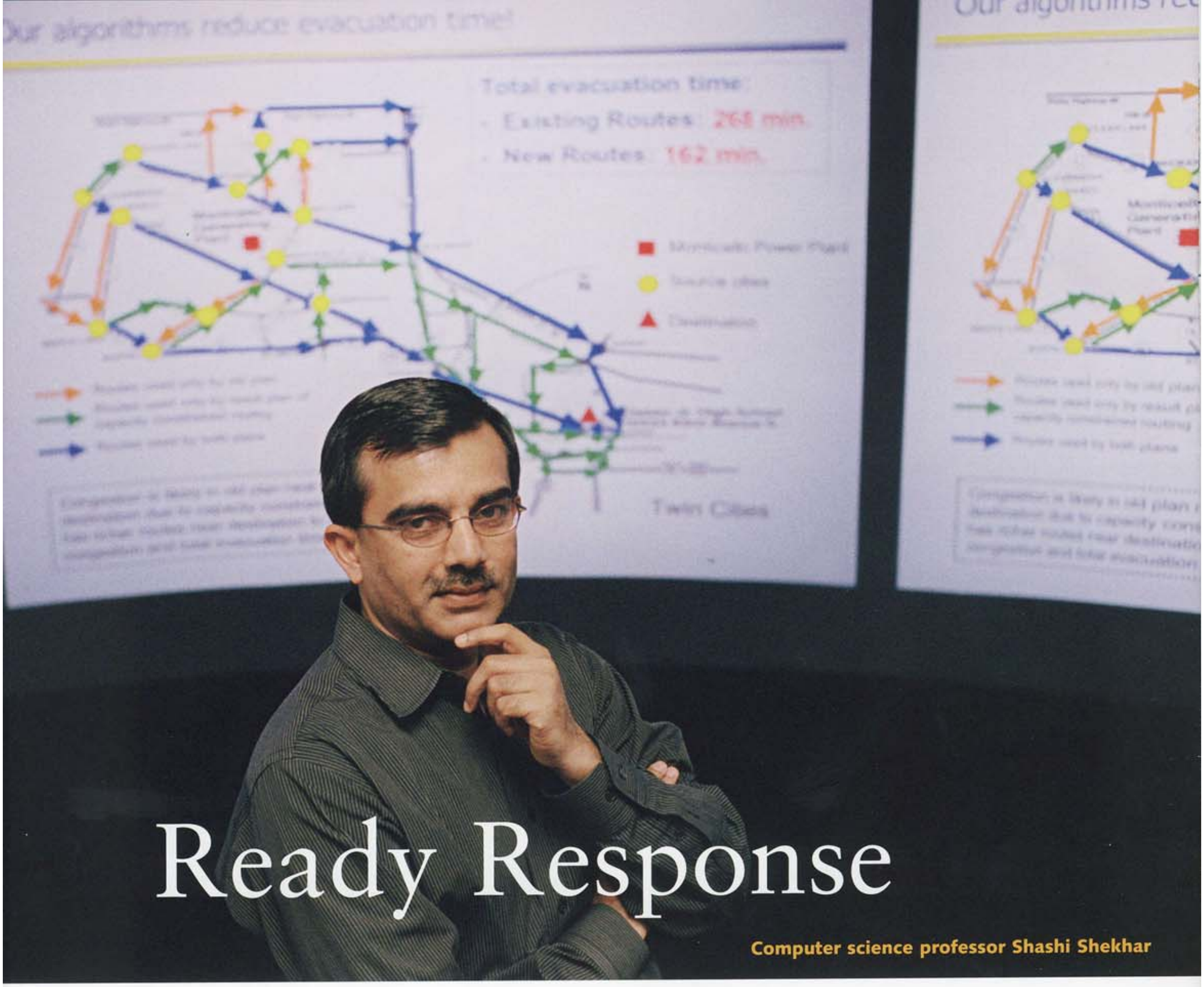


Figure 2.



Ready Response

Computer science professor Shashi Shekhar

Our world is changing. Luckily, U researchers are discovering ways to better prepare for unexpected events.

by Kermit Pattison

As Shashi Shekhar watched video footage of clogged highways leading out of New Orleans during Hurricane Katrina, he witnessed a failure in evacuation planning. He also saw a chance to make it better.

The Distinguished McKnight University Professor in the Department of Computer Science and some of his colleagues, including Jeffrey Wolff, '06 M.S., have developed a tool called Capacity Constraint Route Planning, or CCRP, which uses computer algorithms to determine optimal evacuation routes. "This research is trying to provide adequate tools to first responders," explains Shekhar.

The project grew out of his team's earlier research in routing (think MapQuest directions), which became focused on evacuation after the 9/11 attacks. Instead of moving one person, they now had to move thousands and consider factors such as traffic chokepoints and shelter capacity.

Shekhar's work shows that dispersing people on foot yields dramatic benefits. A simulated evacuation of 100,000 people from the Minnesota State Fair revealed that if people walked one mile before climbing into their cars, the evacuation would take two hours and 37 minutes. If they got into their cars immediately it would take nearly nine hours (see sidebar).

Shekhar's work also demonstrates that phased evacuation—asking some people to wait—saves time in the long run, and that computer

PHOTOGRAPH: RICHARD ANDERSON

"If faced with an event like a highway choked because of a truck accident, in a minute they could specify alternative routes."

—Shashi Shekhar, Distinguished McKnight University Professor

algorithms are better suited than humans to make evacuation recommendations because of the vast amount of data involved.

In 2005, the Minnesota Department of Transportation used Shekhar's work to produce evacuation plans for the Twin Cities as part of a homeland security project. Shekhar is investigating ways to further develop the technology. "It's a tool that can help first responders in both planning and real time," he says. "If faced with an event like a highway choked because of a truck accident, in a minute they could specify alternative routes."

Exit Strategy

Computer science professor Shashi Shekhar and his team have developed a method to determine the best evacuation scenarios in emergency situations. Here's what they found for the Minnesota State Fair:

20,000 people walking 1 mile
Evacuation time: 42 minutes

20,000 people driving 1 mile
Evacuation time: 1 hour 48 minutes

100,000 people walking 1 mile
Evacuation time: 2 hours 37 minutes

100,000 people driving 1 mile
Evacuation time: 8 hours 55 minutes

View computer simulations of State Fair evacuations at giving.umn.edu

Planning Starts at Home

Carol O'Boyle also saw an opportunity to help a group of first responders—health care workers.

O'Boyle, an assistant professor in the School of Nursing, founded the Minnesota Emergency Readiness Education and Training program, which trains statewide health care personnel to respond to bioterrorism and other emergencies. Funded by a $2.7 million federal grant, the program will train nearly 10,000 nurses, physicians, pharmacists, psychologists, social workers, veterinarians, and administrators in its first three years.

The first lesson: Planning begins at home, since health care workers won't be able to do their jobs if they haven't prepared to protect their own families. "When people have that worked out, it gives them a more secure feeling," says O'Boyle. "The challenge is to prepare when there's no imminent danger."

Disaster drills form another part of the curriculum. Last summer in the Iron Range town of Virginia, a simulated chemical explosion taught participants how to use protective gear, decontaminate victims, and administer treatment. "We react emotionally to crises," says O'Boyle. "One of the ways you control the emotional response is by building familiarity with it."

These workshops also strengthen ties between key community partners who will need to rely on each other during emergencies. According to O'Boyle, "That integration of effort is essential. It's what the federal government wants and it's thrilling for us to see it."

Focus on Flu

Similar interdisciplinary teamwork is helping the U monitor a flu pandemic. The new Minnesota Center of Excellence for Influenza Research and Surveillance is one of six such sites in the United States funded by the National Institutes of Health, which will provide $22.5 million over seven years. Another $3 million from the U.S. Centers for Disease Control will allow the U to investigate the human-animal interface of influenza.

