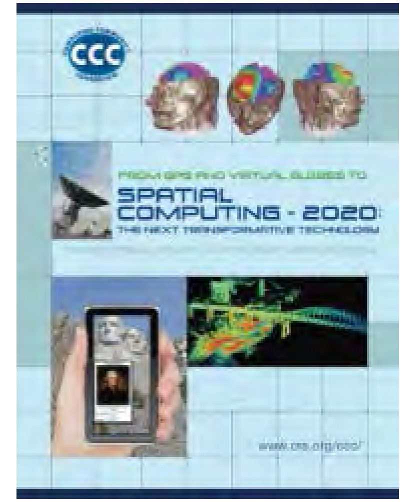
From GPS and Google Maps to Spatial Computing

Biennial Intl. Conf. on Geo-computation
Dallas, TX, USA. :: May, 2015



Shashi Shekhar
McKnight Distinguished University Professor
Department of Computer Science and Eng.
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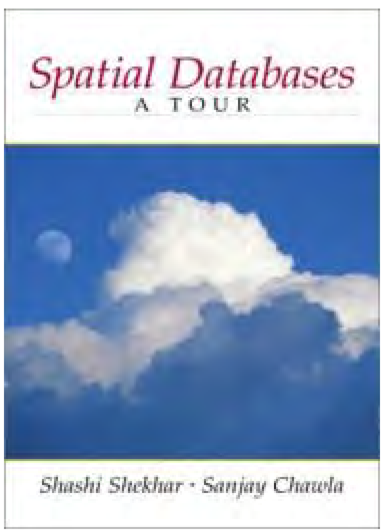
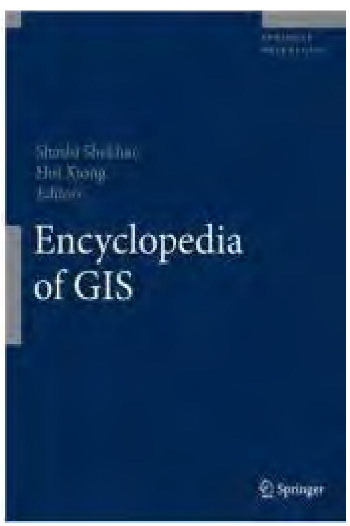
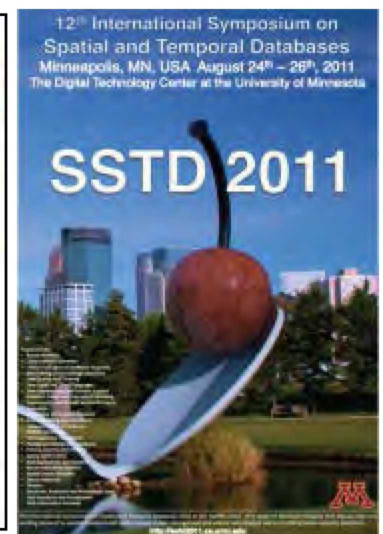
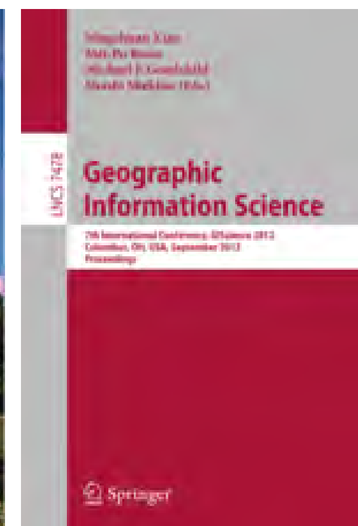
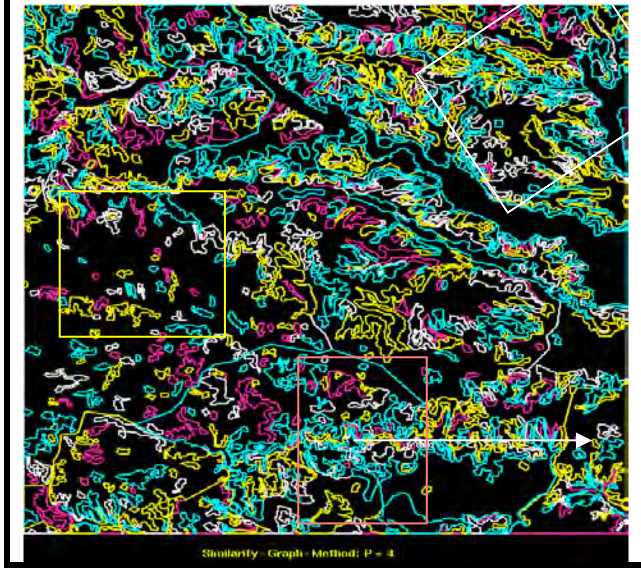






