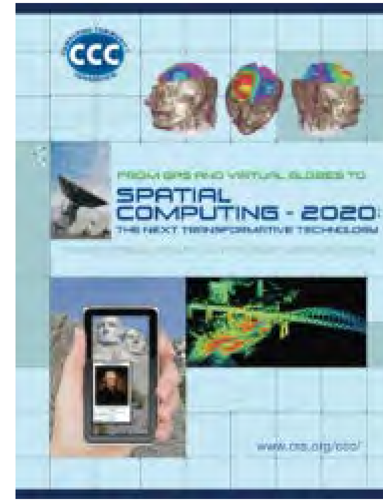
From GPS and Google Maps to Spatial Computing

IEEE Intl. Conf. on Comtemporary Computing (IC3), JIIT, Delhi, India, Aug., 2015
GMU Intl. Symposium on Spatiotemporal Computing, VA, USA, July 2015.



Shashi Shekhar
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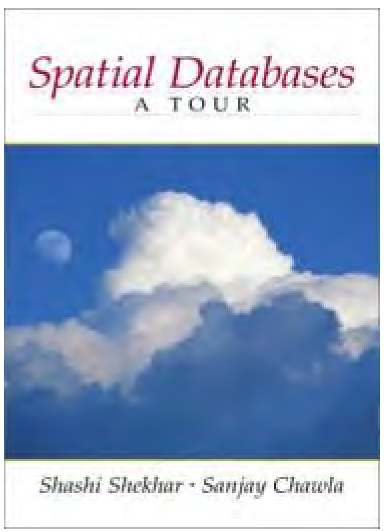
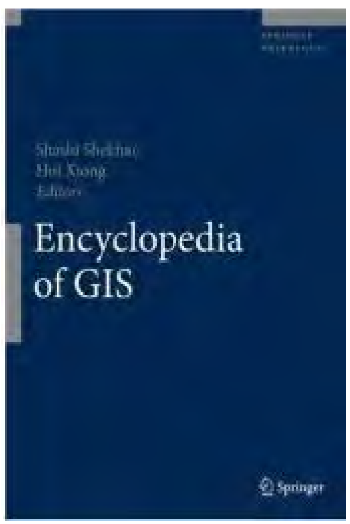
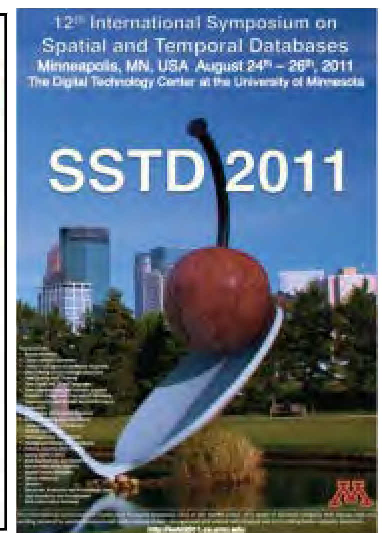
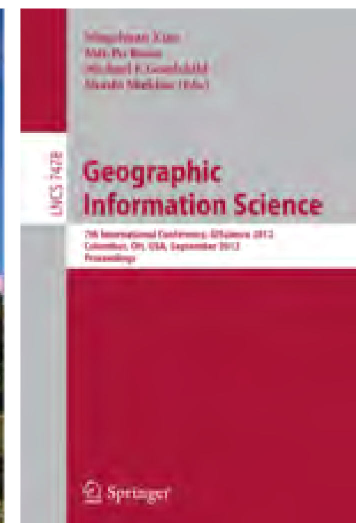
Department of Computer Science and Eng.
University of Minnesota
www.cs.umn.edu/~shekhar









Acknowledgements: Work supported by NSF (grant IIS-1320580) and USDOD (grant HM0210-13-1-0005).

Courses

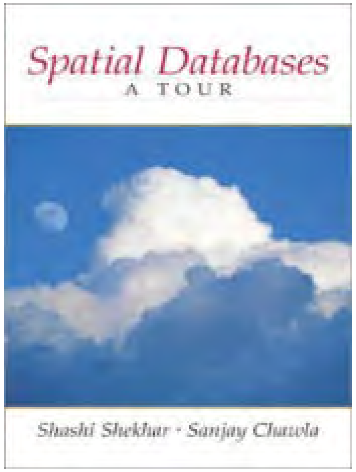
CSCI 5715: From GPS and Virtual Globes to Spatial Computing

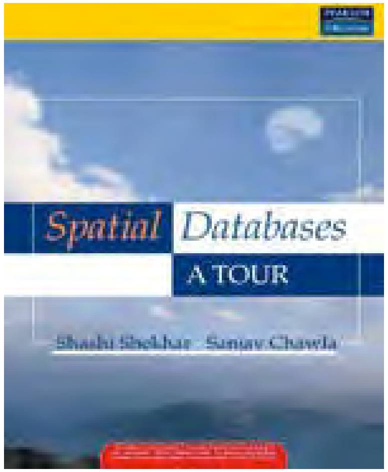
Map of students online at Coursera.org

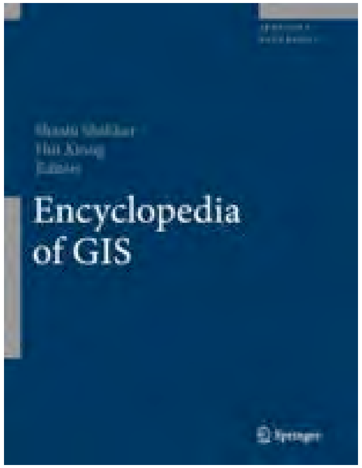
www.coursera.org/course/spatialcomputing