"Disease surveillance is really the backbone of preparedness," says Marguerite Pappaioanou, the principal investigator and professor in the School of Public Health. "The more we know what we can expect day to day, the more we can detect any blips."

The center will coordinate studies in eight countries, including monitoring wild birds in U.S. wetlands and coastal Vietnam, poultry and swine on domestic farms, and wild bird markets from the United States to Laos. Information gained about the genetic makeup of viruses will help researchers develop vaccines.

The U was chosen because of its long history of disease surveillance among poultry and swine. "The U has some of the country's top experts," says Pappaioanou. "With this center, we just pulled everybody together in a coordinated effort on surveillance."

Kermit Pattison is a writer based in St. Paul.

From Tanzania to U

CSE professors collaborate with U ecologists to analyze chimpanzee research data


© Michael Neugebauer

Dr. Jane Goodall with an orphan Chimpanzee at the Tchimpounga Sanctuary in the Republic of Congo.

By Robyn White

In the lush tropical forest of Tanzania's Gombe National Park, famed chimpanzee expert Dr. Jane Goodall and her research team spent decades documenting chimpanzee behavior and habitat. Researchers there are still following chimpanzees daily, recording their travel, food choice, interactions with other chimpanzees, and geographical data.

Far from the forest, the products of this work — 46 years worth of paper-based maps, hand written checksheets, notes, video, and satellite images — have found a home at the Jane Goodall Institute's Center for Primate Studies (JGI-CPS), on the University of Minnesota's St. Paul campus.

While Goodall's research in Gombe and her outreach efforts have given the world a better understanding and appreciation for chimpanzees, University ecologists and computer scientists teamed up to find new ways to use the data. They are analyzing the data for patterns in everything from female grouping habits to male aggression and mating habits relating to the Simian Immune Deficiency Virus (SIV). They are also constantly seeking new research techniques and areas of study.

CSE Professors Shashi Shekhar and Jaideep Srivastava have worked with their students for nearly five years on two of the University center's projects. CSE Professor John Carlis and his students also helped set up a database of the behavioral data for the center in the late 1990s. Dr. Anne Pusey, director of the University primate center, said interdisciplinary collaborations with CSE have been very helpful in understanding the chimpanzee data.

For one of the current projects CSE graduate student Mete Celik created a searchable database prototype that would organize more than 600 hours of chimpanzee video footage from the Jane Goodall Institute's (JGI) Videographer Bill Wallauer. The video database is housed in the University's Digital Technology Center (DTC).

Celik explained how the technology works in a presentation to Goodall when she visited the University center in March. "It's kind of a Google-like search engine," he said. A chimpanzee's name and behavior can be entered to retrieve the corresponding video clips. Eventually the researchers would like to make the database into a searchable library that allows users to add their own perceptions of the research material.

"Years and years and years of data is being computerized, so that questions that I used to ask which entailed going back through file after file after file by hand, can now be found very quickly by pressing buttons. It's quite extraordinary," Goodall said in a campus press conference. "It makes me very jealous, because I could have done so much. We didn't have some of these technologies back then."

The other CSE related project focuses on analyzing the data. For this project, behavioral ecology doctoral student Carson Murray used Shekhar and Srivastava's expertise in temporal, spatial, and spatio-temporal data mining to study patterns and commonalities in female chimpanzee relationships and location behavior. CSE graduate student Sandeep Mane also worked on this project.

Srivastava said they discovered patterns in female chimpanzee association and location behavior that revealed the importance of dominance. In her presentation to Goodall, Murray said she found that a high dominance rank equals an increased loyalty to core areas in the wild. Core areas are specific territories occupied by a chimpanzee. "[CSE researchers] helped me to come up with a way to look at these point patterns," she said, adding that she's now looking at male core areas. "They are very much driven by food. It looks like they inherit their mother's core area," Murray said.

Shekhar said his CSE collaboration with the University primate center started in 2002 when Pusey approached the DTC seeking collaborators for the project. Andrew Odlyzko, director of the DTC, helped facilitate the research partnership, funded by the DTC and later the National Science Foundation (NSF). Srivastava said these projects appealed to them because they had tremendous opportunity for data analysis. "Data mining is suited for exploration," he added.

Shekhar and Srivastava said they have been amazed at the information gleaned from the data so far. "To me personally, it's fascinating," Srivastava said. "I learned how similar chimpanzee behavior is to human behavior." Pusey said this is a common realization. "Because chimps are our closest relatives, we're always thinking about their similarities and differences," she said.

Pusey, who studied in Gombe with Goodall in the 1970s, said computer scientists have proved helpful in both organizing the data and analyzing it. "Computer Science can bring interesting new ways of understanding factors that control group composition and size and even disease transmission," Pusey said.

While work is still ongoing for these two projects, new areas of study are being discussed. "We're interested in the different types of social bonds you see in the [chimpanzee] community," Pusey said.

JGI funds the long-term field work at Gombe. The University center work is funded by NSF, the National Institutes of Health (NIH), and a private grant from Milton Harris. Pusey said she is continuously working on fund raising and hopes that JGI will partner with the center on future fund-raising initiatives.

On her visit to campus, Goodall touted the value in the University center's work and expressed hope for future study of the data. "It means that years and years and years of blood and toil, crawling through the forest, being scratched by thorns, having your hair caught, is put down on these bits of paper and is now amazingly is being amalgamated and will be useful to students all over the world," she said.

For more information, visit **www.discoverchimpanzees.org.**

© JGI -Bill Wallauer

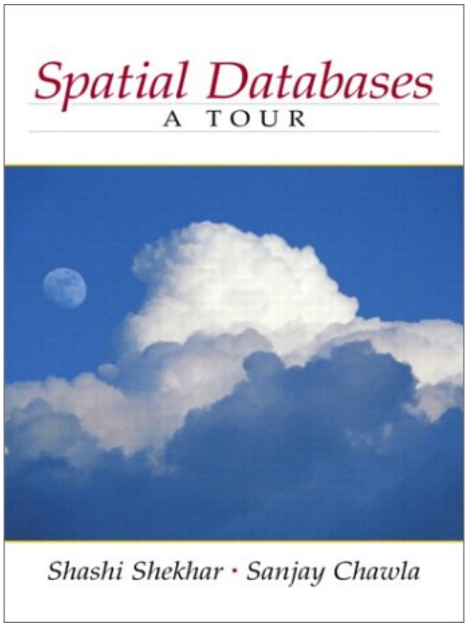
Infant chimpanzee Taurus at Gombe National Park.

Understanding Spatio-Temporal Data Mining

Most of the work done by ecologists on the chimpanzee research data relates to using statistical techniques to prove various hypotheses. In these University projects, CSE Professors Shekhar and Srivastava apply temporal, spatial, and spatio-temporal data mining techniques to identify patterns and pull out desired information.

Shekhar said that classical data mining techniques fail when studying this type of data, because it's assumed that each chimpanzee observation is independent from others. But spatio-temporal data mining accounts for auto-correlations. Through using these techniques, CSE researchers are helping University ecologists gain a new understanding of chimpanzee behavior, identify new patterns, and are able to find new ways to look for hypotheses.

(From left to right) CSE Professor Shashi Shekhar, CSE doctoral student Mete Celik, Dr. Jane Goodall, and CSE Professor Jaideep Srivastava.



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Pub. Date: 2003.
Web-site: sample chapters, slides, labs. etc. at http://www.cs.umn.edu/research/shashi-group/Book

SAMPLE COMMENTARIES :

"I just finished reading your excellent book on spatial databases. It is lovely, I could visualize the lectures unfolding as I read it. You presentation is concise and covers a huge breadth. Very nice book." - *Jim Gray*, Microsoft Research

"It covers the entire field, from representation through query to analysis, in a style that is clear, logical, and rigorous. Especially welcome is the chapter on data mining." - *M. F. Goodchild,* NCGIA and Dept. of Geography, Univ. of California, Santa Barbara.