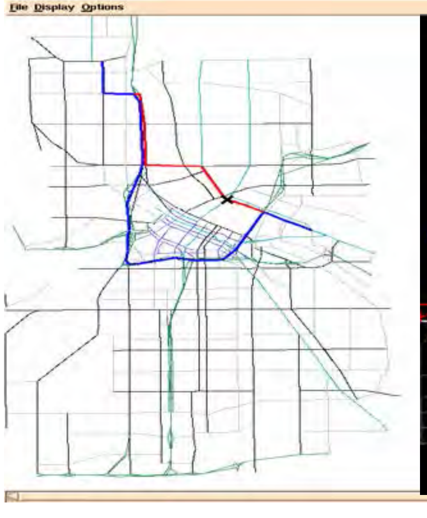


Research Theme 1: Spatial Databases

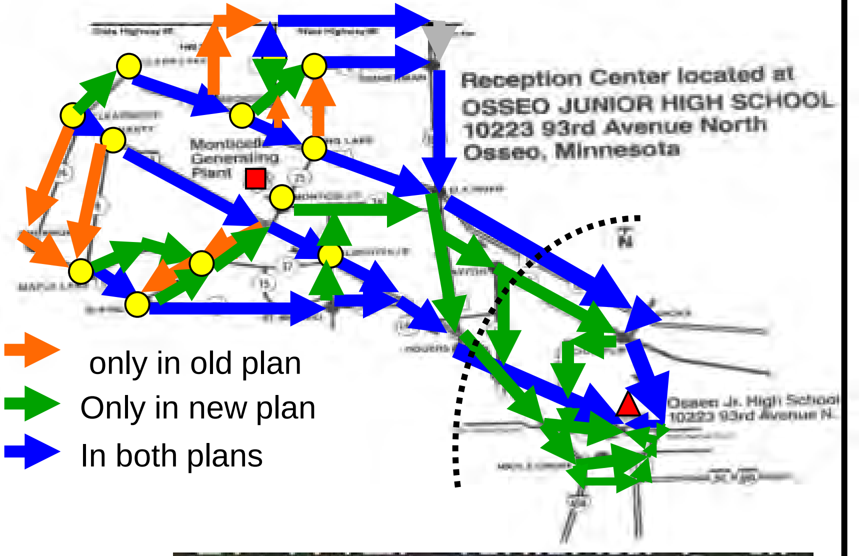


Parallelize Range Queries

Shortest Paths **Storing graphs in disk blocks**



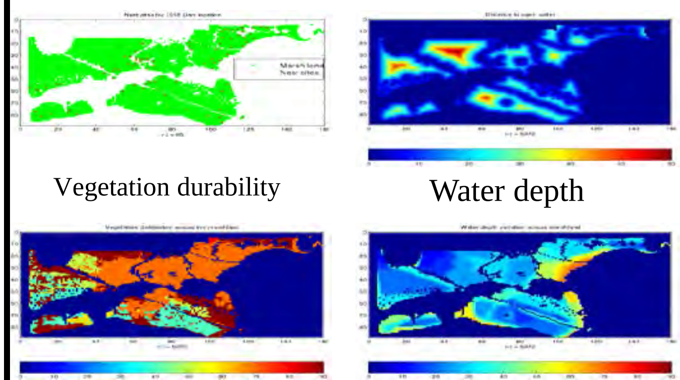
Evacutation Route Planning



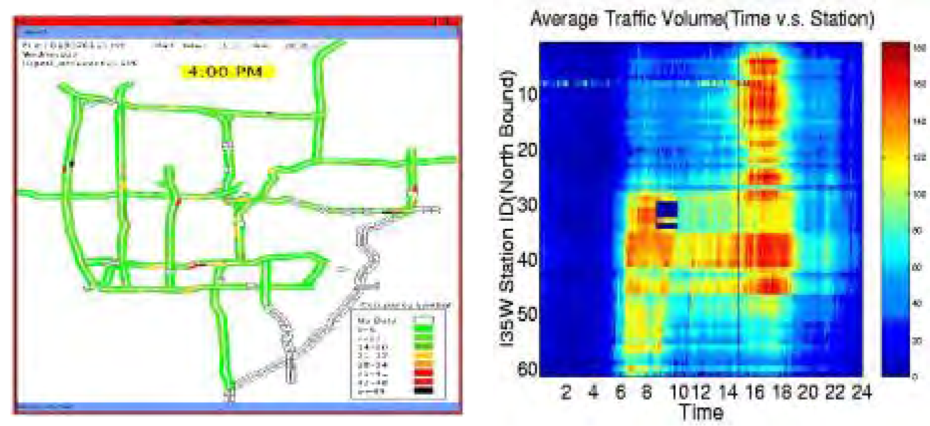
Theme 2 : Spatial Data Mining

Location Prediction: nesting sites

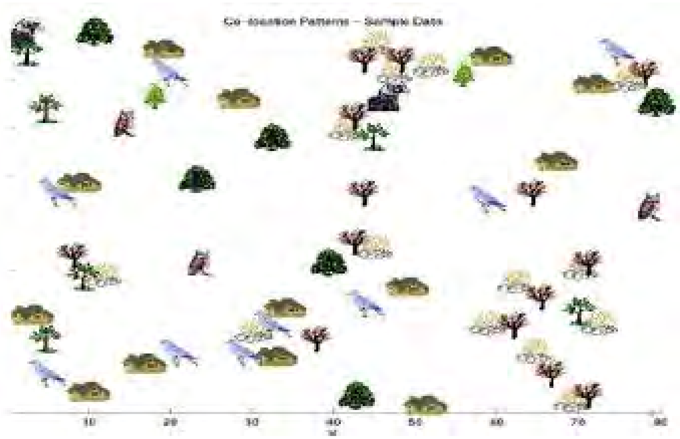
Nest locations Distance to open water



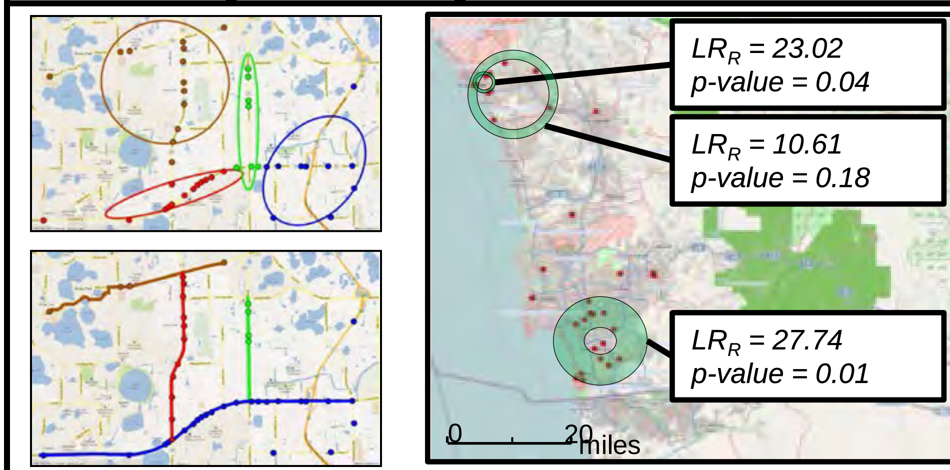
Spatial outliers: sensor (#9) on I-35



Co-location Patterns



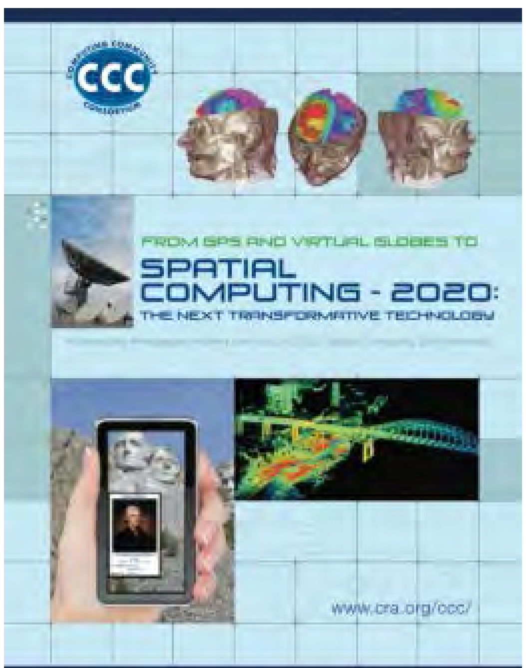
Spatial Concept Aware Summarization

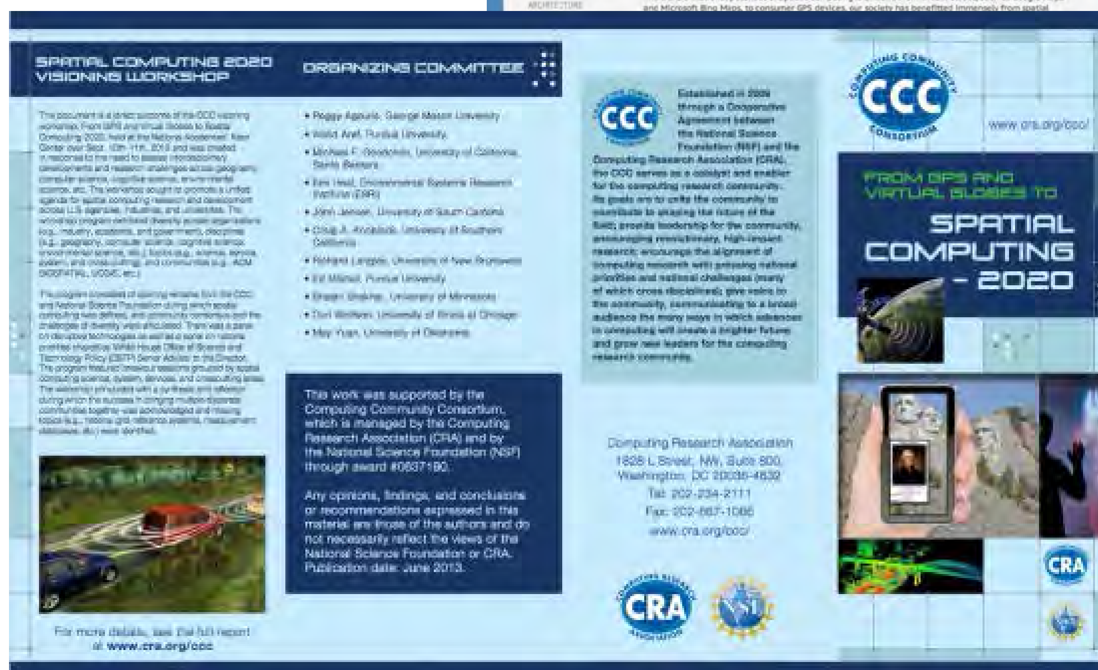


Sources

- From GPS and Virtual Globes to Spatial Computing 2020, CCC Report, 2013. www.cra.org/ccc/visioning/visioning-activities/spatial-computing

- With few slides on work from presenter's group
  Identifying patterns in spatial information: a survey of methods, Wiley Interdisc. Reviews: Data Mining and Know. Discovery , 1(3):193-214, May/June 2011. (DOI: 10.1002/widm.25).





Outline

- Introduction
  - Spatial Computing Audience: Niche => Everyone
  - Spatial Computing 2020 - Workshop
- GPS
- Location Based Services
- Spatial Statistics
- Spatial Database Management Systems
- Virtual Globes
- Geographic Information Systems
- Conclusions

What is Spatial Computing?

- Transformed our lives though understanding spaces and places
  - Examples: localization, navigation, site selection, mapping,
  - Examples: spatial context, situation assessment (distribution, patterns), …

The Changing World of Spatial Computing

	Last Century	Last Decade
Map User	Well-trained few	Billions
Mappers	Well-trained few	Billions
Software, Hardware	Few layers, e.g., Applications: Arc/GIS, Databases: SQL3/OGIS	Almost all layers
User Expectations & Risks	Modest	Many use-case & Geo-privacy concerns

It is widely used by Government!

Geospatial Information and Geographic Information Systems (GIS): An Overview for Congress

May 18th, 2011

Congressional Research Service

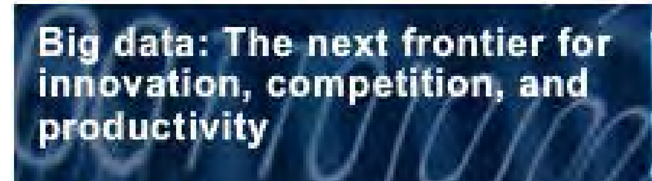
Table 1. Members of the Federal Geographic Data Committee (FGDC)

Dept. of Agriculture	Environmental Protection Agency
Dept. of Commerce	Federal Emergency Management Agency
Dept. of Defense	General Services Administration
Dept. of Energy	Library of Congress
Dept. of Health and Human Services	National Aeronautics and Space Administration
Dept. of Housing and Urban Development	National Archives and Records Administration
Dept. of the Interior (Chair)	National Science Foundation
Dept. of Justice	Tennessee Valley Authority
Dept. of State	
Dept. of Transportation	Office of Management and Budget (Co-Chair)

Folger, Peter. Geospatial Information and Geographic Information Systems (GIS): Current Issues and Future Challenges. Congressional Research Service. June 8th, 2009.

It is only a start! Bigger Opportunities Ahead!

McKinsey Global Institute



The study estimates that the use of personal location data could save consumers worldwide more than $600 billion annually by 2020. Computers determine users' whereabouts by tracking their mobile devices, like cellphones. The study cites smartphone location services including Foursquare and Loopt, for locating friends, and ones for finding nearby stores and restaurants.

But the biggest single consumer benefit, the study says, is going to come from time and fuel savings from location-based services — tapping into real-time traffic and weather data — that help drivers avoid congestion and suggest alternative routes. The location tracking, McKinsey says, will work either from drivers' mobile phones or GPS systems in cars.

The New York Times

Published: May 13, 2011

New Ways to Exploit Raw Data May Bring Surge of Innovation, a Study Says

CCC Visioning Workshop: Making a Case for Spatial Computing 2020
http://cra.org/ccc/spatial_computing.php

Computing Community Consortium

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From GPS and Virtual Globes to Spatial Computing-2020

About the workshop

This workshop outlines an effort to develop and promote a unified agenda for Spatial Computing research and development across US agencies, industries, and universities. See the original workshop proposal here.

Spatial Computing

Spatial Computing 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 Globes such as Google Maps and Microsoft Bing 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. Large

Logistics

Date: Sept. 10th-11th, 2012
Location: Keck Center
Hotel: Liaison Hotel

Steering Committee

Erwin Gianchandani

Hank Korth

Organizing Committee

Peggy Agouris, George Mason University

Walid Aref, Purdue University

Michael F. Goodchild, University of California - Santa Barbara

Workshop Participants

Academia

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Divyakant Agrawal, University of California Santa Barbara
Cecilia Aragon, University of Washington
Walid G. Aref, Purdue University
Elisa Bertino, Purdue University
Henrik Christensen, Georgia Institute of Technology
Isabel Cruz, University of Illinois at Chicago
Michael R. Evans, University of Minnesota
Steven Feiner, Columbia University
Jie Gao, Stony Brook University
Michael Goodchild, University of California Santa Barbara
Sara Graves, University of Alabama Huntsville
Rajesh Gupta, University of California San Diego
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Stephen Hirtle, University of Pittsburgh
Krzysztof Janowicz, University of California Santa Barbara
John Jensen, University of South Carolina
Daniel Keefe, University of Minnesota
John Keyser, Texas A&M University
Craig A. Knoblock, Information Sciences Institute

Hank Korth, Lehigh University
Benjamin Kuipers, University of Michigan
Vipin Kumar, University of Minnesota
Richard Langley, University of New Brunswick
Chang-Tien Lu, Virginia Tech
Dinesh Manocha, University of North Carolina
Edward M. Mikhail, Purdue
Harvey Miller, University of Utah
Joe Mundy, Brown University
Dev Oliver, University of Minnesota
Rahul Ramachandran, UA Huntsville
Norman Sadeh, CMU
Shashi Shekhar, University of Minnesota
Daniel Z. Sui, Ohio State
Roberto Tamassia, Brown University
Paul Torrens, University of Maryland
Shaowen Wang, University of Illinois at Urbana-Champaign
Greg Welch, University of North Carolina
Ouri E. Wolfson, University of Illinois at Chicago
Mike Worboys, University of Maine
May Yuan, University of Oklahoma
Avideh Zakhor, University of California Berkeley

>30 Universities

Industry

Mark Abrams, ESG
Mohamed Ali, Microsoft
Lee Allison, Arizona Geological Survey
Virginia Bacon Talati, Computer Science and Telecommunications Board (CSTB)
Ramon Caceres, AT&T Research
Vint Cerf, Google
Jade DePalacios, Naval Postgraduate School
Jon Eisenberg, Computer Science and Telecommunications Board (CSTB)
Tom Erickson, IBM
Erwin Gianchandani, CCC
Eric Hoel, ESRI
Xuan Liu, IBM
Siva Ravada, Oracle
Jagan Sankaranarayanan, NEC Labs
Lea Shanley, Wilson Center
Kevin Pomfret, Centre for Spatial Law and Policy

14 Organizations

Government

Nabil Adam, DHS
Vijay Atluri, NSF
David Balshaw, NIH/NIEHS
Budhendra Bhaduri, ORNL
Kelly Crews, NSF
Beth Driver, NGA
Walton Fehr, USDOT
Myron Gutmann, NSF
Susanne Hambrusch, NSF
Michelle Heacock, NIH/NIEHS
Clifford Jacobs, NSF
Farnam Jahanian, NSF
Todd Johanesen, NGA
Thomas Johnson, NGA
Henry Kelly, OSTP
Alicia Lindauer, USDOE
Keith Marzullo, NSF
John L. Schnase, NASA
Jim Shine, Army Research
Raju Vatsaval, ORNL
Eric Vessey, NSA
Howard D. Wactlar, NSF
Tandy Warnow, NSF
Nicole Wayant, Army Research
Mark Weiss, NSF
Maria Zemankova, NSF
Li Zhu, NIH/NCI