CSCI 8715: Spatial Databases

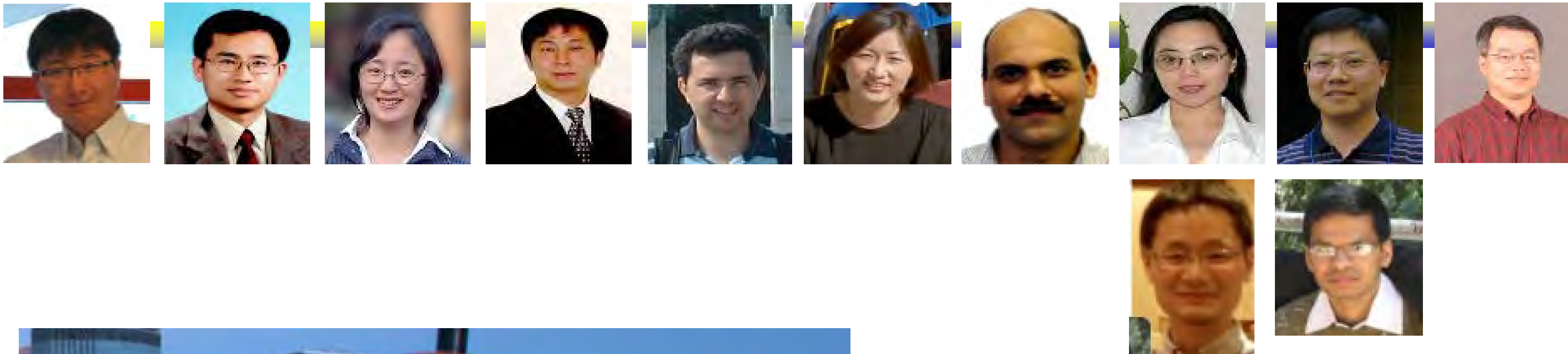
www.spatial.cs.umn.edu/Courses/Fall13/8715