"This book was extremely valuable in understanding the state of the art in spatial databases due to emphasis on industry standard OGIS instead of on individual products." - *Siva Ravada, Manager, Spatial Data Products Division, Oracle Corporation*

"It is more up-to-date and provides a single reference for the topic, which otherwise gets dispersed in other books and papers. It provides a more detailed coverage of the basic issues in Spatial Database systems." - Alia I. Abelmoty, University of Glamorgan, Wales, UK

"This volume, by surveying GIS and Database topics, allows it to be a stand-alone reference. There is really nothing else on the market, and it is a valuable and important area. It follows a good progression of topics and builds on previous chapters. Good coverage on indexing; good examples for querying." - Fred Petry, Tulane University

About the Book:

This inter-disciplinary comprehensive text shows how to manage spatial data in GIS, CAD, and multimedia systems and their application domains. This book helps readers master various stages of traditional spatial database design and implementation, introducing conceptual models (e.g. pictogram-enhanced ERD), explaining query languages (e.g. OGIS, SQL3), and finally describing efficient implementations using query optimization algorithms as well as spatial storage and indexing methods (e.g. R-trees). For students and professionals, this book balances cutting-edge research and practice to provide many firsts.

Shashi Shekhar is a McKnight Distinguished University Professor of Computer Science and the Director of the Army High Performance Computing Research Center at the University of Minnesota. Shashi was elected a fellow of the IEEE for contributions to spatial database storage methods, data mining, and geographic information systems. He has published numerous articles and has advised many organizations on spatial database issues. He holds a Ph.D. degree in Computer Science from the University of California, Berkeley. *Sanjay Chawla* is an Associate Professor at University of Sydney, Australia. He holds a Ph.D. degree from the University of Tennessee.

Table of Contents

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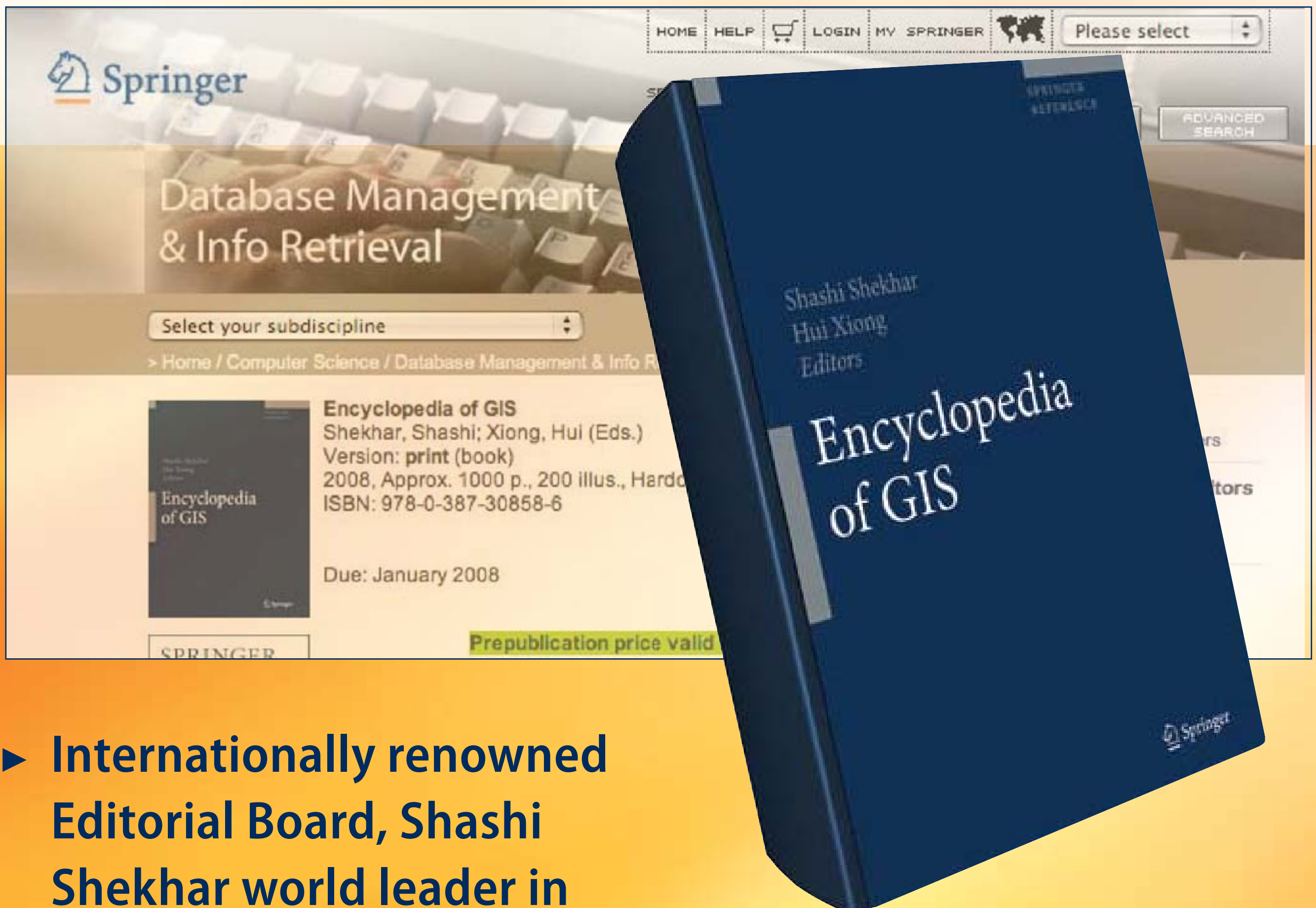

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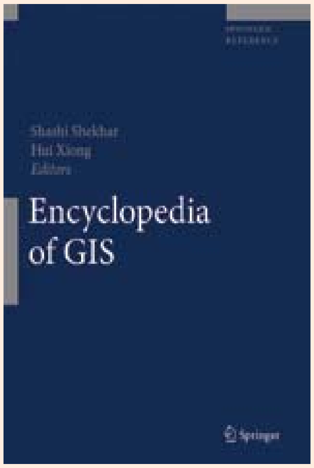