12 Agencies

Workshop Highlights

Agenda

- Identify fundamental research questions for individual computing disciplines
- Identify cross-cutting research questions requiring novel, multi-disciplinary solutions

Organizing Committee

- Peggy Agouris, George Mason University
- Walid Aref, Purdue University
- Michael F. Goodchild, University of California - Santa Barbara
- Erik Hoel, Environmental Systems Research Institute (ESRI)
- John Jensen, University of South Carolina
- Craig A. Knoblock, University of Southern California
- Richard Langley, University of New Brunswick
- Ed Mikhail, Purdue University
- Shashi Shekhar, University of Minnesota
- Ouri Wolfson, University of Illinois -
- May Yuan, University of Oklahoma

Workshop Highlights

Pull Panel: National Priorities, Societal Applications of Spatial Computing

Chair: Henry Kelly, OSTP

Members

US-DoD: Eric Vessey

US-DoD: Todd Johanesen

NIH/NIEHS: Michelle Heacock

NASA: John L Schnase

DHS: Nabil Adam

NSF EarthCube: Clifford Jacobs

DOT: Walton Fehr

DOE: Alicia Lindauer

Push Panel: Spatial Computing (SC) Platform Trends, Disruptive Technologies

Chair: Dinesh Manocha, UNC

Members:

Graphics & Vision: John Keyser, TAMU

Interaction Devices: Steven Feiner, Columbia University

LiDAR : Avideh Zakhor, UCB

GPS Modernization: Mark Abrams, Advisor to USG

Cell Phones: Ramon Caceres, AT&T

Indoor Localization: Greg Welch, UNC

Internet Localization: Rajesh Gupta, UCSD

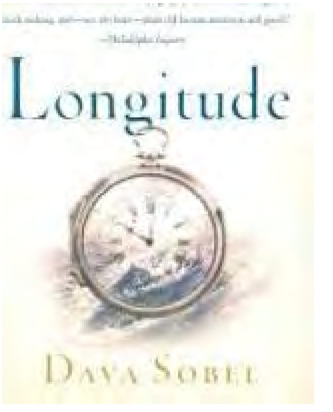
Cloud Computing: Divyakant Agarwal, UCSB

Outline

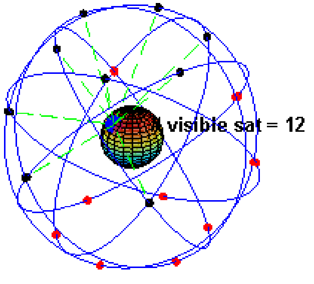
- Introduction
- GPS
  - Outdoors => Indoors
- Location Based Services
- Spatial Statistics
- Spatial Database Management Systems
- Virtual Globes
- Geographic Information Systems
- Conclusions

Global Positioning Systems (GPS)

- Positioning ships
  - Latitude f(compass, star positions)
  - Longitude: dead-reckoning => marine chronometer
  - Longitude prize (1714), accuracy in nautical miles

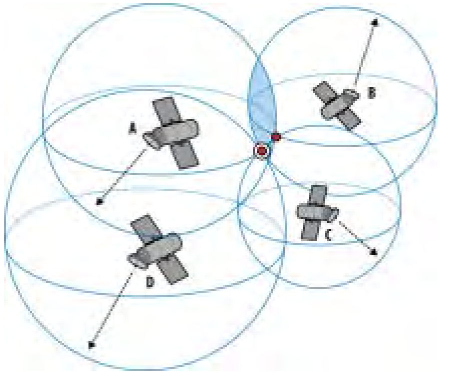


- Global Navigation Satellite Systems
  - Infrastructure: satellites, ground stations, receivers, …
  - Use: Positioning (sub-centimeter), Clock synchronization



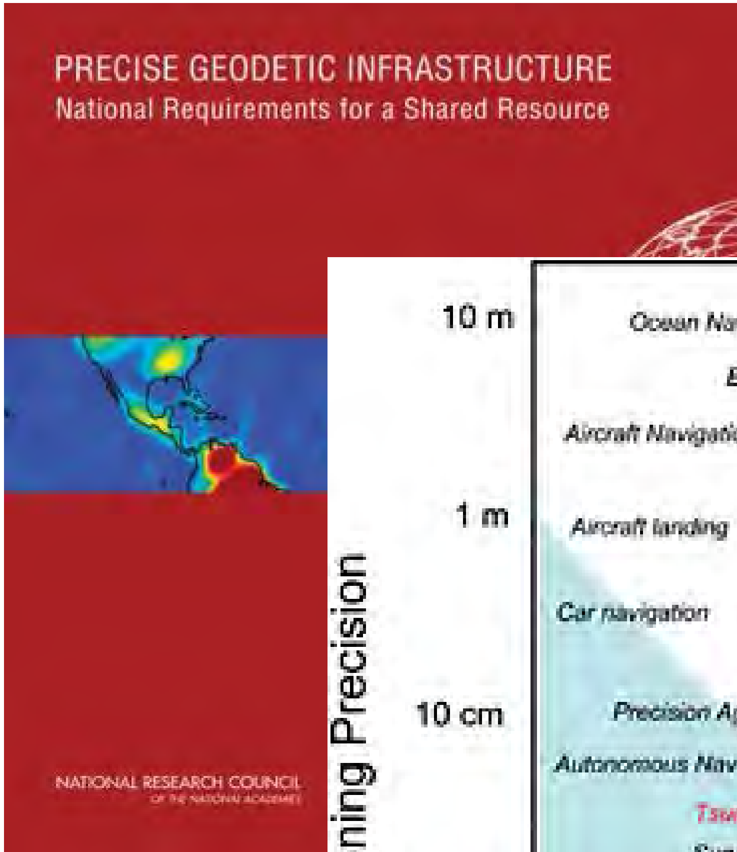
http://en.wikipedia.org/wiki/Global_Positioning_System

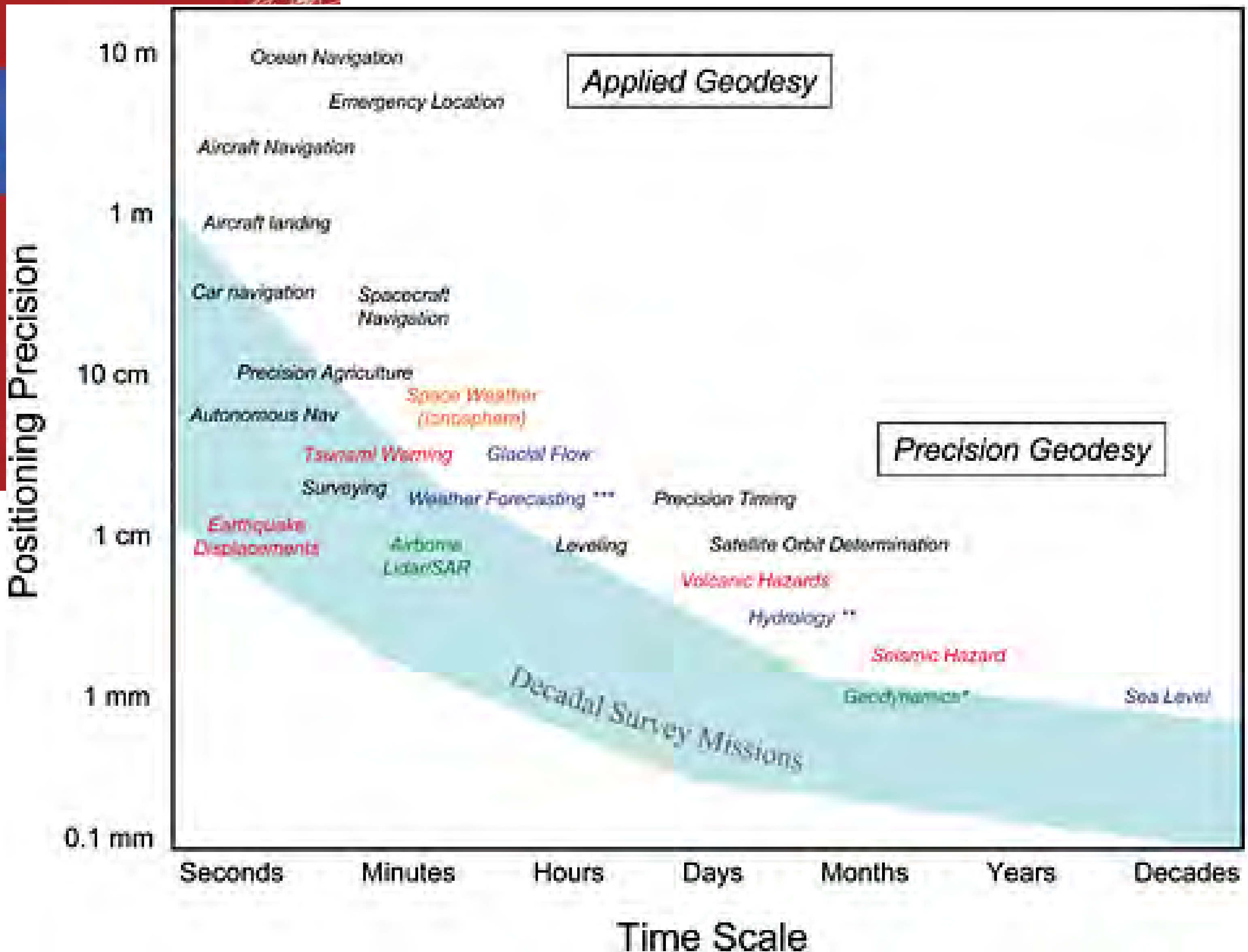
Trilateration



http://answers.oreilly.com/topic/2815-how-devices-gather-location-information/

Positioning Precision

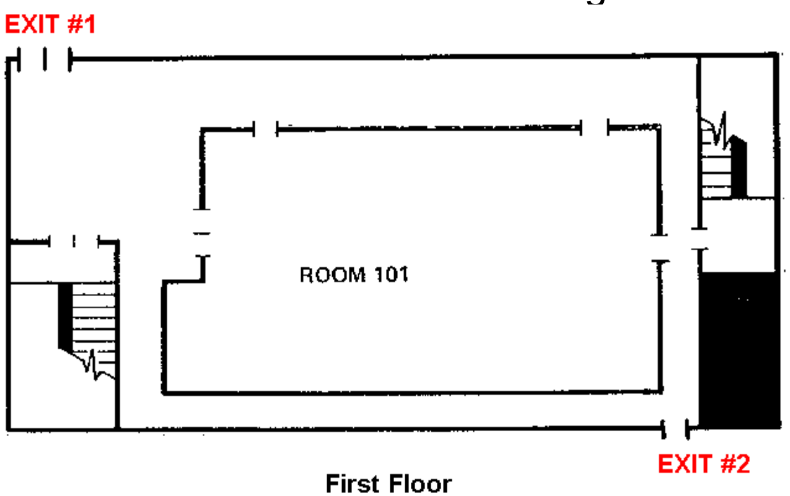




Trends: Localization Indoors and Underground

- GPS works outdoors, but,
  - We are indoors 90% of time!
  - Ex. malls, hospitals, airports, etc.
  - Indoor asset tracking, exposure hotposts, …
- Leveraging existing indoor infrastructure
  - Blue Tooth, WiFi, Cell-towers, cameras, Other people?
- How to model indoors for navigation, tracking, hotspots, …?
  - What are nodes and edges ?