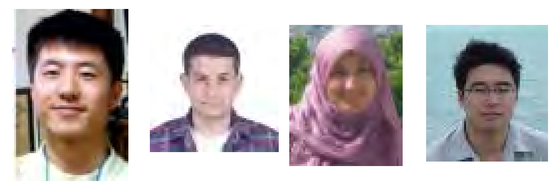




Alumni in Academia



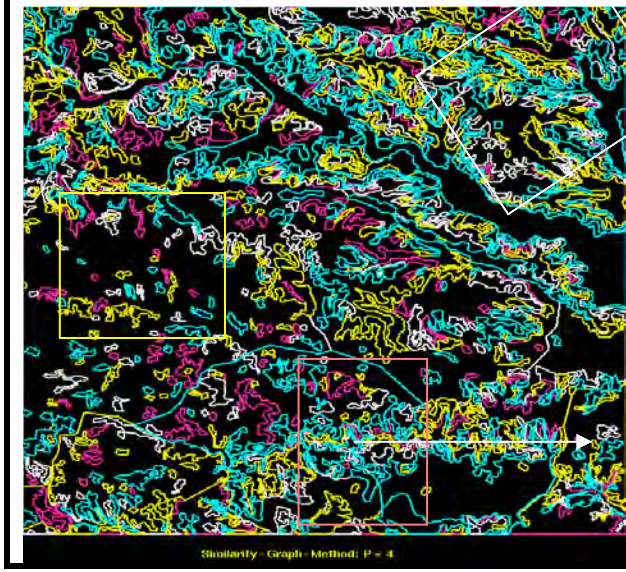
Current Students



Alumni in Industry

Alumni in Government Agency

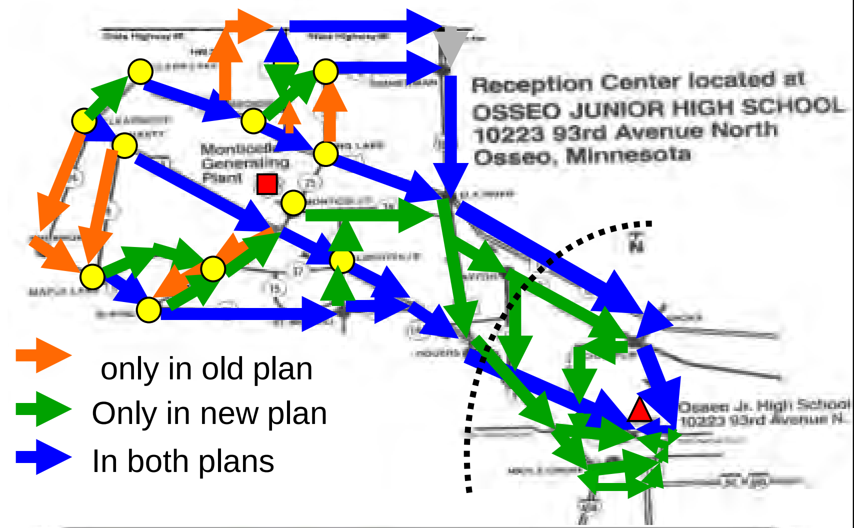
Research Theme 1: Spatial Databases

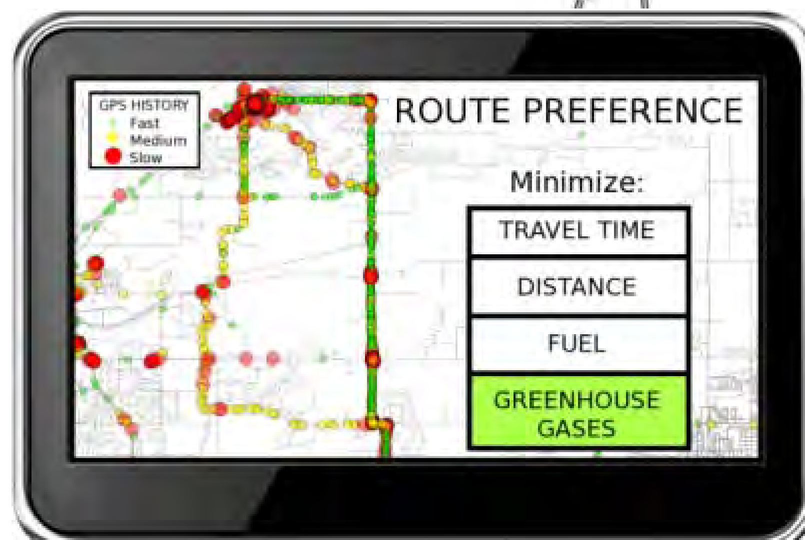


Parallelize Range Queries

Shortest Paths **Storing graphs in disk blocks**

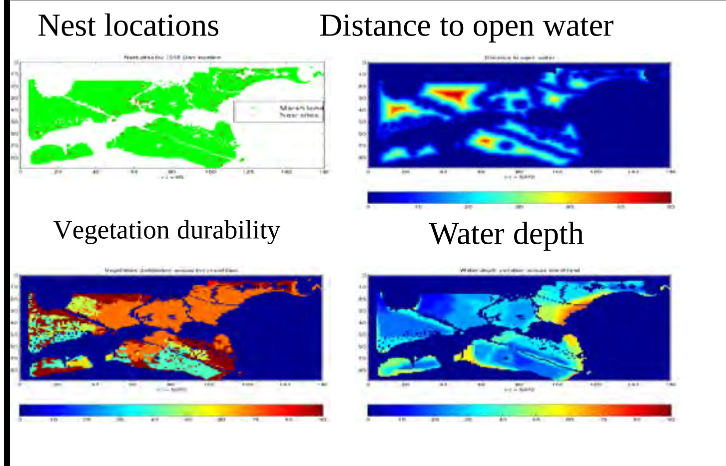
Evacutation Route Planning



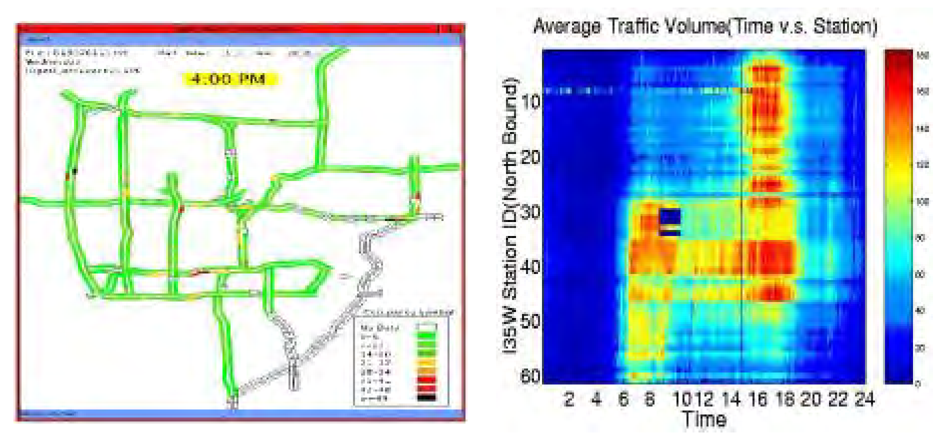


Theme 2 : Spatial Data Mining

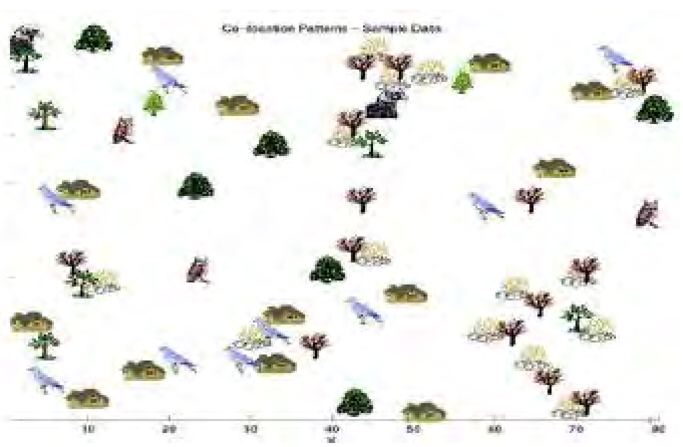
Location Prediction: nesting sites



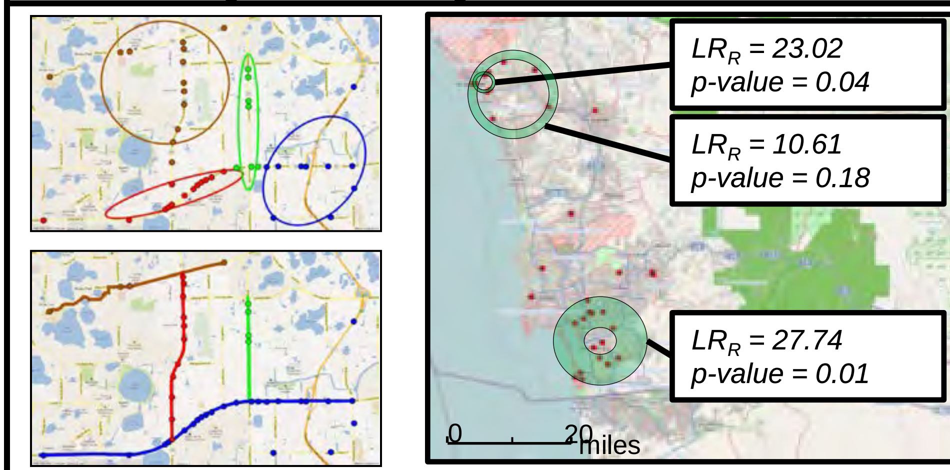
Spatial outliers: sensor (#9) on I-35



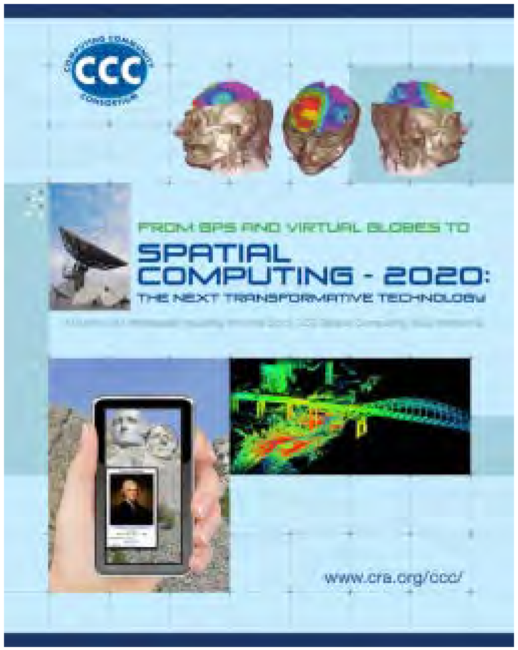