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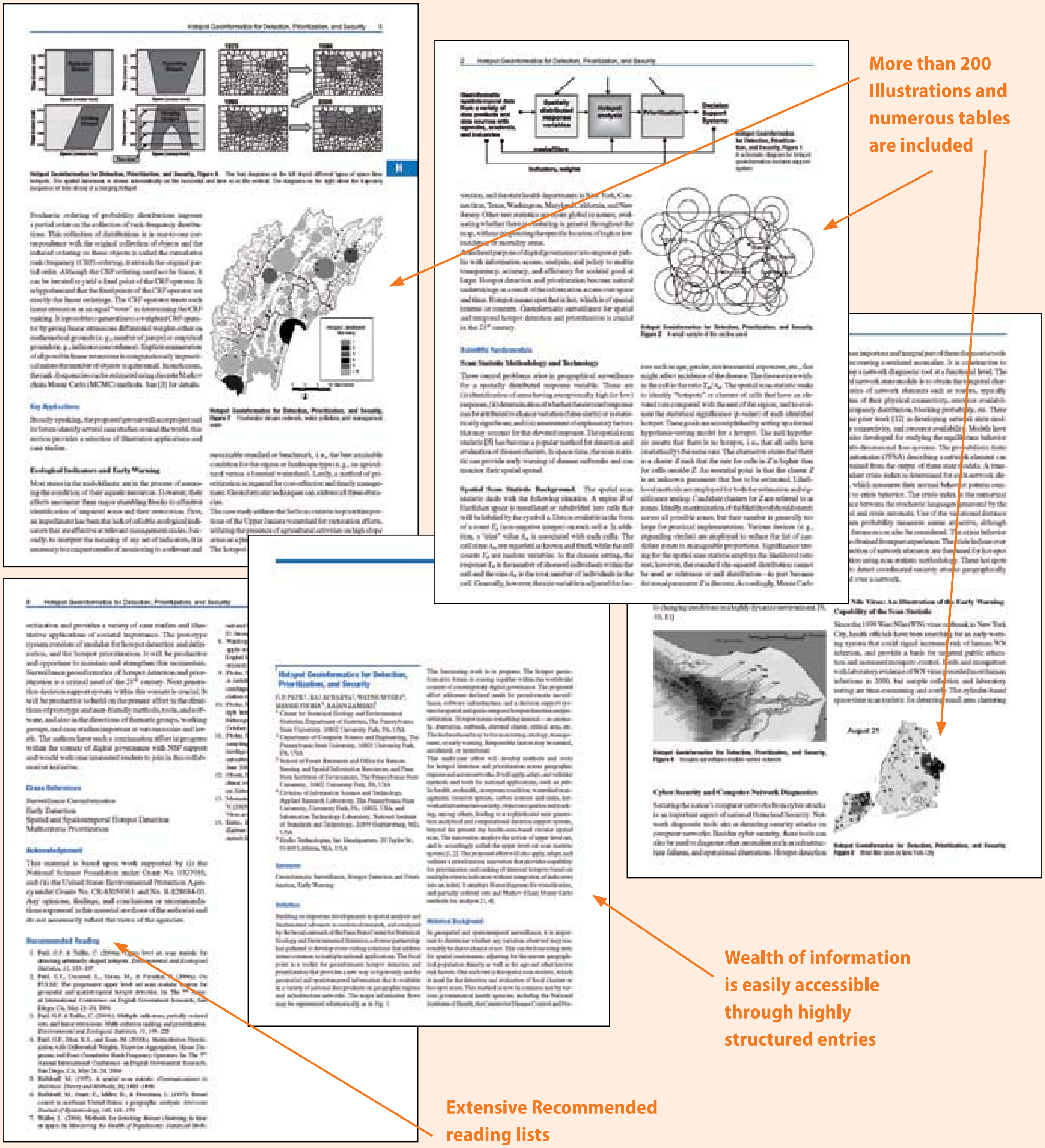

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Critical Evaluation of Standard Proposals ► Liping Di, George Mason University, USA

GeoSpatial Semantic Web
► Frederico Fonseca, The Pennsylvania State University, USA

Spatial Thinking ► Andrew U. Frank, Technical University of Vienna, Austria

Emergency Evacuations
► Oscar Franzese , Oak Ridge National Laboratory, USA

Information Collection Using Sensor Networks ► Dimitrios Gunopulos, University of California at Riverside, USA

Commercial GIS ► Erik Hoel, ESRI, USA

Spatio-temporal data modeling
► Kathleen Hornsby,The University of Maine, USA

Spatial Co-location Rule Mining
► Yan Huang, University of North Texas, USA

GIS Issues and Applications ► Robert Kauffman, Arizona State University, USA

Spatial Prediction
► Baris Kazar, Oracle Corporation, USA

Basic Concepts ► Sangho Kim, University of Minnesota, USA

Commercial Spatial Databases
► Ravi Kothuri, Oracle Corporation, USA

Spatial Uncertainty and Imprecision
► Phaedon C. Kyriakidis, University of California at Santa Barbara, USA

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► Henry Liu, University of Minnesota, USA

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Spatial Data Warehousing and Decision Support ► Nikos Mamoulis, The University of Hong Kong, HK

Photogrammetry
► Helmut Mayer, Institute for Photogrammetry and Cartography, Germany

Cartography and visualization
► Liqiu Meng, Technical University Munich, Germany

Basic Storage and Retrieval Structure
► Mohamed F. Mokbel, University of Minnesota, USA

Open Source GIS Software
► Andreas Neumann, Institute of Cartography, Switzerland

Geosensor Networks ► Silvia Nittel, The University of Maine, USA

Use of Spatial Data for Simulation
► Leon Osborne, University of North Dakota, USA

Tesselation data models
► Sudhanshu Sekhar Panda, Gainesville State College, USA

Spatial Aspects of Bioinformatics
► Srinivasan Parthasarathy, The Ohio State University, USA

Spatial Constraint Databases
► Peter Revesz, University of Nebraska-Lincoln, USA

Spatial Analysis ► Ashok K. Samal University of Nebraska-Lincoln, USA

Representation of Inexact Spatial Information ► Markus Schneider, University of Florida, USA

Road Network Databases
► Cyrus Shahabi ,University of Southern California, USA

GIS in Business Intelligence, Routing
► Jayant Sharma,Oracle Corporation, USA

Spatial Indexing ► Yufei Tao, The Chinese University of Hong Kong, HK

Spatio-temporal databases
►Vassilis J. Tsotras, University of California at Riverside, USA

Spatial Aspects of Mobile Computing
► Ouri E. Wolfson, University of Illinois at Chicago, USA

Spatial Aspects of Distributed Computing ► Chaowei (Phil) Yang, George Mason University, USA

Spatial Time Series ► Pusheng Zhang, Microsoft Corporation, USA

Data Exchange and Interoperability
► Naijun Zhou, University of Maryland, USA

CSci 5980-001: From GPS and Google Earth to Spatial Computing

Instructor: Prof. Shashi Shekhar *Contact:* shekhar@cs.umn.edu,
(612) 624-8307, 5-203, Keller Hall

Credits: 3
Class Time & Place: Tu,Th: 4-515pm, 3-125 KHKH
Class Webpage: http://www.cs.umn.edu/~shekhar/5980/
To Register: Computer Science in 4-192 Keller Hall.
Pre-requisites: CSci 1902 (required), CSci 2011 (preferred) or equivalent.
Text: GIS: A Computing Perspective, M. Worboys et al. CRC Press. 2004.
Supplement: R. Ferraro et al., Location Aware Applications, Manning, 2011 (isbn 978-1-935182-33-7).

Long Title: Spatial Computing: How are GPS, Location-based Social Networks, Geo-Social Media and Cell-phone based Location Based Services transforming computing?

Motivation: Spatial Computing is a set of ideas and technologies that transform our lives by understanding the physical world, knowing and communicating our relation to places in that world, and navigating through those places. The transformational potential of Spatial Computing is already evident. From Google Maps to consumer GPS devices, our society has benefitted immensely from spatial technology. We've reached the point where a hiker in Yellowstone, a schoolgirl in DC, a biker in Minneapolis, and a taxi driver in Manhattan know precisely where they are, nearby points of interest, and how to reach their destinations. Groups of friends can form impromptu events via "check-in" models used by Facebook and foursquare. Scientists use GPS to track endangered species to better understand behavior and farmers use GPS for precision agriculture to increase crop yields while reducing costs. Google Earth is being used in classrooms to teach children about their neighborhoods and the world in a fun and interactive way. Augmented reality applications are providing real-time place labeling in the physical world and providing people detailed information about major landmarks nearby.

Hands-on Labs: Four labs will allow for hands-on development with real systems and applications: developing Android/iPhone applications, mining GPS data from Twitter feeds, developing plugins for Google Earth with KML, etc.