http://www.mobilefringe.com/products/square-one-shopping-center-app-for-iphone-and-android/



WiFi Localization

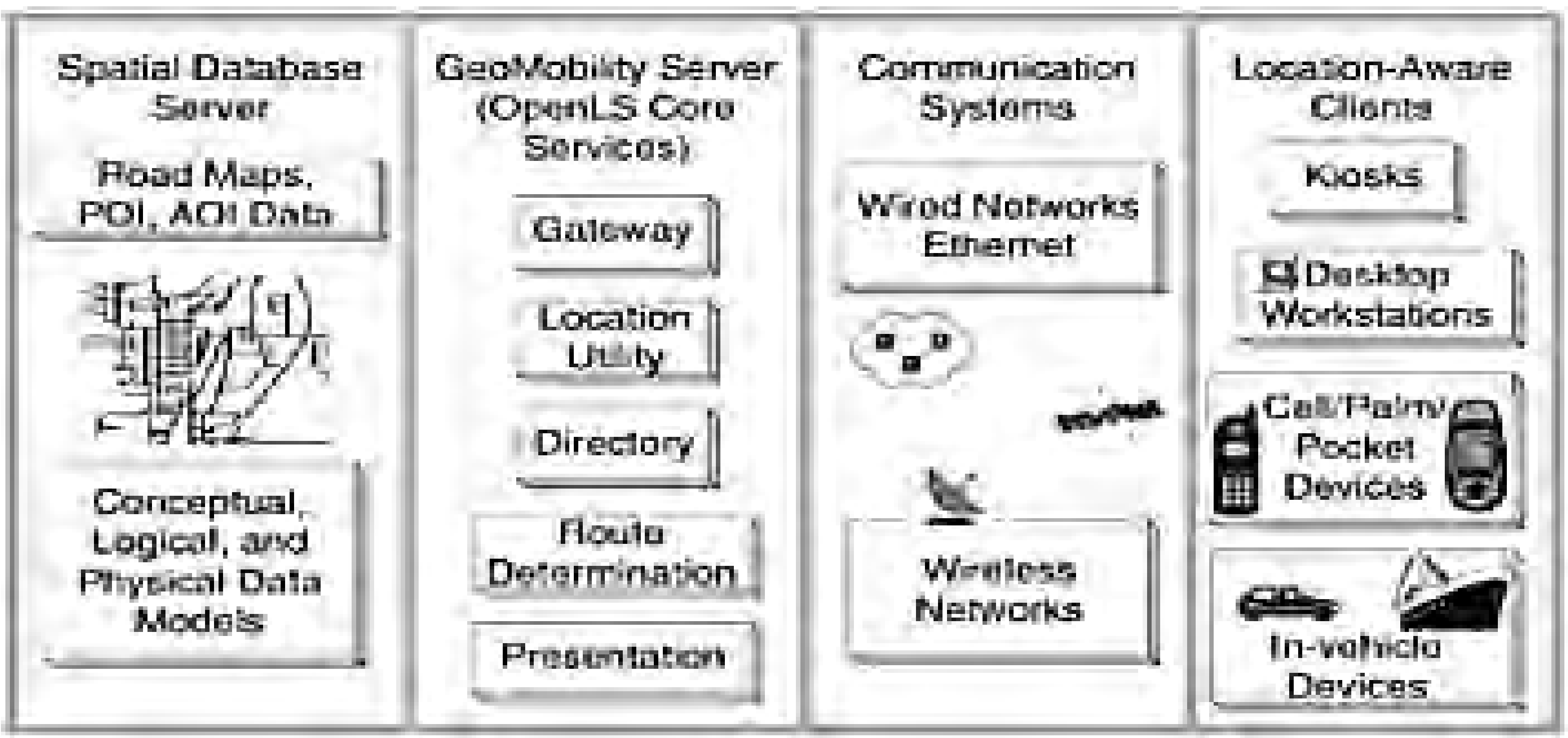
http://rfid.net/basics/rtls/123-wi-fi-how-it-works

Outline

- Introduction
- GPS
- Location Based Services
  - Queries => Persistent Monitoring
- Spatial Statistics
- Spatial Database Management Systems
- Virtual Globes
- Geographic Information Systems
- Conclusions

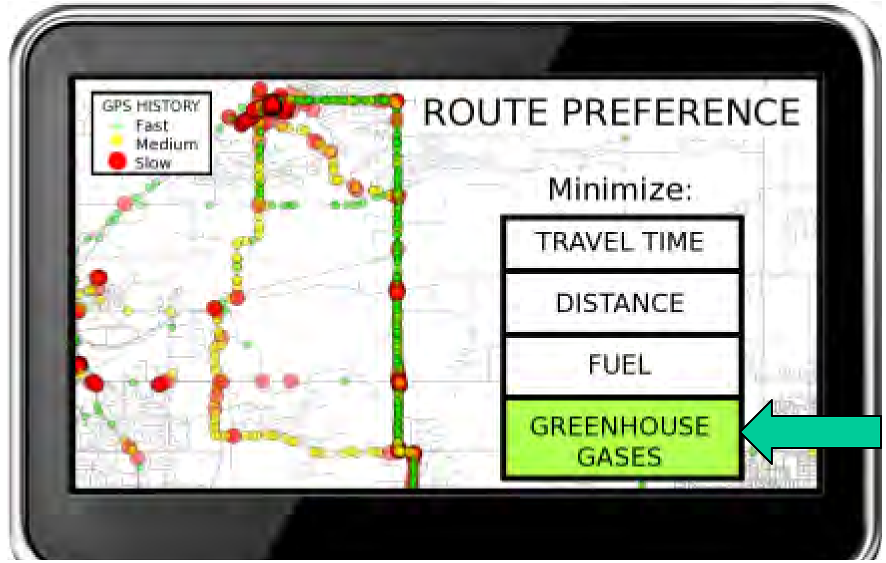
Location Based Services

- Open Location Services: Queries
  - <u>Location:</u> Where am I? (street address, <latitude, longitude>
  - <u>Directory:</u> Where is the nearest clinic (or doctor)?
  - <u>Routes:</u> What is the shortest path to reach there?



Next Generation Navigation Services

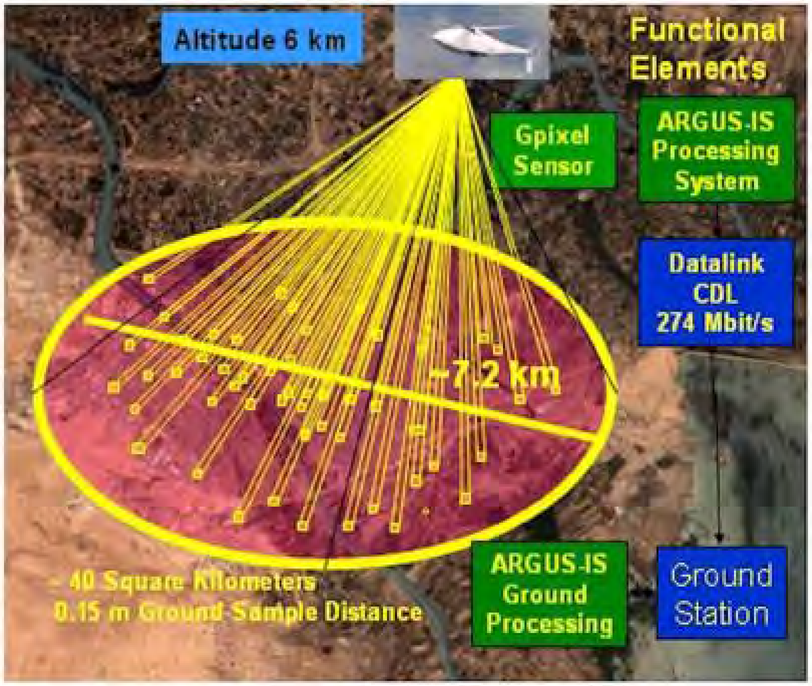
- Eco-Routing
- Best start time
- Road-capacity aware



Static	Time-Variant
Which is the shortest travel time path from downtown Minneapolis to airport?	

Trends: Persistent Geo-Hazard Monitoring

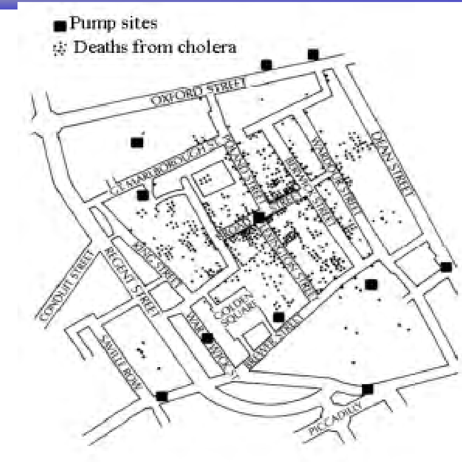
- Environmental influences on our health & safety
  - air we breathe, water we drink, food we eat
- Surveillance
  - Passive > Active > Persistent
  - How to economically cover all locations all the time ?
  - Crowd-sourcing, e.g., smartphones, tweets,
  - Wide Area Motion Imagery



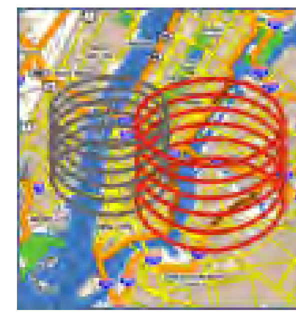
Outline

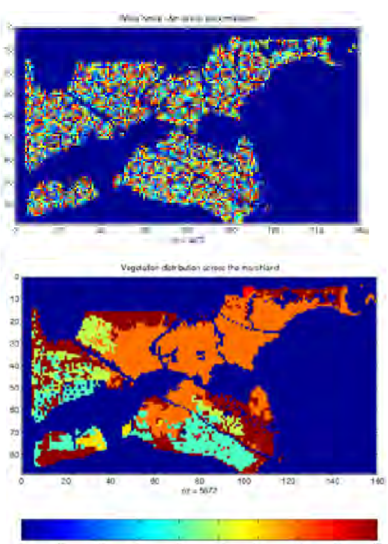
- Introduction
- GPS
- Location Based Services
- Spatial Statistics
  - Concepts: Mathematical => Spatial
- Spatial Database Management Systems
- Virtual Globes
- Geographic Information Systems
- Conclusions

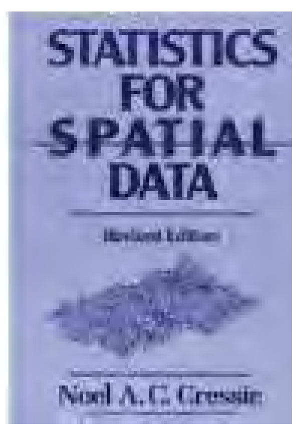
Spatial Statistics: Mathematical Concepts