Co-location Patterns



Spatial Concept Aware Summarization

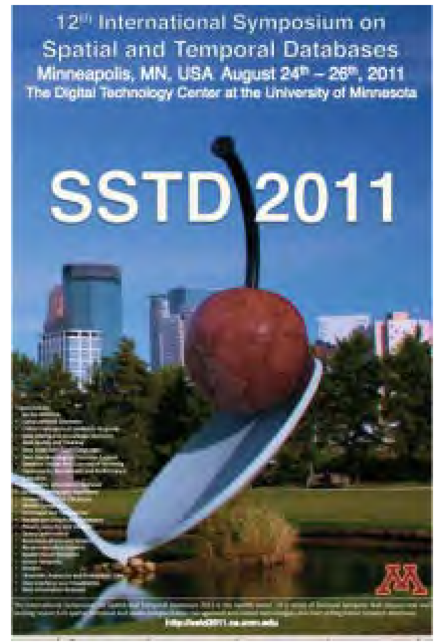


Recent Professional Activities

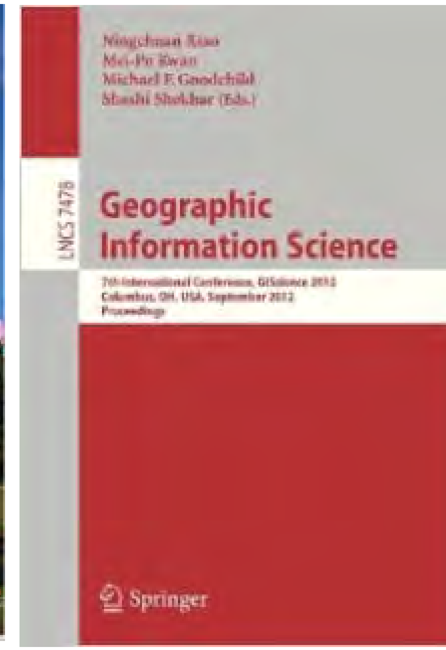


Spatial Computing Visioning Workshop Computing Community Consortium (CCC)

Geoinformatica Journal



Symposium on Spatial and Temporal Database 2011

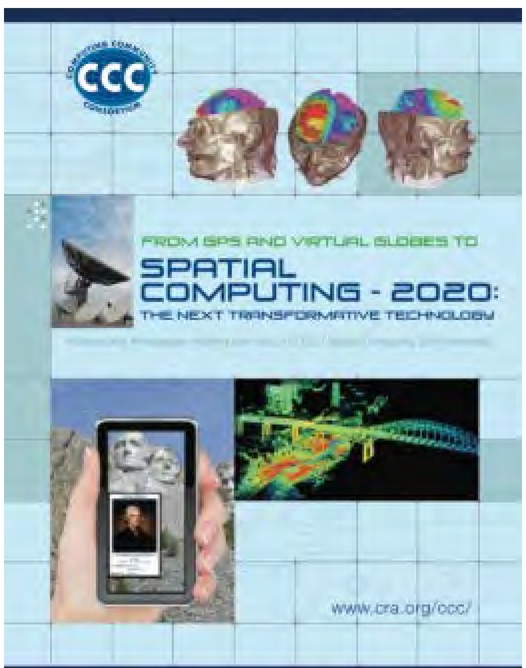


GIScience Conference 2012

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

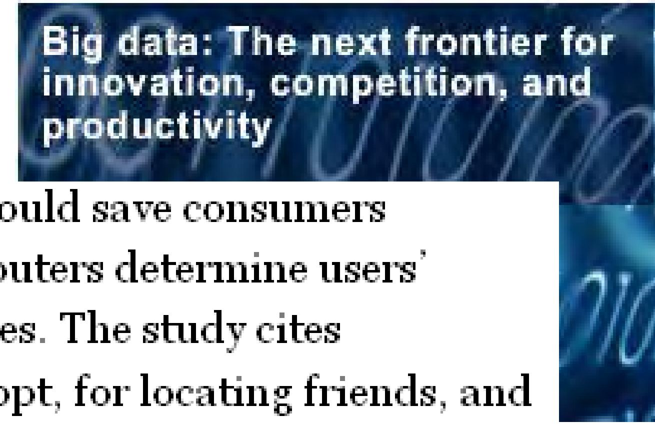
Table 1. Members of the Federal Geographic Data Committee (FGDC)

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

We support the computing research community in creating compelling research visions and the mechanisms to realize these visions.