Check-in

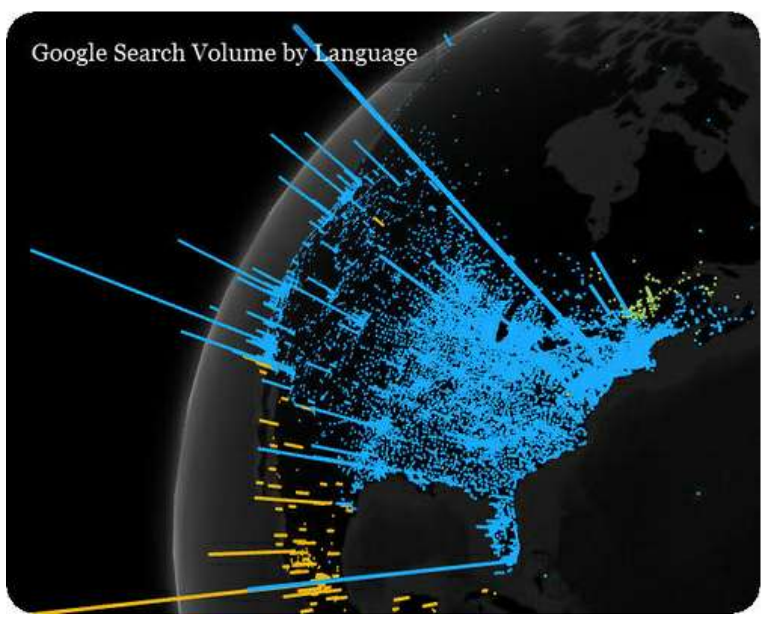
Topics: This course introduces the fundamental ideas underlying the geo-spatial services, systems, and sciences. These include mathematical concepts (e.g. Euclidean space, topology of space, network space), geo-information models (e.g. field-based, object-based), representations (e.g. discretized, spaghetti, tessellation, Vornoi diagram), algorithms (e.g. metric and Euclidean, topological, set-based, triangulation, graph-based), data-structures and access methods (e.g. space filling curves, quad-trees, R-tree), analysis (e.g. spatial query languages, spatial statistics, spatial data mining), architectures (e.g. location sensor, location based services), interfaces (e.g. cartography, Geo-visualization), reasoning (e.g. data quality, approaches to uncertainty), and time (e.g. valid time, events and processes).

Required Work: Course has a set of four assignments and two examinations. The weighting scheme used for grading is: Midterm exam. - 25%, Final exam. - 25%, Assignments including a project - 40%, Class participation - 10%. Examinations will emphasize problem solving and critical thinking. Assignments will include pen-and-paper problems and computer based laboratory experiments/projects to reinforce concepts uncovered in the classroom. Class participation includes spatial-news presenting and active group learning. Participants will take turn to review current spatial news and present selected news items in the class. During active learning, participants will work in small groups on exercises provided in the class meeting. After this, a randomly chosen group will be invited to summarize the discussion in his/her group. Other groups in the class may critique constructively.

Career Opportunities: Major computer science employers looking for geospatial knowledge and skills include ESRI, Facebook, Google, IBM, Microsoft, Nokia, Oracle, Yahoo, and many government agencies related to public health, public safety, transportation, etc. As per a recent article in the Nature magazine "the US Department of Labor identified geo-technology as one of the three most important emerging and evolving fields, along with nanotechnology and biotechnology. Job opportunities are growing and diversifying as geospatial technologies prove their value in ever more areas. "

Auxiliary Information: Representing geo-spatial information services include *virtual globes* (e.g., Google Earth), *location based services* (Google Maps), *location-based social networks* (e.g., foursquare), *enterprise consulting* (e.g. IBM smarter planet). Representative application programming interfaces include HTML 5 Geolocation API , Google Maps API , Bing Maps API , Yahoo Maps Web Services , Flickr Flickr Maps , Twitter location API.

Non-intuitive geo-spatial concepts include map projections, scale, auto-correlation, heterogeneity and non-stationarity etc. First two impact computation of spatial distance, area, direction, shortest paths etc. Spatial (and temporal) autocorrelation violates the omni-present independence assumption in traditional statistical and data mining methods. Non-stationarity violates assumptions underlying dynamic programming, a popular algorithm design paradigm in Computer Science. This course will also explore these concepts particularly in context of the gap between traditional Computer Science (CS) paradigms and the computational needs of spatial domains. We will examine current approaches to address these new challenges possibly via talks from prominent geospatial thinkers at our university.

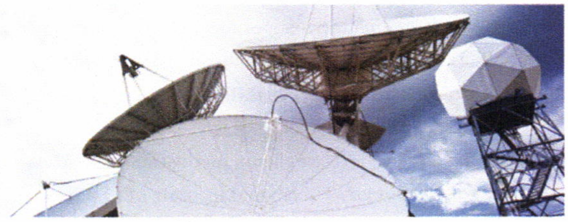


Source: Google Earth

A Service for the Computing Research Community

From GPS and Virtual Globes to Spatial Computing-2020

September 17th, 2012 by Erwin Gianchandani Leave a reply »



[http://www.cccblog.org/wp-content/uploads/2012/09/satellite2.jpeg] The following is a special contribution to this blog from the organizing committee [http://cra.org/ccc/spatial_computing.php] of the Computing Community Consortium's (CCC) [http://cra.org/ccc] visioning workshop on spatial computing – From GPS and Virtual Globes to Spatial Computing-2020 [http://cra.org/ccc/spatial_computing] – held last Monday and Tuesday in Washington, DC. The committee summarizes some of the highlights of the workshop.

Spatial computing (SC) is a set of ideas and technologies that will transform our lives by understanding the physical world, knowing and communicating our relation to places in that world, and navigating through those places. The transformational potential of spatial computing is already evident. From virtual maps to consumer GPS devices, our society has benefitted immensely from spatial technology. We've reached the point at which a hiker in Yellowstone, a schoolgirl in DC, a biker in Minneapolis, and a taxi driver in Manhattan know precisely where they are, nearby points of interest, and how to reach their destinations. Large organizations already use spatial computing for site-selection, asset tracking, facility management, navigation and logistics. Scientists use GPS to track endangered species to better understand behavior, and farmers use GPS for precision agriculture to increase crop yields while reducing costs. Virtual globes (e.g., Google Earth, NASA World Wind) are being used in classrooms to teach children about their neighborhoods and the world in a fun and interactive way. Augmented reality applications (such as Google Goggles [http://www.cccblog.org/2012/04/05/googles-project-glass-augmented-reality-glasses/]) are providing real-time place-labeling in the physical world and providing people detailed information about major landmarks nearby.

This is just the beginning.

[http://www.cccblog.org/wp-content/uploads/2012/09/IMG_2116.jpeg] SC has transformative potential in many other areas. Logistics companies such as UPS are exploiting smarter routing decisions (e.g., avoiding left turns [http://www.nytimes.com/2007/12/09/magazine/09left-handturn.html?_r=0]) to save over three million gallons of fuel and associated greenhouse gas emissions annually. Imagine the savings in fuel costs and greenhouse gases if other fleet owners (e.g., public transportation) and consumers utilized this technology. GPS navigation services are just beginning to experiment with providing eco-routes that aim to reduce fuel consumption, as compared to reducing distance traveled or time spent. The McKinsey Global Institute recently published a report [http://www.mckinsey.com/insights/mgi/research/technology_and_innovation/big_data_the_next_frontier_for_innovation] estimating that "smart routing could have a global worth of about $500 billion by 2020" in terms of fuel and time saved.

While the transformative potential of SC is evident, the current research is scattered across many sub-disciplines, which is hampering progress. In order to address these issues, the Spatial Computing-2020 workshop was organized.