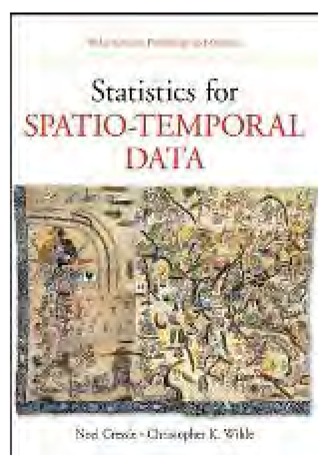


- Spatial Statistics
  - Quantify uncertainty, confidence, …
  - Is it significant?
  - Is it different from a chance event or rest of dataset?
    - e.g., SaTScan finds circular hot-spots
- Models of Auto-correlation, Heterogeneity, Edge-effect, …
  - Point Process, e.g., Ripley's K-functions, SatScan
  - Geo-statistics, e.g., Kriging, GWR
  - Lattice-based models









SaTScan™

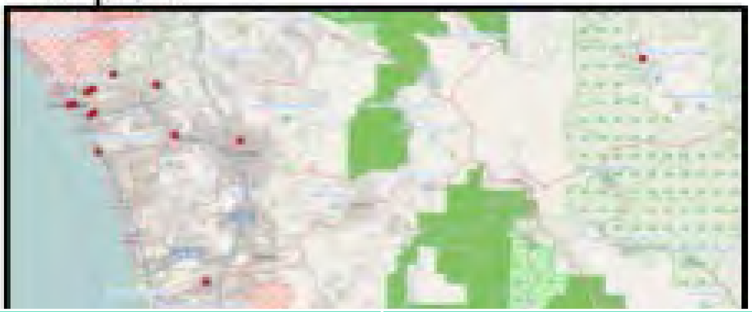
Software for the spatial, temporal, and space-time scan statistics

Ring-Shaped Hotspot Detection: A Summary of Results, IEEE ICDM 2014 (w/ E. Eftelioglu et al.)

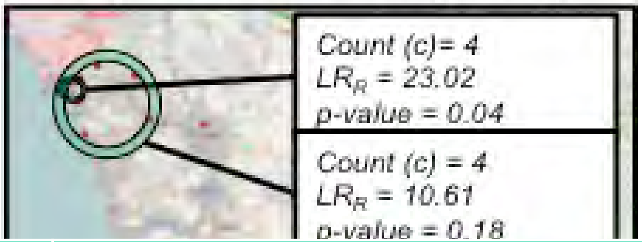
Comparison with Machine Learning

- Representation beyond Linear Algebra, Machine Learning
- Environmental Criminology
  - Routine Activities Theory, Crime Pattern Theory, Doughnut Hole pattern
- Formulation: rings, where inside density is significantly higher than outside …

Input

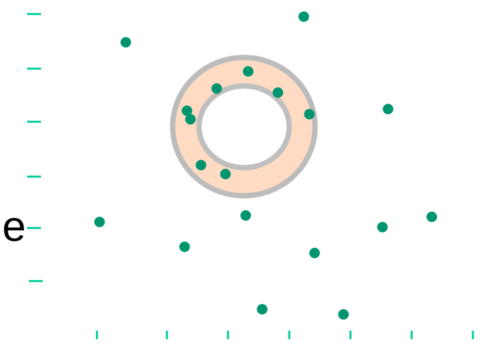


Output: Ring Shaped Hotspot Detection (RHD)

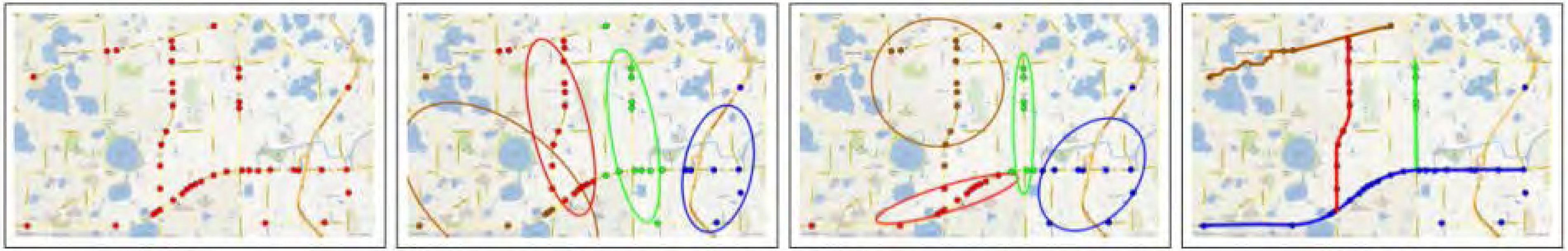


Mathematics	Concepts	Relationships
Sets	Set Theory	Member, set-union, set-difference, …
Vector Space	Linear Algebra	Matrix & vector operations
Euclidean Spaces	Geometry	Circle, Ring, Polygon, Line_String, Convex hull, …
Boundaries, Graphs, Spatial Graphs	Topology, Graph Theory, Spatial graphs, …	Interior, boundary, Neighbor, inside, surrounds, …, Nodes, edges, paths, trees, … Path with turns, dynamic segmentation, …

Trends: Spatial-Concept Aware Patterns



- Spatial Concepts
  - Natural geographic features, e.g., rivers, streams, …
  - Man-made geographic features, e.g., transportation network
  - Spatial theories, e.g., environmental criminology – doughnut hole
- Spatial-concept-aware patterns
  - Hotspots: Circle => Doughnut holes
  - Hot-spots => Hot Geographic-features

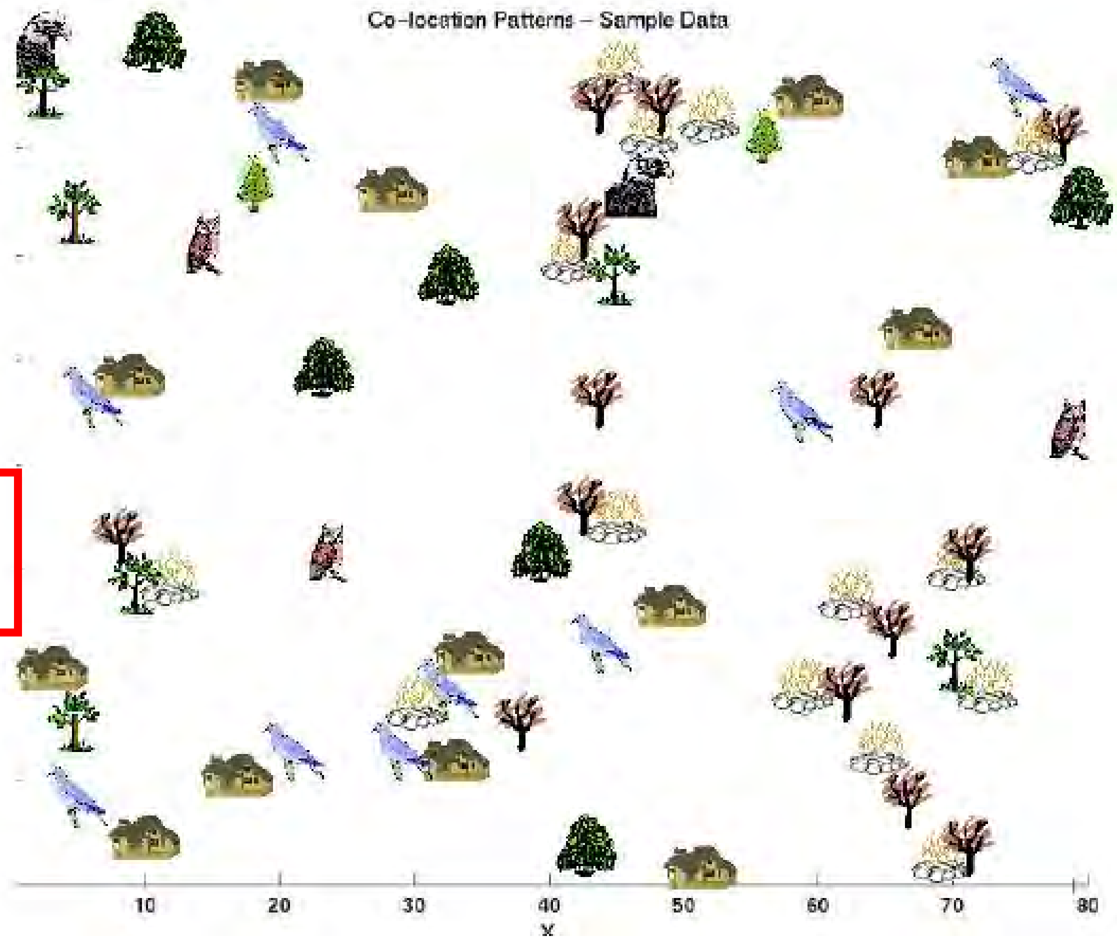


(a) Input (b) Crimestat K-means with Euclidean Distance (c) Crimestat K-means with Network Distance (d) KMR

Details: A K-Main Routes Approach to Spatial Network Activity Summarization, IEEE Transactions on Knowledge and Data Engineering, pre-print, (doi.ieeecomputersociety.org/10.1109/TKDE.2013.135)

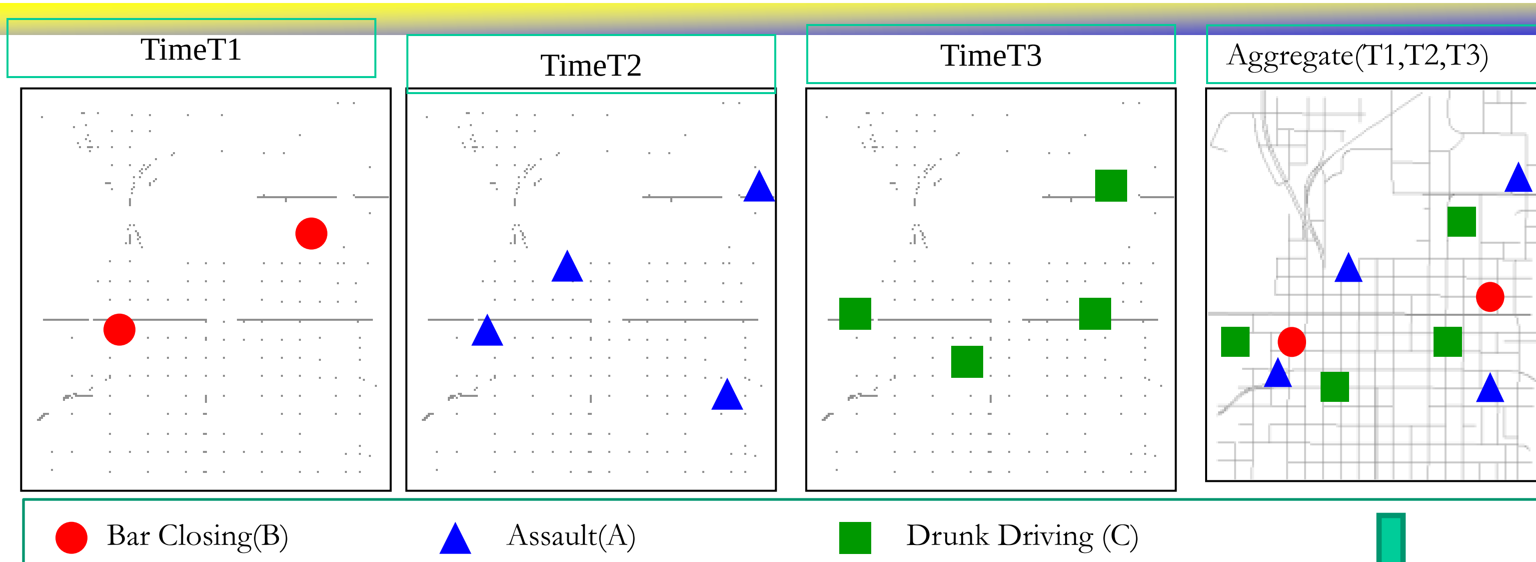
Co-locations/Co-occurrence

- Given: A collection of different types of spatial events
- Find: Co-located subsets of event types