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Funded Visioning Activities

Disaster Management · SEES IT · HealthIT · Interactive Tech · Architecture · XLayer · Robotics · Learning Tech · Open Source · Cyber Physical Systems · Global Development · Theoretical CS · Big Data Computing · NetSE · Spatial Computing

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

- **Peggy Agouris,** George Mason University
- **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
- **Chuck Hansen,** University of Utah
- **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 Vatsavai,** 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

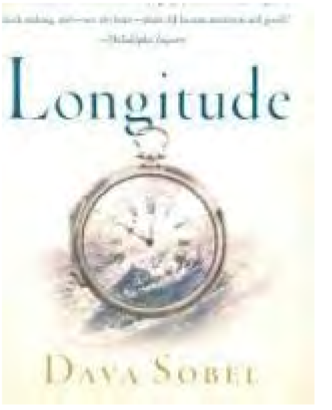
Cloud Computing: Divyakant Agarwal, UCSB

Outline

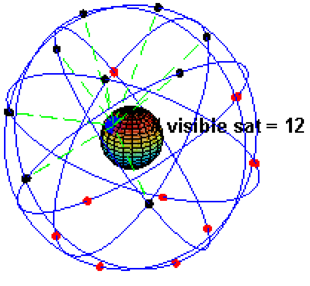
- Introduction
- GPS
  - Outdoors => Indoors
- Location Based Services
- Spatial Statistics
- Spatial Database Management Systems
- Virtual Globes
- Geographic Information Systems
- Conclusions

Global Positioning Systems (GPS)

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

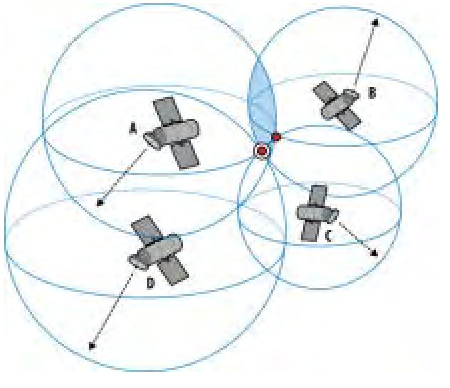


- Global Navigation Satellite Systems
  - Infrastructure: satellites, ground stations, receivers, …
  - Use: Positioning (sub-centimeter), Clock synchronization



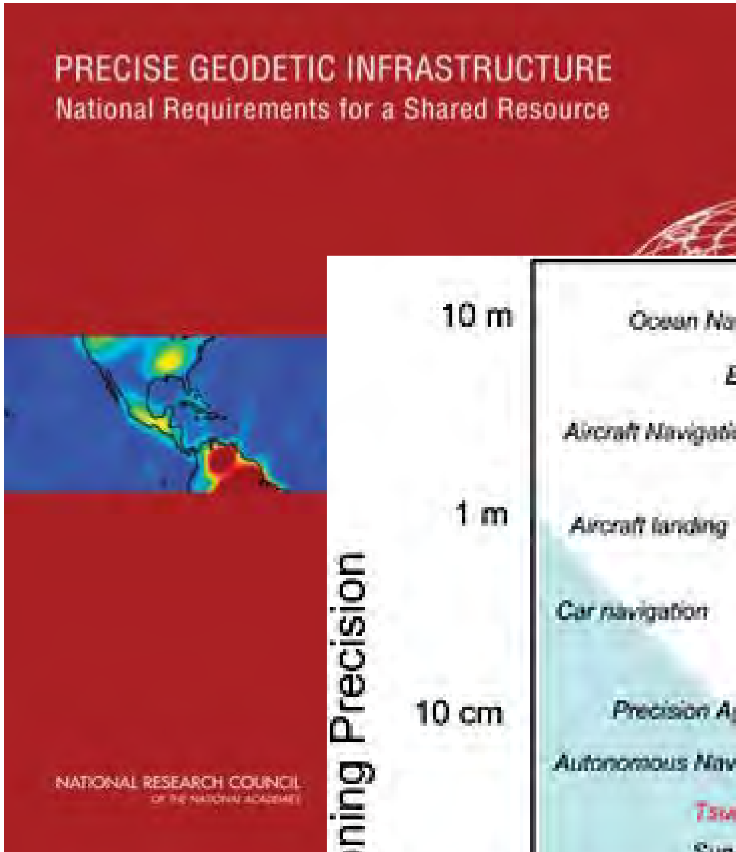
http://en.wikipedia.org/wiki/Global_Positioning_System