[http://www.cccblog.org/wp-content/uploads/2012/09/IMG_2117.jpeg] We were delighted to host the CCC visioning workshop From GPS and Virtual Globes to Spatial Computing-2020 [http://cra.org/ccc/spatial_computing.php] at the National Academies' Keck Center [http://www.nationalacademies.org/about/contact/] last Monday and Tuesday, where we sought to promote a unified agenda for spatial computing research and development across U.S. agencies, industries (e.g., IBM, Microsoft, Oracle, Google, AT&T, Garmin, ESRI, UPS, Rockwell, Lockheed

Martin, Navteq, etc.), and universities. The workshop program exhibited diversity across organizations (e.g., industry, academia, and government), disciplines (e.g., geography, computer science, cognitive science, environmental science, etc.), topics (e.g, science, service, system, and cross-cutting), and communities (e.g., ACM SIGSPATIAL [http://www.sigspatial.org/] , UCGIS [http://www.ucgis.org/] , the National Research Council's Mapping Science Committee [http://dels.nas.edu/global/besr/MSC] , etc.). (See the full list of participants [http://cra.org/ccc/sc_participants.php] .)

[http://www.cccblog.org/wp-content/uploads/2012/09/IMG_2118.jpeg] The program consisted of opening remarks from the CCC and National Science Foundation (NSF) [http://www.nsf.gov/] during which spatial computing was defined, and community consensus and the challenges of diversity were articulated. There was a panel on disruptive technologies (graphics and vision, interaction devices, LiDAR, GPS modernization, cell phones, indoor localization, internet localization, and cloud computing) as well as a panel on national priorities [comprising officials from the Department of Defense (DoD) [http://www.defense.gov/] , Department of Energy (DoE) [http://www.energy.gov/] , Department of Transportation's (DoT) [http://www.dot.gov/] Research and Innovative Technology Administration (RITA) [http://www.rita.dot.gov/] , National Institute of Environmental Health Sciences (NIEHS) [http://www.niehs.nih.gov/] within the National Institutes of Health (NIH) [http://www.nih.gov/] , NASA [http://www.nasa.gov/] , Department of Homeland Security (DHS) Science and Technology Direcotrate (S&T) [http://www.dhs.gov/directorate-science-and-technology] , and NSF's EarthCube [http://earthcube.ning.com/] , and chaired by White House Office of Science and Technology Policy (OSTP) [http://www.ostp.gov/] Senior Advisor to the Director **Henry Kelly**]. The program featured breakout sessions grouped by SC science, system, services and cross-cutting areas. The workshop concluded with a synthesis and reflection during which the success in bringing multiple disparate communities together was acknowledged and missing topics (e.g., national grid reference systems, measurement databases, etc.) were identified.

[http://www.cccblog.org/wp-content/uploads/2012/09/IMG_2119.jpeg] The Spatial Computing-2020 workshop identified (1) fundamental research questions for individual computing disciplines and (2) cross-cutting research questions requiring novel, multi-disciplinary solutions. Among the themes that emerged were the myriad roles spatial computing may play in our day-to-day lives in the year 2020, such as fantastic voyages through the brain, trustworthy peer-to-peer communication, intelligent transportation systems, and so on. Some of the key research challenges identified were spatial cognition, localization, navigation indoors and inside human body, etc.

Some of the highlights included identifying the key objectives, challenges, and transformative potential in several fundamental research questions for spatial computing as well as fostering a common understanding between several communities (e.g., resolving vocabulary differences, visioning, etc.). In his video to the participants (below), Google's Vint Cerf [http://en.wikipedia.org/wiki/Vint_Cerf] touches on many of the exciting possibilities ahead in this space.

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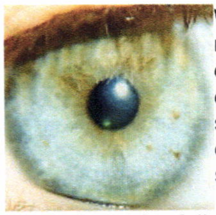
Mapping Our Friendships Over Time and Space: The Future of Social Network Analysis

By Marshall Kirkpatrick / January 17, 2011 8:20 PM / 10 Comments



What new things could we discover if social network analysis took *time and space* into account, in addition to the raw connections between people? In most cases, social network analysis today is limited to discovering friend connections, community leaders and outlines, influential people and personal friend recommendations - in a static or snap-shot kind of way. If new factors could be taken into consideration, specifically changes over time and space, then social network analysis could discover things like emergence or decay of leadership, changes in trust over time, migration and mobility within particular communities online. That's very valuable information that the social web has barely begun to tackle capturing.

That's the topic of discussion in a new paper by Shashi Shekhar *(http://www-users.cs.umn.edu/~shekhar/)* and research assistant Dev Oliver, spatial data scientists at the University of Minnesota, titled *Computational Modeling of Spatio-temporal Social Networks: A Time-Aggregated Graph Approach* (PDF *(http://www.ncgia.ucsb.edu/projects/spatio-temporal/docs/Shekhar-position.pdf)*). The paper was highlighted on the blog GIS and Science *(http://gisandscience.com/2011/01/17/computational-modeling-of-spatio-temporal-social-networks-a-time-aggregated-graph-approach/)* today. We've excerpted and put in context key points below.

The Impact of Space and Time on Networking

Space and time are big factors in determining the diverse friend connections that different people form. Or, as Shekhar and Oliver put it, "Spatio-temporal constraints (e.g., geographic space, travel, schedules and diurnal [daily] cycles) play a major role in determining baseline homophily due to reasons like opportunity and minimization of cost and effort."

In other words, if we don't pay attention to the way space and time factor into our lives, if we just see who knows whom and who chatters about what, then we'll have a very blunt understanding of the world. Diurnal cycle in, and diurnal cycle out (!) businesses and software users seem likely to call for more clarity than that in the future.

Consider the diagram below, for example, from Shekhar and Oliver's paper. It might look a little intimidating, but if you follow it step by step from left to right, it's not. Today we might look at a group of four participants in some network and just see the final timeframe of connections (t10). You can see who knows who and who doesn't know who. But imagine if time were taken into consideration as it is here. You can see how this particular mini-network unfolded from the first connections, through the end-point. That's a much richer understanding of this group.

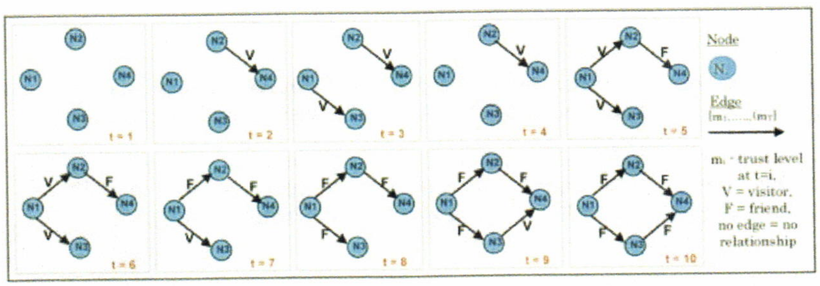


Figure 1: *A Time-series of Snapshots for a trust Network for time instants 1 through 10*

Look at poor little Node 3, for example, in the bottom of the square. It took them longer to go from Visitor to Friend than it took anyone else, in each of the relationships Node 3 formed. Node 2 at the top, on the other hand, looks friendly and effective at building strong relationships quickly.

Social network analysis services see these differences in the way people interact already and they see the way changes in spacial relations impact them, but it's a very nascent field.

"We see the spatio-temporal effect manifest in Twitalyzer *(http://Twitalyzer.com)* data during conferences, tradeshows, and live events (e.g., SXSW)," says Eric Peterson, creator of professional Twitter analysis service Twitalyzer.

> "The results are pretty obvious in our data: individuals who exhibit an otherwise 'normal' level of Impact, Influence, and Engagement in our data go 'off the charts.'
>
> "The simplest explanation is that there is a compressing effect on an individual's network when they are more spatially proximate (e.g., can grab a drink and interact face to face.) When this happens, especially when it happens over a short period of time, people's scores change, their networks expand (typically, although we have seen contraction), and their 'chatter' (in your words) becomes more focused."