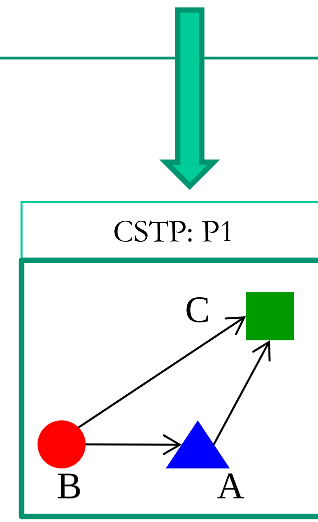


Details: Discovering colocation patterns from spatial data sets: a general approach,, IEEE Transactions on Knowledge and Data Engineering, 16(12), Dec. 2004.

Cascading spatio-temporal pattern (CSTP)

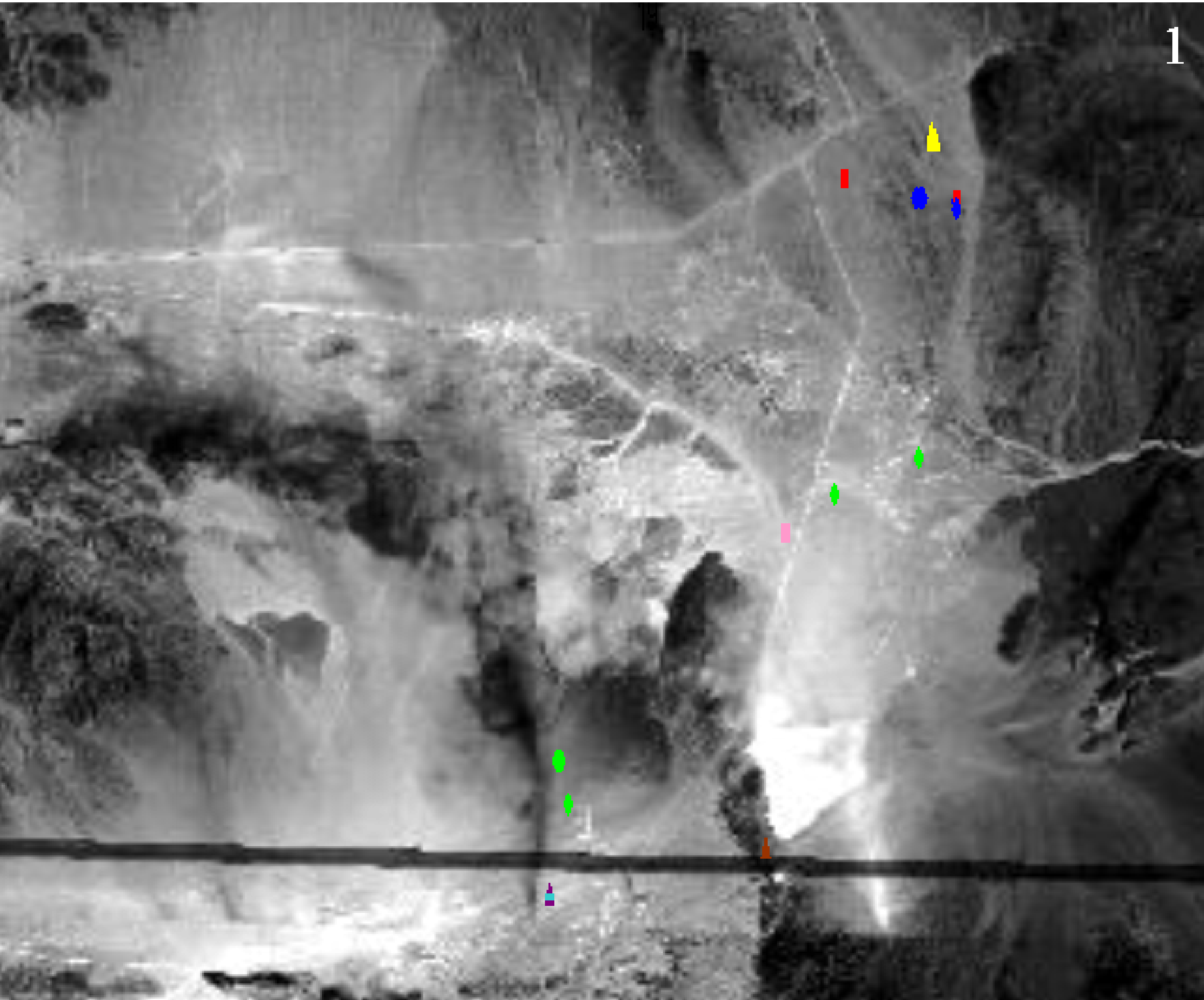


- *Input:* Urban Activity Reports
- *Output: CSTP*
  - *Partially ordered* subsets of ST event types.
  - Located together in space.
  - Occur in *stages* over time.
- Applications: Public Health, Public Safety, …



Details: Cascading Spatio-Temporal Pattern Discovery,
IEEE Transactions on Knowledge and Data Engineering, 24(11), Nov. 2012.

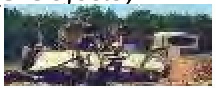
MDCOP Motivating Example : Input



- Manpack stinger (2 Objects)

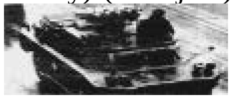
- M1A1_tank (3 Objects)

- M2_IFV (3 Objects)



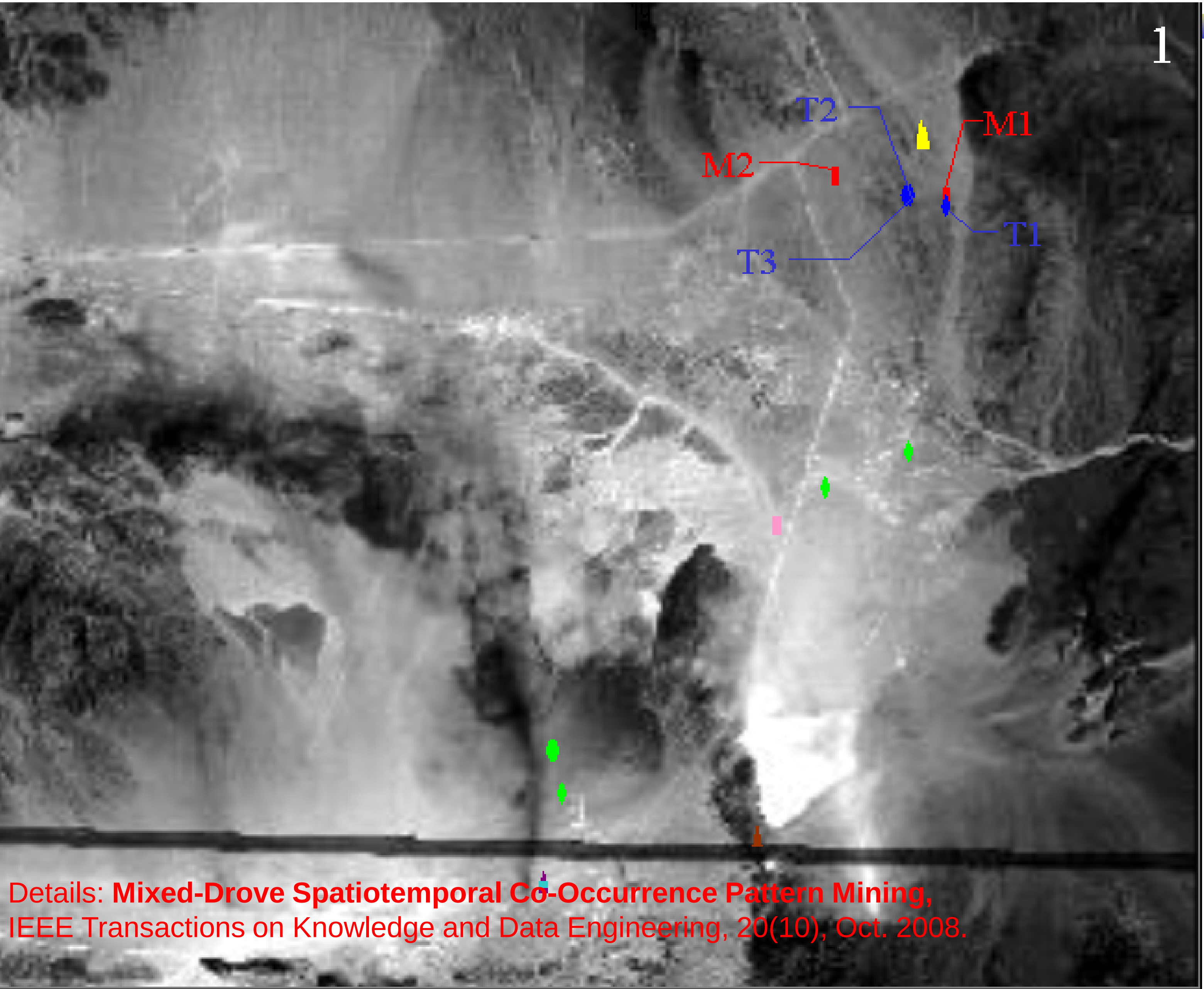
- Field_Marker (6 Objects)
- T80_tank (2 Objects)

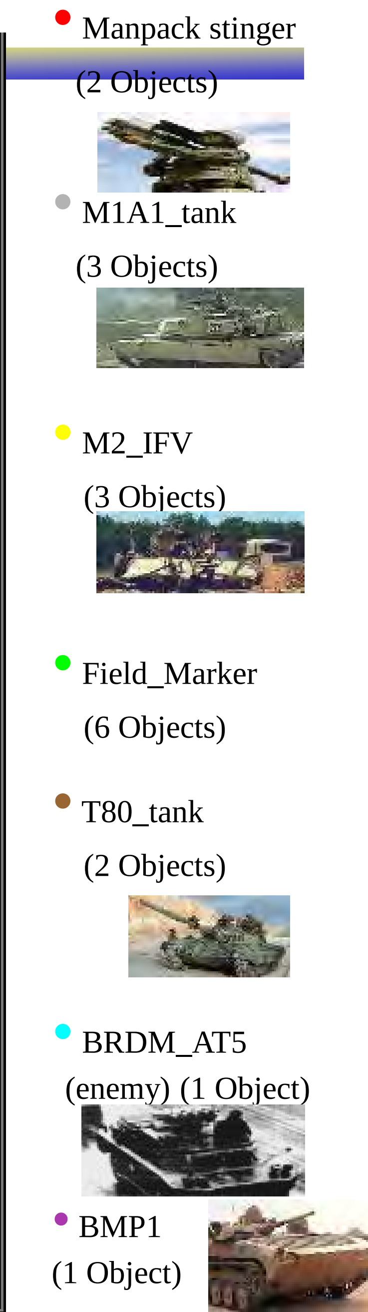
- BRDM_AT5 (enemy) (1 Object)