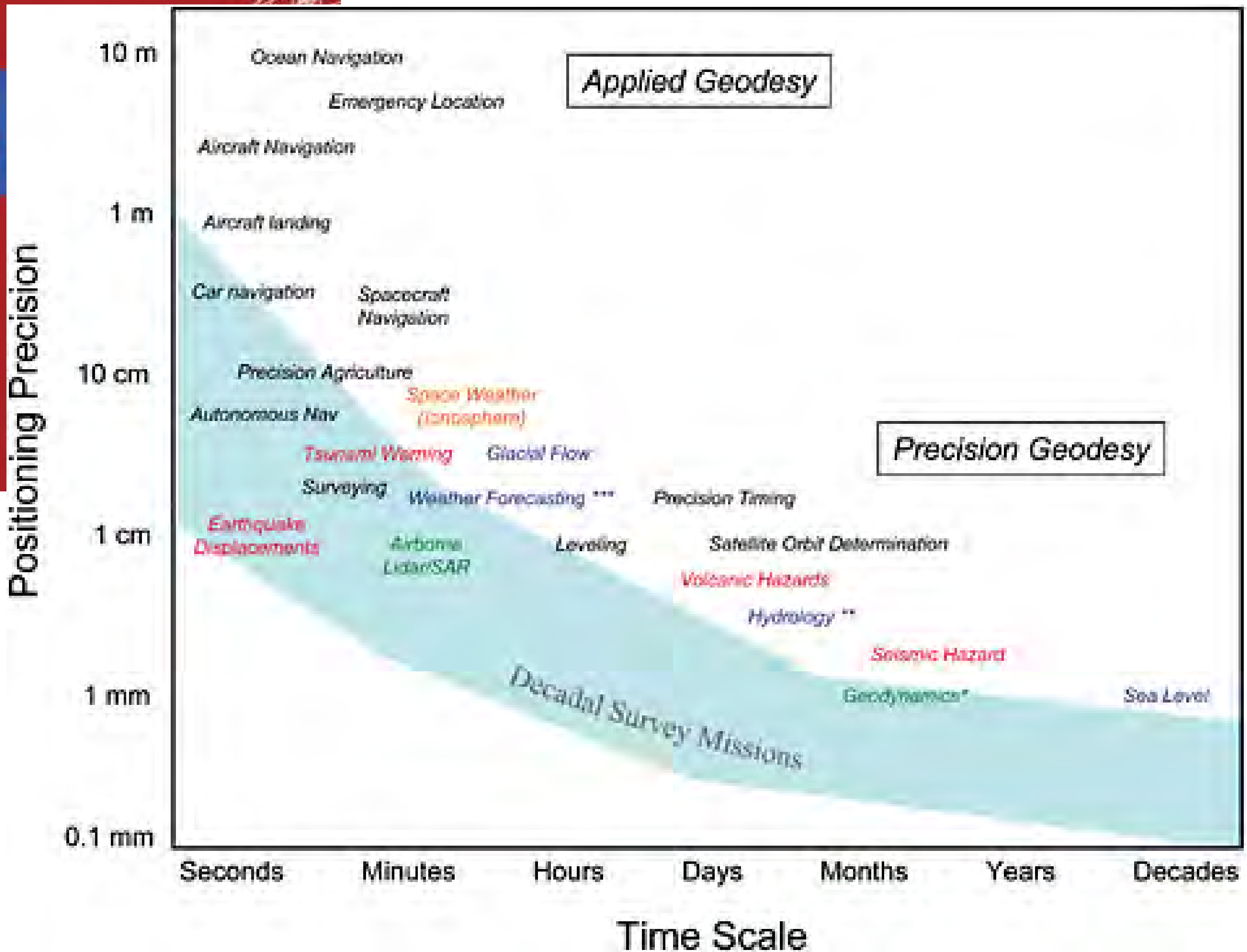
Trilateration



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

Positioning Precision





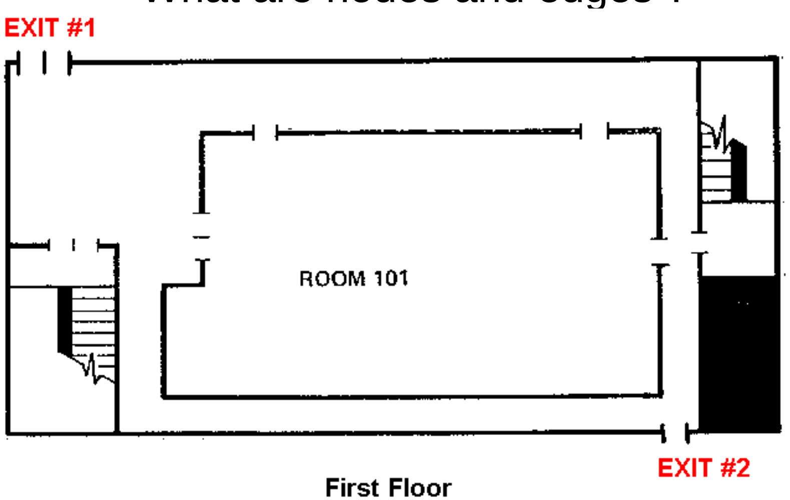
Trends: Localization Indoors and Underground

- GPS works outdoors, but,
  - We are indoors 90% of time!
  - Ex. malls, hospitals, airports, etc.
  - Indoor asset tracking, exposure hotposts, …

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

- 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 ?



WiFi Localization

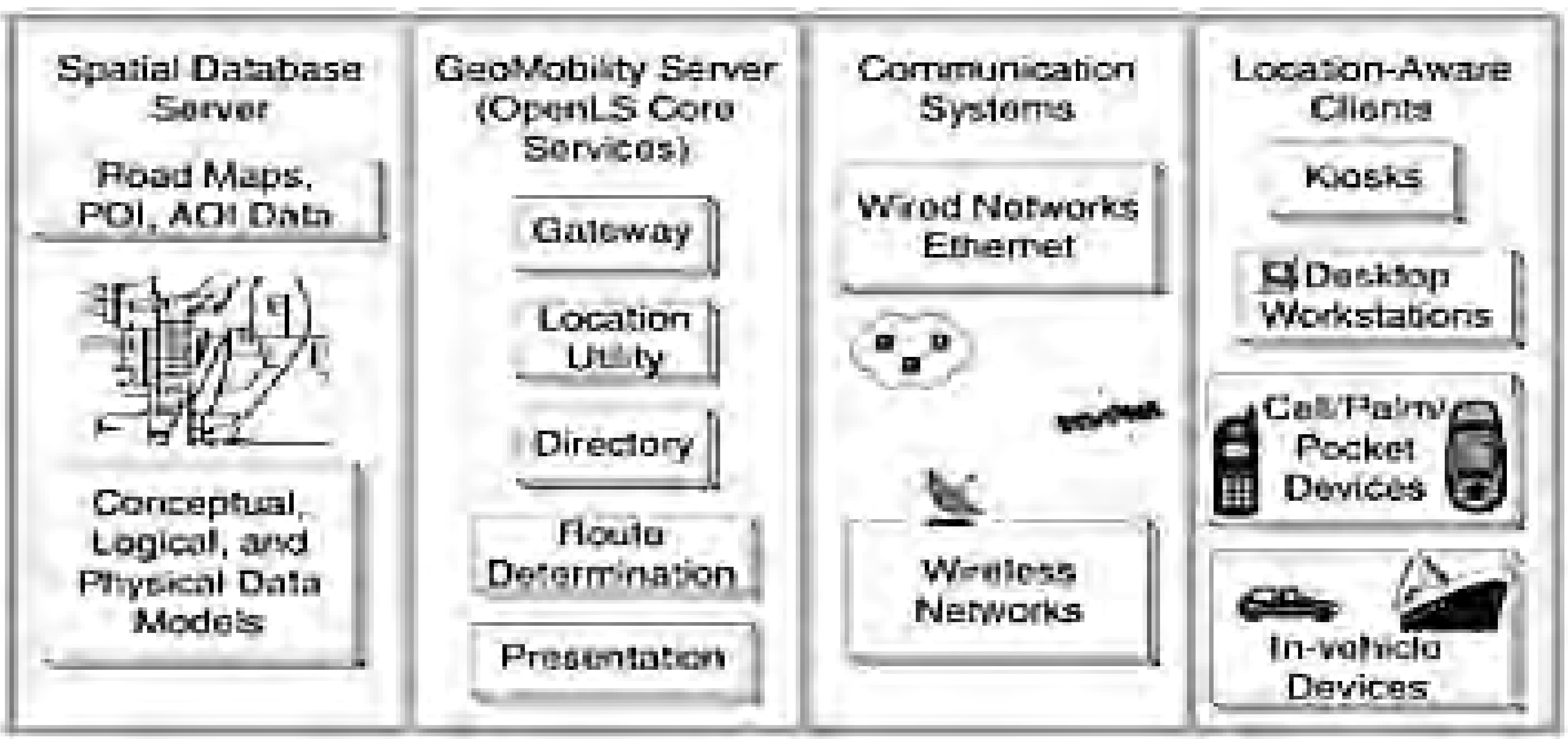
http://rfid.net/basics/rtls/123-wi-fi-how-it-works