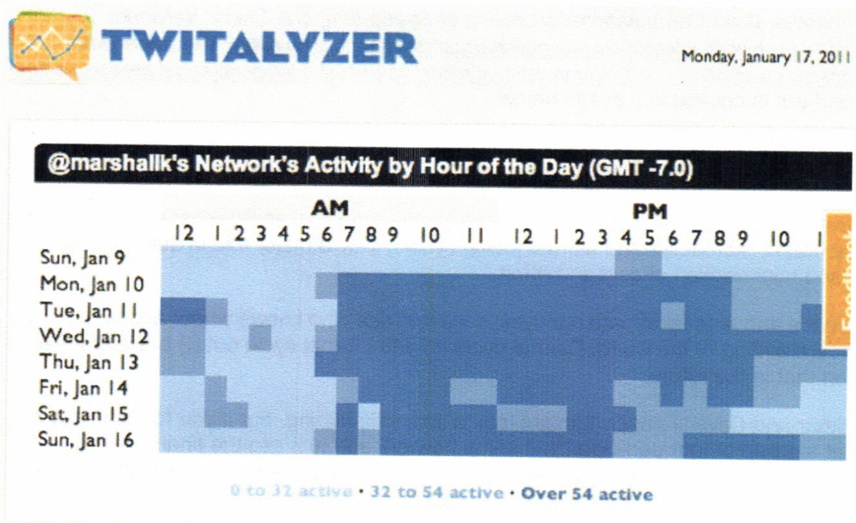
As Yet Unanswered Time-based Questions of Value for Any Community

- How is trust or leadership changing over time?
- Who are the emerging leaders in a group?
- What are the recurring changes in a group?
- How long is the tenure of a leader in a group?
- How long does it take to elevate the level of trust such as a relationship changing from visitor to friend?

Now imagine that kind of temporal and spacial analysis being performed on much larger networks, over greater periods of time.

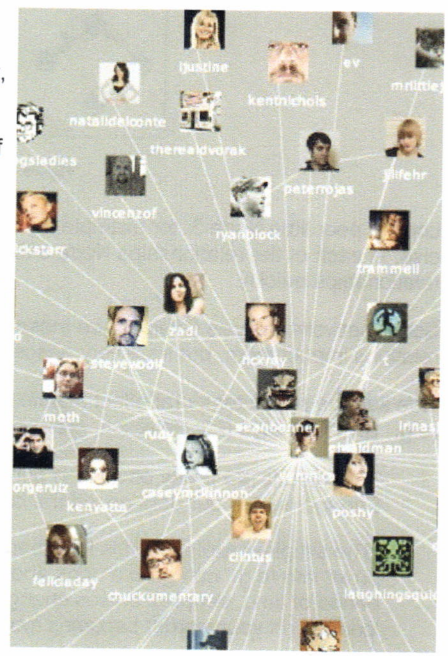
"This added dimension or set of data points is out there and generally widely available as 'exhaust data', so to harness it and factor it in with the rest of the social graph would be truly valuable," says Eileen Burbidge, a London angel investor at White Bear Yard and a former product manager at Skype, among other *(http://uk.linkedin.com/in/eileenburbidge)* positions.

> "From an investment (i.e. value creation) point of view, spatio-temporal data has the potential to add an element of value, context and relevance to otherwise 'flat' data points.
>
> "Take LinkedIn for example. I use it to see who in my network knows (and might endorse) whom, but I'm often cross-referencing/checking a person's contacts by their work history to discern if a specific contact was established at one spatio-temporal point vs another (ie relevancy)... The ability to build this into social network analysis would be extremely valuable as space and time offer tremendous context and relevance to social connections and relationships. "



The Hard Parts

That could very well be the kind of sophisticated social network analysis that service providers aspire to in the future and that their customers seek. Identifying some basic opportunities doesn't mean it will be easy to get there, however.



Shekhar and Oliver say this points to the need for "a central role for computation and computational models, not only to scale up to the large and growing data volumes, but also to address new spatiotemporal social questions related to change, trends, duration, mobility, and travel.

"The need for computational efficiency conflicts with the requirement for expressive power of the model and balancing these two conflicting goals is challenging."

If each historical moment of our relative connective history becomes no longer exhaust data, but points on a chart, that sure is going to be a challenge in the computational efficiency department! Presumably, it will just be timestamped changes of state that will be preserved.

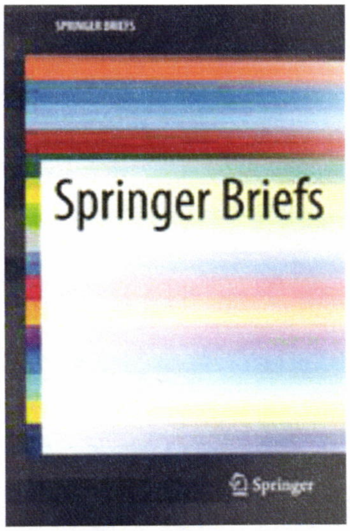
Scaling that analysis is one challenge, finding new ways to recognize, tell and leverage the stories unearthed by analysis of that data is a whole other challenge.

Shekhar and Oliver cast themselves into the abyss of that data-centric future with their conclusion: "We welcome collaboration towards identifying datasets and use-cases to evaluate the potential of TAG [the time aggregated graph model] to address spatio-temporal questions about social networks."

Good luck guys, may you help open up this whole new frontier to us all. You've certainly articulated something that a whole lot of people are going to be very interested in in the future.

Right: A slice of Veronica Belmont's closest Twitter buds, per Mailana, a system without

SpringerBriefs



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Mapping opportunities

Scientists who can combine geographic information systems with satellite data are in demand in a variety of disciplines. Virginia Gewin gets her bearings.

Forest fires ravaging southern California, foot-and-mouth disease devastating the British livestock industry, the recent outbreak of severe acute respiratory syndrome (SARS) — all of these disasters have at least one thing in common: the role played by geospatial analysts, mining satellite images for information to help authorities make crucial decisions. By combining layers of spatially referenced data called geographic information systems (GIS) with remotely sensed aerial or satellite images, these high-tech geographers have turned computer mapping into a powerful decision-making tool.

Natural-resource managers aren't the only ones to take notice. From military planning to real estate, geospatial technologies have changed the face of geography and broadened job prospects across public and private sectors.

Earlier this year, the US Department of Labor identified geotechnology as one of the three most important emerging and evolving fields, along with nanotechnology and biotechnology. Job opportunities are growing and diversifying as geospatial technologies prove their value in ever more areas.

The demand for geospatial skills is growing worldwide, but the job prospects reflect a country's geography, mapping history and even political agenda. In the United States, the focus on homeland security has been one of many factors driving the job market. Another is its vast, unmapped landscape. While European countries are integrating GIS into government decision-making, their well-charted lands give them little need for expensive satellite imagery.

AN EXPANDING MARKET

All indications are that the US$5-billion worldwide geospatial market will grow to $30 billion by 2005 — a dramatic increase that is sure to create new jobs, according to Emily DeRocco, assistant secretary at the US Department of Labor's employment and training division. NASA says that 26% of its most highly trained geotech staff are due to retire in the next decade, and the National Imagery and Mapping Agency is expected to need 7,000 people trained in GIS in the next three years.

Of the 140,000 organizations globally that use GIS, most are government agencies — local, national and international. A ten-year industry forecast put together last year by the American Society for Photogrammetry & Remote Sensing (ASPRS) identified environmental, civil government, defence and security, and transportation as the most active market segments.

Business at the Earth-imagery provider Space Imaging, of Thornton, Colorado, increased by 70% last year, says Gene Colabatistto, executive vice-president of the company's consulting service. To keep up momentum, the company plans to hire more recruits with a combination of technical and business skills. Colabatistto cites the increased adoption of GIS technologies by governments as a reason for the rise. He adds that the US military, the first industry to adopt GIS and remote sensing on a large scale, has spent more than $1 billion on commercial remote sensing and GIS in the past two years.