- BMP1 (1 Object)

MDCOP Motivating Example : Output





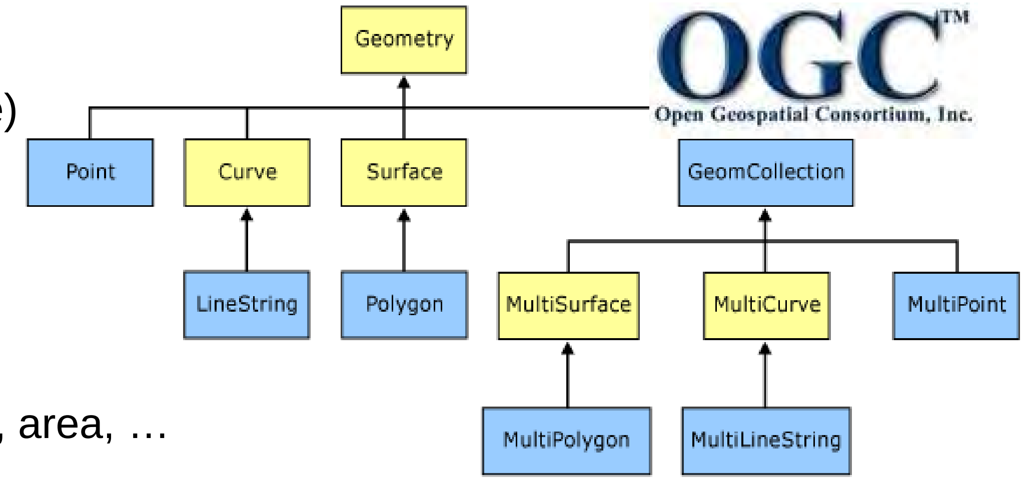
Details: **Mixed-Drove Spatiotemporal Co-Occurrence Pattern Mining,**
IEEE Transactions on Knowledge and Data Engineering, 20(10), Oct. 2008.

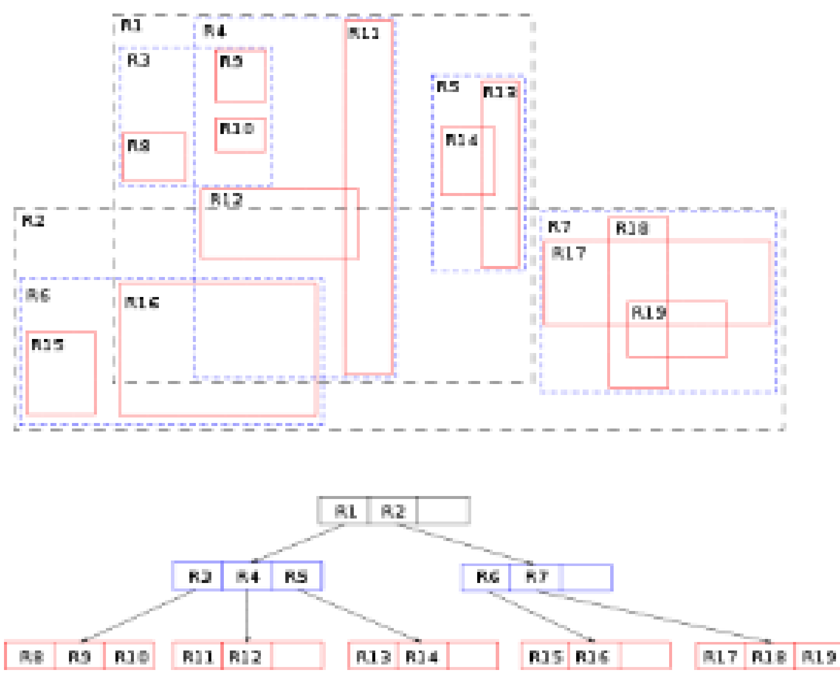
Outline

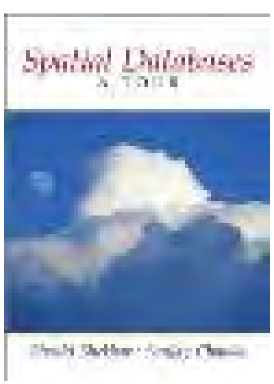
- Introduction
- GPS
- Location Based Services
- Spatial Statistics
- Spatial Database Management Systems
  - Geometry => Spatial Network Databases
- Virtual Globes
- Geographic Information Systems
- Conclusions

Spatial Databases for Geometry

- Dice, Slide, Drill-down, Explore, …
  - Closest pair(school, pollution-source)
  - Set based querying
- Reduce Semantic Gap
  - Clumsy code for inside, distance, …
  - 6 data-types
  - Operations: inside, overlap, distance, area, …
- Scale up Performance
  - Data-structures: B-tree => R-tree
  - Algorithms: Sorting => Geometric







Challenge: Privacy vs. Utility Trade-off

- Check-in Risks: Stalking, GeoSlavery, …
- Ex: Girls Around me App (3/2012), Lacy Peterson [2008]
- Others know that you are not home!

The Girls of Girls Around Me. It's doubtful any of these girls even know they are being tracked. Their names and locations have been obscured for privacy reasons. (Source: Cult of Mac, March 30, 2012)

Challenge: Geo-privacy, geo-confidentiality, …

- Emerging personal geo-data
  - Trajectories of smart phones, gps-devices, life-trajectories and migrations, …
- Privacy: Who gets my data? Who do they give it to? What promises do I get?
- Socio-technical problem
  - Need policy support
  - Challenges in fitting location privacy into existing privacy constructs (i.e HIPPA, Gramm-Leach-Bliley, Children's Online Privacy Protection Act)
- Groups interested in Geo-Privacy
  - Civil Society, Economic Entities, Public Safety ,Policy Makers

GEOTARGETED
ALERTS AND WARNINGS

Table 4.2: Geo-privacy Policy Conversation Starters

1. Emergencies are different (E-911)
2. Differential geo-privacy can improve saftey (E-911 → PLAN, CMAS)
3. Send apps to data, not vice-versa (e.g., eco-routing)
4. Transparent transactions for location traces for increased consumer confidence
5. Responsible entities for location traces (Credit-bureau/census, HIPPA++ for responsible parties)

AMBER ALERT

http://illumemagazine.com/zine/articleDetail.php?FBI-GPS-Tracking-and-Invasion-of-Privacy-13346

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- Virtual Globes & VGI
  - Quilt => Time-travel & Depth
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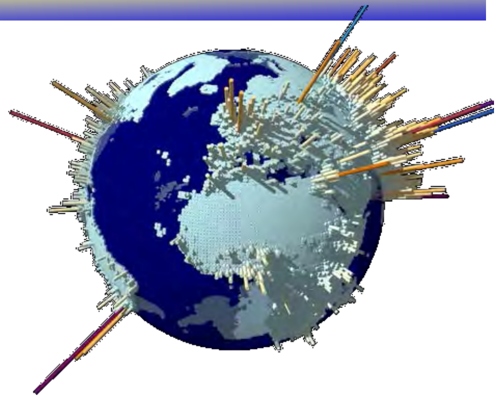
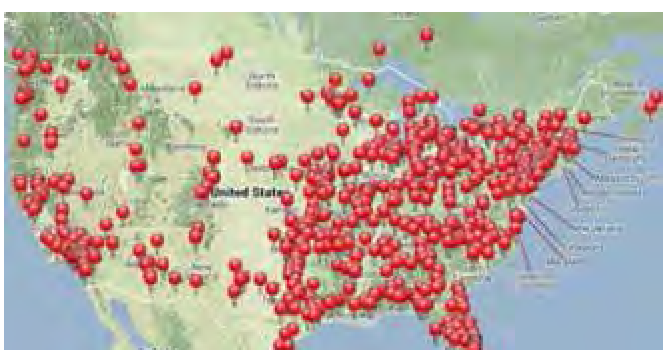
Virtual Globes & Volunteered Geo-Information



- Virtual Globes
  - Visualize Spatial Distributions, Patterns
  - Visual drill-down, e.g., fly-through
    - Change viewing angle and position
    - Even with detailed Streetview!
- Volunteered Geo-Information
  - Allow citizens to make maps & report
  - Coming to public health!
  - People's reporting registry (E. Brokovich)
  - www.brockovich.com/the-peoples-reporting-registry-map/



Virtual Globes in GIS Education

- Coursera MOOC: From GPS and Google Earth to Spatial Computing
  - 21,844 students from 182 countries (Fall 2014)
  - 8 modules, 60 short videos, in-video quizzes, interactive examinations, …
  - 3 Tracks: curious, concepts, technical
  - Flipped classroom in UMN on-campus course

Opportunities: Time-Travel and Depth in Virtual Globes

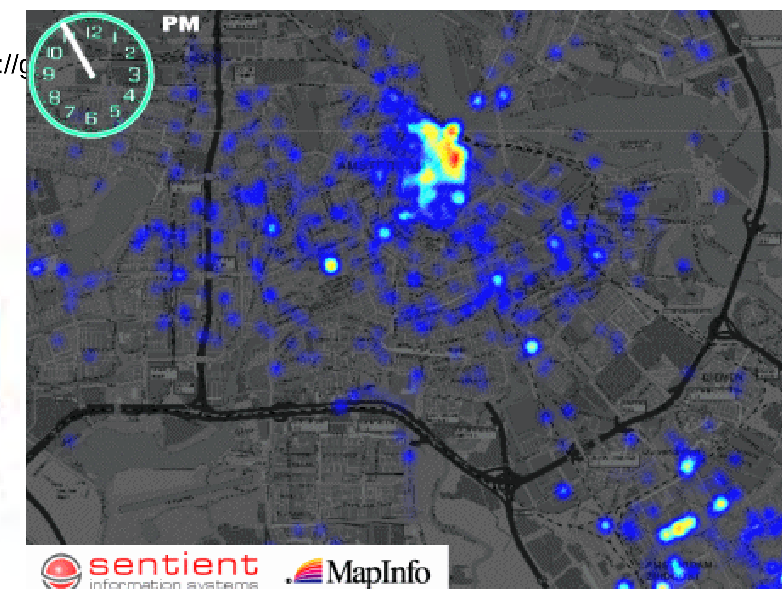
- Virtual globes are snapshots

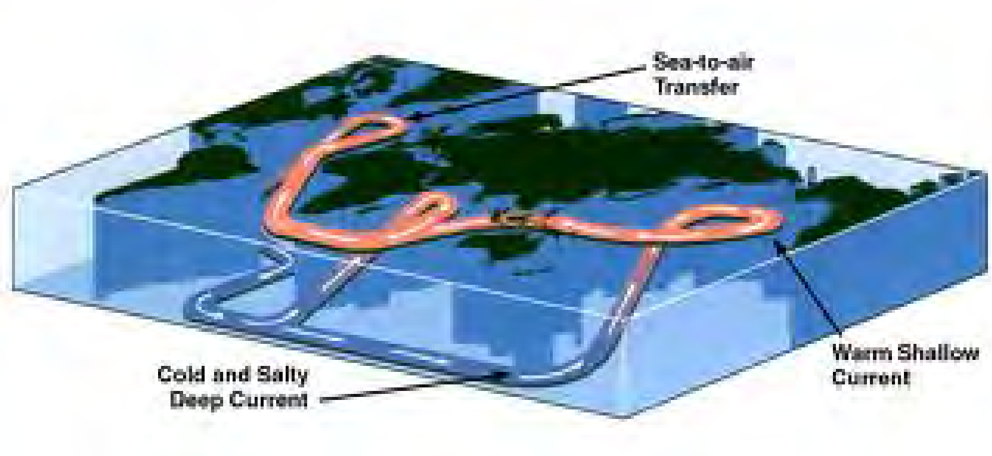
- How to add time? depth?
  - Ex. Google Earth Engine
  - Ex. Google Timelapse: 260,000 CPU core-hours for global 29-frame video