Outline

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

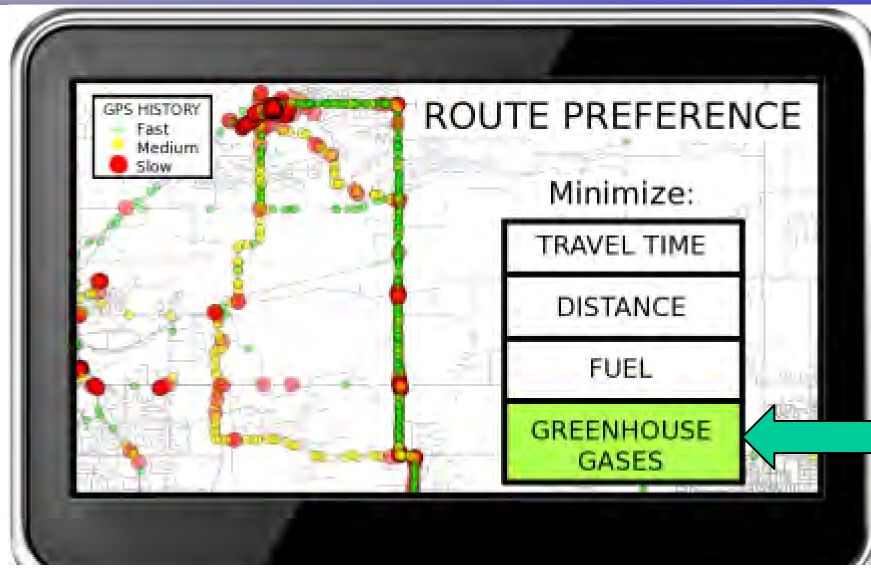
Location Based Services

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



Next Generation Navigation Services

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

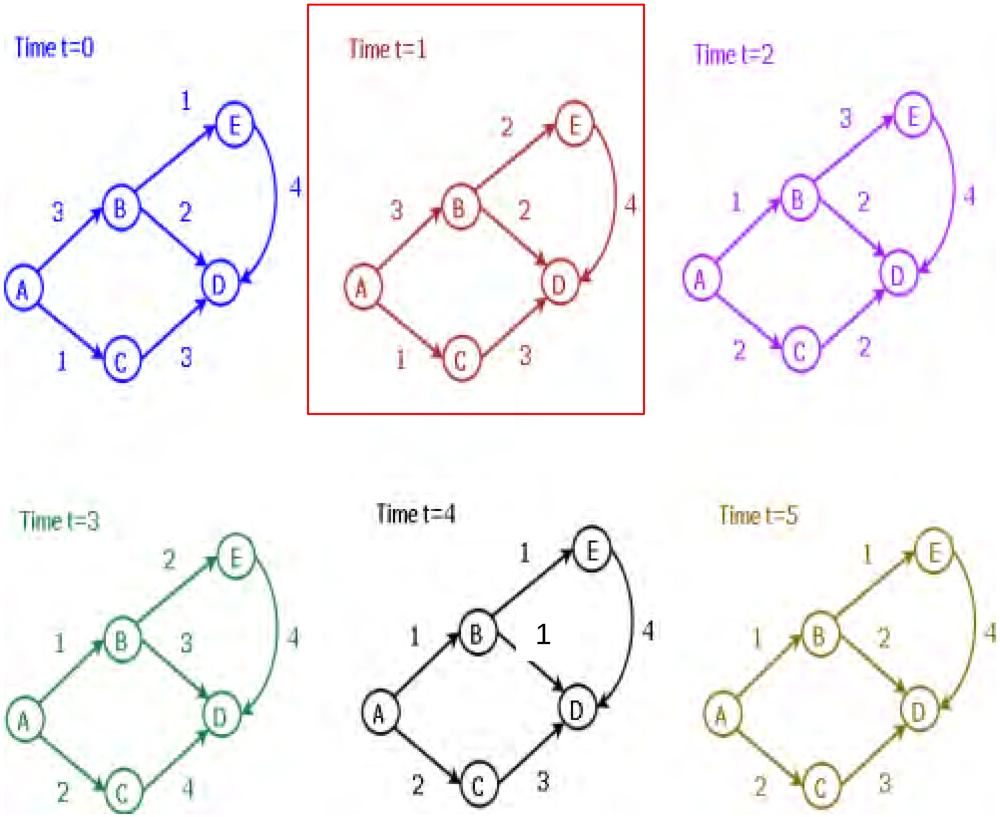


Static	Time-Variant
Which is the shortest travel time path from downtown Minneapolis to airport?	