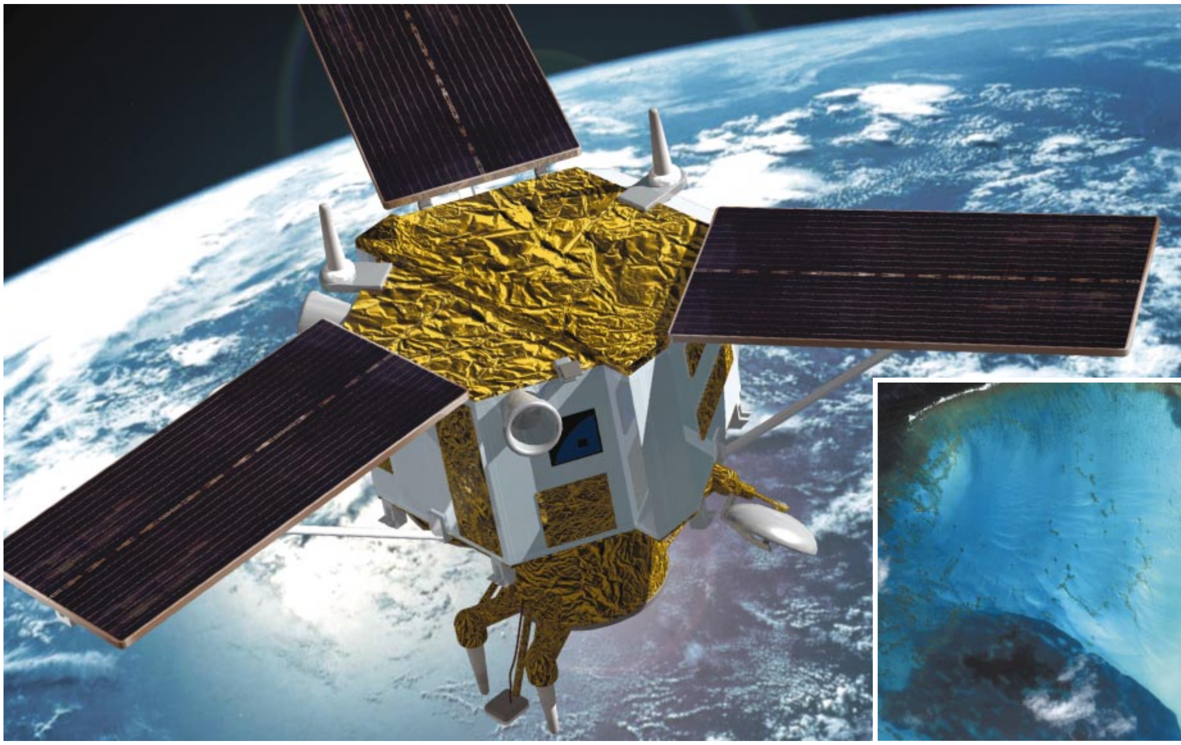
LOOKING DOWN IS LOOKING UP

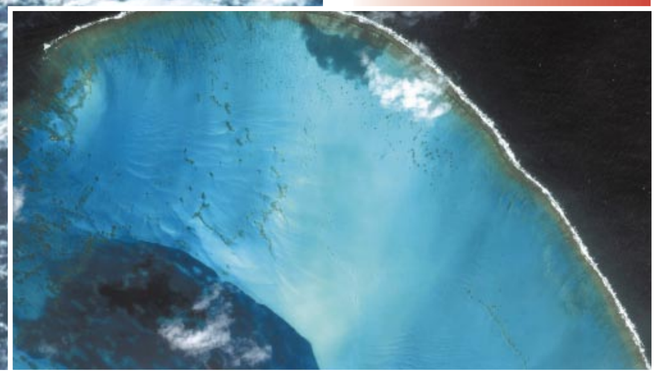
The private sector hasn't traditionally offered many jobs for geographers, but location-based services and mapping — or 'geographic management systems' — are changing the field. "The business of looking down is looking up," says Thomas Lillesand, director of the University of Wisconsin's Environmental Remote Sensing Center in Madison, Wisconsin.

Imagery providers such as Digital Globe of Longmont, Colorado, also need more GIS-trained workers as markets continue to emerge. Spokesman Chuck Herring says that the company has identified 54 markets in which spatial data are starting to play a role.

The Environmental Systems Research Institute (ESRI), in Redlands, California, sets the industry standards for geospatial software. Most of its 2,500 employees have undergraduate training in geography or information technology, although PhDs are sought after to fill the software-development positions. Many private companies, including the ESRI and Space Imaging, offer valuable work experience to both graduate and final-year undergraduate students.

Graduates in natural-resource management note that GIS and remote-sensing skills are becoming as important as fieldwork. GIS platforms, which manipulate all forms of image data, are transforming





A fresh view: high-resolution imaging satellites such as IKONOS are providing researchers with unparalleled insight and information about the world (inset).

disciplines such as ecology, marine biology and forestry.

"Science has discovered geography," says Doug Richardson, executive director of the Association of American Geographers (AAG). Many of the National Science Foundation's multidisciplinary research programmes now include a geospatial component.

SKILLED LABOUR

Some universities are offering two-year non-thesis master's programmes in geospatial technologies, including communication and business courses — perfect for professionals who want to build on existing skills or move into a new field. The non-profit Sloan Foundation has funded several geospatially related professional master's programmes. In addition, numerous short courses are available to bring professionals up to speed. Indeed, the ESRI alone trains over 200,000 people a year. AAG and ASPRS conferences also offer training sessions.

Although technical skills are important, Richardson stresses that employees need a deep understanding of underlying geographic concepts. "It's a mistake to think that these technologies require only technician-oriented functions," he says.

Throughout the European Union (EU), the many top-quality graduate geography programmes remain the primary training grounds. Recently, a few pan-European projects have also emerged, including a new international institute designed to train future geographers. Building on a collaboration between the European Space Agency and the US National Science Foundation, the Vespucci Initiative in 2002 began three-week summer workshops training students from around the world in spatial data infrastructure, spatial analysis and geodemographics. The EU even promotes distance learning: UNIGIS, a network of European universities, prides itself on being the only virtual, global, multilingual GIS programme in the world.

Doug Richardson sees a combination of technological skills and an understanding of geographical concepts as important.

Although GIS is increasingly incorporated into UK government practices, there is little demand for remote-sensing expertise in this small and heavily mapped country. Mark Linehan, director of the London-based Association for Geographic Information, says that although the public-sector market is growing, it remains a struggle to find jobs for MScs at the appropriate pay scale and qualification level.

The European Commission (EC) is laying the groundwork to ease data-sharing across countries in anticipation of wider adoption of GIS among the member-state governments and to cut the costs of data gathering. That process alone will require at least a couple of thousand people trained in GIS, and many more proposals are expected.

Indeed, the EC and the European Space Agency have joined to propose a Global Monitoring for Environment and Security initiative, to provide permanent access to information on environmental management, risk surveillance and civil security. Given the scope of the mandate, this is likely to need people who understand how to interpret, integrate and manage satellite information — those who also have a background in natural-resource issues will be in highest demand.

Considering the role that GIS played in staving the spread of foot-and-mouth disease, such a system will not only increase the prevalence of geospatial skills in Europe, it will better connect data with Europe's resource managers. ■

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Web links

Environmental Systems Research Institute
- **www.esri.com**

Association of American Geographers
- **www.aag.org**

American Society for Photogrammetry & Remote Sensing
- **www.asprs.org**

The Vespucci Initiative
- **www.vespucci.org**

Global Monitoring for Environment and Security
- **intelligence.jrc.cec.eu.int/space/baveno/baveno.html**

Association for Geographic Information
- **www.agi.org.uk**

UNIGIS
- **www.unigis.at/net**

US Department of Labor's Career Voyages
- **www.careervoyages.gov**

Sloan Foundation professional master's programmes
- **www.sciencemasters.com**