- How may one convey provenance, accuracy, age, and data semantics?
- What techniques are needed to integrate and reason about diverse available

http://g

html





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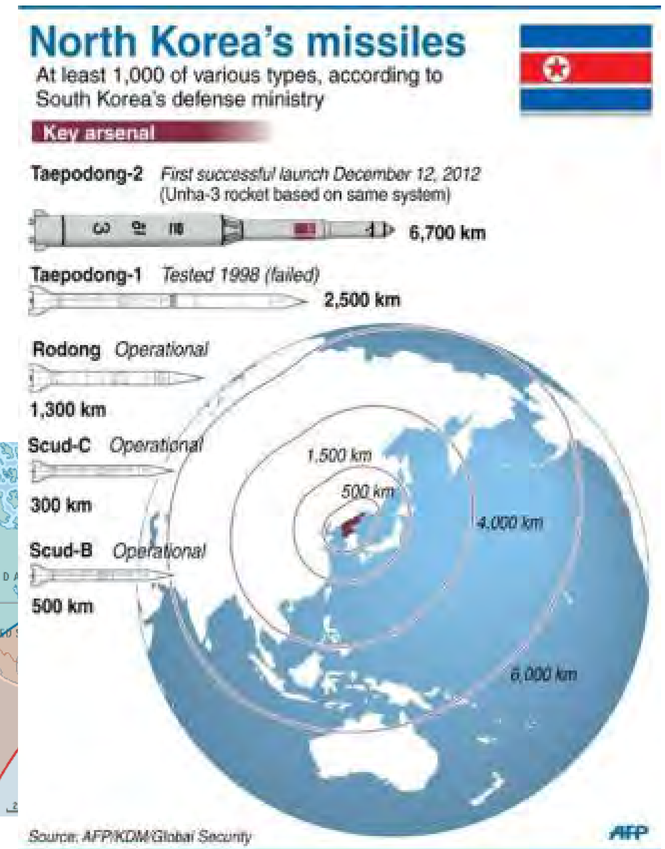
  - Geo => Beyond Geo
- Conclusions

Geographic Information Systems & Geodesy

- **GIS**: An umbrella system to
  - capture, store, manipulate, analyze, manage, and present diverse geo-data.
  - SDBMS, LBS, Spatial Statistics, …
  - Cartography, Map Projections, Terrain, etc.
- Reference Systems
  - Which countries in North Korea missile range?
  - 3D Earth surface displayed on 2D plane
  - Spherical coordinates vs. its planar projections



Original

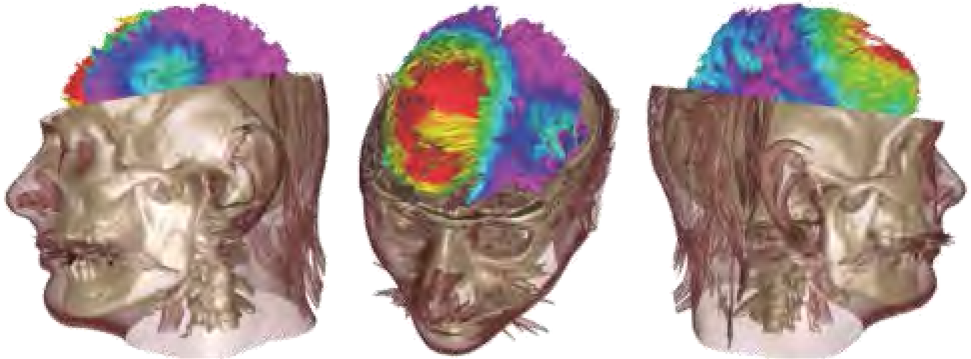
Correction

Opportunities: Beyond Geographic Space

- Spaces other than Earth
  - Challenge: reference frame?
- Ex. Human body
  - What is Reference frame ?
    - Adjust to changes in body
    - For MRIs, X-rays, etc.
  - What map projections?
  - Define path costs and routes to reach a brain tumor ?

Outer Space	Moon, Mars, Venus, Sun, Exoplanets, Stars, Galaxies
Geographic	Terrain, Transportation, Ocean, Mining
Indoors	Inside Buildings, Malls, Airports, Stadiums, Hospitals
Human Body	Arteries/Veins, Brain, Neuromapping, Genome Mapping
Micro / Nano	Silicon Wafers, Materials Science

http://convergence.ucsb.edu/issue/14



Oliver, Dev, and Daniel J. Steinberger. "From geography to medicine: exploring innerspace via spatial and temporal databases." Advances in Spatial and Temporal Databases. Springer Berlin Heidelberg, 2011. 467-470.

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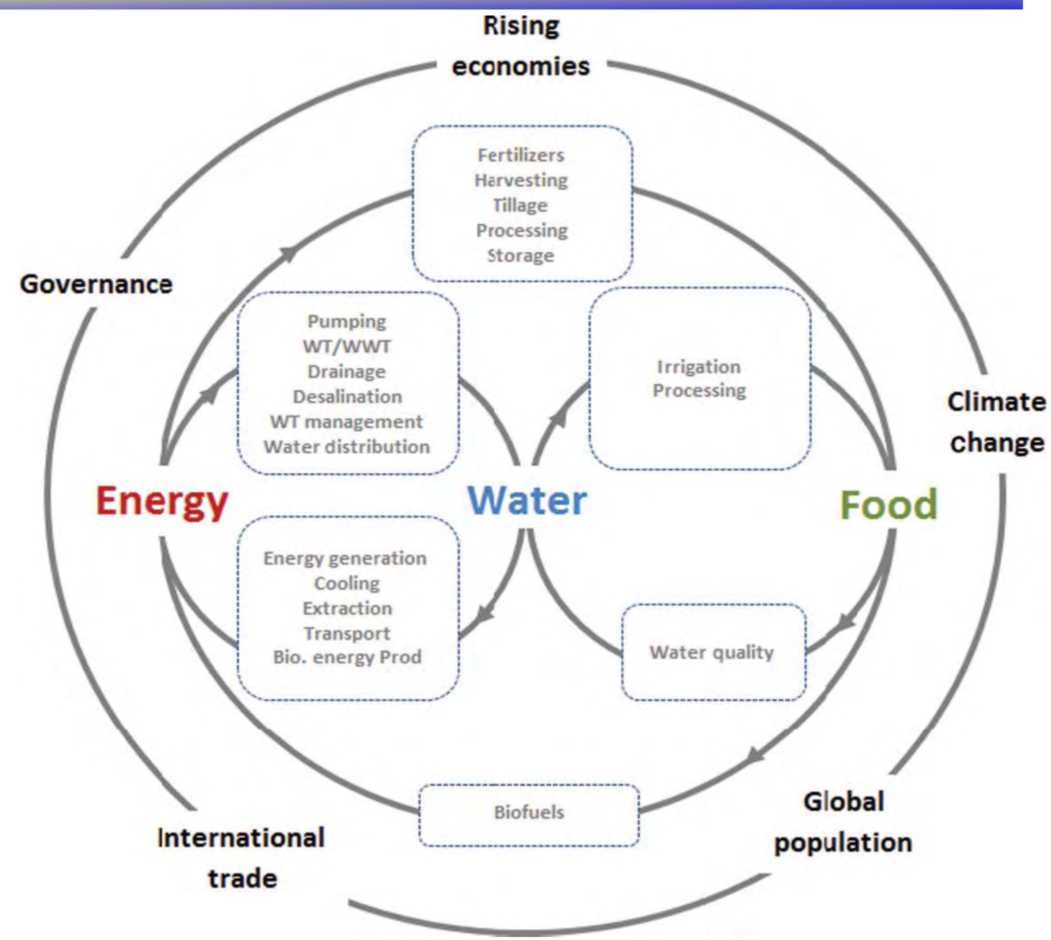


Interaction of food system with energy and water systems [Mohtar 2012].

Recommendations

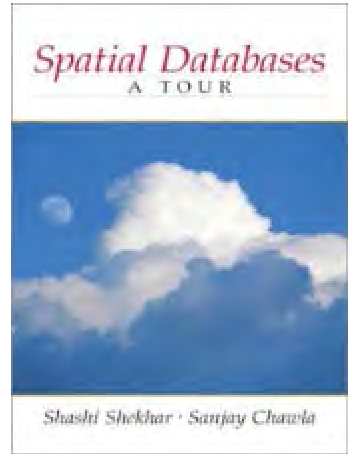
- Spatial Computing has transformed our society
  - It is only a beginning!
  - It promises an astonishing array of opportunities in coming decade
- However, these will not materialize without support
- Universities
  - Institutionalize spatial computing
    - GIS Centers, a la Computing Centers of the 1960's
  - Incorporate spatial thinking in STEM curriculum
    - During K-12, For all college STEM students?
- Government
  - Increase support spatial computing research
  - Larger projects across multiple universities
  - Include spatial computing topics in RFPs
  - Include spatial computing researchers on review panels
  - Consider special review panels for spatial computing proposals

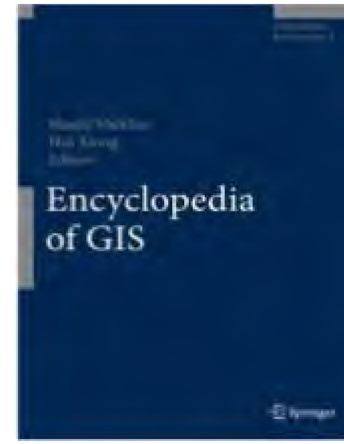
Courses

CSCI 5715 – From GPS and Google Maps to Spatial Computing (Fall 2015)

Note: Coursera MOOC (Fall 2014, ?Fall 2015)

- Conceptual Data Models
- Logical Data Models (e.g., SQL3/OGIS)
- Physical Data Models
- Spatial Networks, Routing Algorithm
- Spatial Data Mining





CSCI 8715 – Spatial Database Research (Spring 2016)

- Research Literature
- Trends: Spatial Big Data,
  Spatio-temporal,
  IoT, VGI, …
- Research Projects