Routing Challenges: Lagrangian Frame of Reference

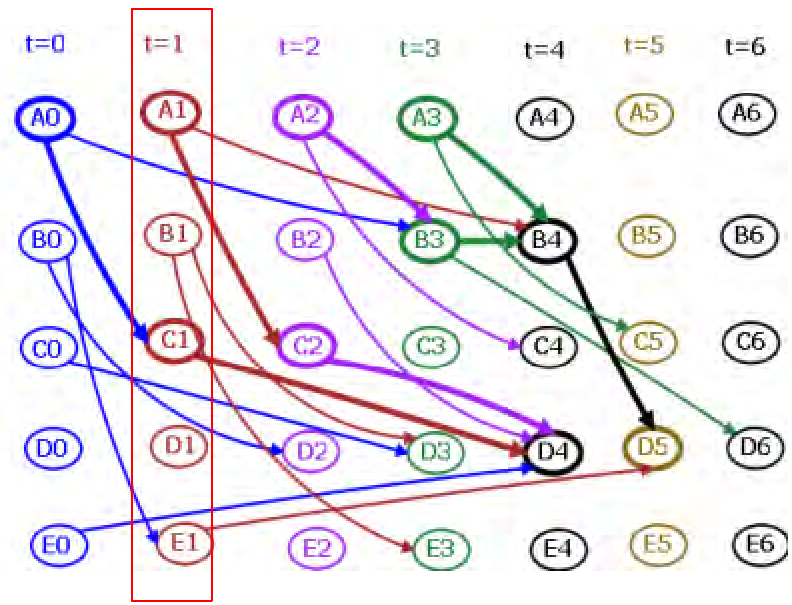
Q? What is the cost of Path <A,C,D> with start-time t=1 ? Is it 3 or 4 ?

Snapshots of a Graph



Path	T = 0	T = 1	T = 2	T = 3
<A,C,D>	4	3	5	4
<A,B,D>	6	4	4	3

Lagrangian Graph



Details:A Critical-Time-Point Approach to All-Start-Time Lagrangian Shortest Paths: A Summary of Results, (w/ V. Gunturi et al.), Proc. Intl. Symp. on Spatial and Temporal Databases, Springer LNCS 6849, 2011. Complete results accepted for the IEEE Transactions on Knowledge and Data Engineering.

Spatio-temporal Graphs: Computational Challenges

Ranking changes over time

Violates stationary assumption in Dynamic Programming

Time	Preferred Routes
7:30am	Via Hiawatha
8:30am	Via Hiawatha
9:30am	via 35W
10:30am	via 35W

Waits, Non FIFO Behavior

Violate assumption of Dijkstra/A*

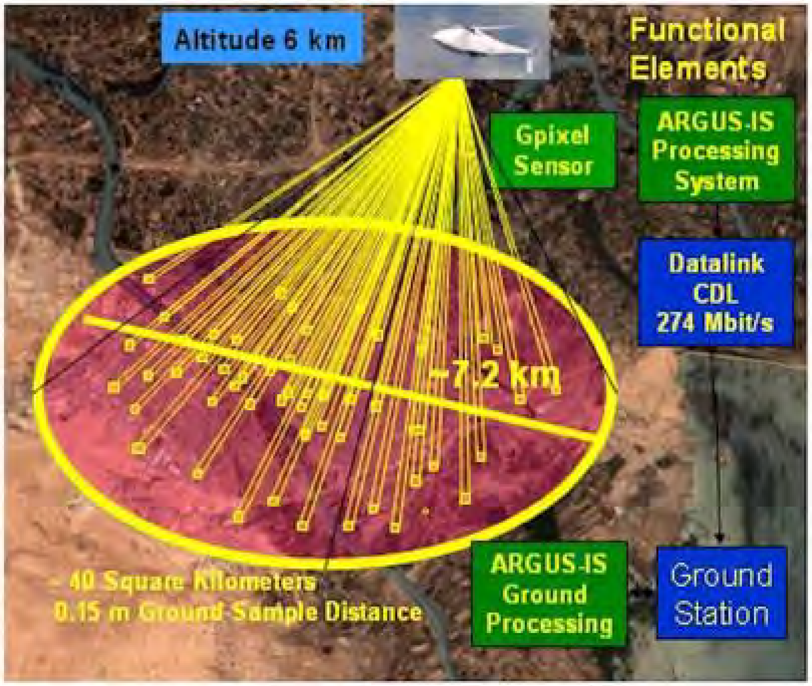
Time	Route	Flight Time
8:30am	via Detroit	6 hrs 31 mins
9:10am	direct flight	2 hrs 51 mins
11:00am	via Memphis	4 hrs 38mins
11:30am	via Atlanta	6 hrs 28 mins
2:30pm	direct flight	2 hrs 51 mins

*Flights between Minneapolis and Austin (TX)

Details:A Critical-Time-Point Approach to All-Start-Time Lagrangian Shortest Paths: A Summary of Results, (w/ V. Gunturi et al.), Proc. Intl. Symp. on Spatial and Temporal Databases, Springer LNCS 6849, 2011. Complete results accepted for the IEEE Transactions on Knowledge and Data Engineering.

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
  - From Mathematical (e.g., hotspot)
  - To Spatial (e.g., hot features)
- Spatial Database Management Systems
- Virtual Globes
- Geographic Information Systems
- Conclusions

N.Y. / REGION 34 COMMENTS

Hotel That Enlivened the Bronx Is Now a 'Hot Spot' for Legionnaires'

By WINNIE HU and NOAH REMNICK AUG. 10, 2015

Contaminated Cooling Towers

Five buildings have been identified as the potential source of the Legionnaires' disease outbreak in the South Bronx.

- Possible sources of Legionnaires' outbreak
- Additional sites found with legionella bacteria
- Locations of people with Legionnaires'

Source: New York Mayor's Office

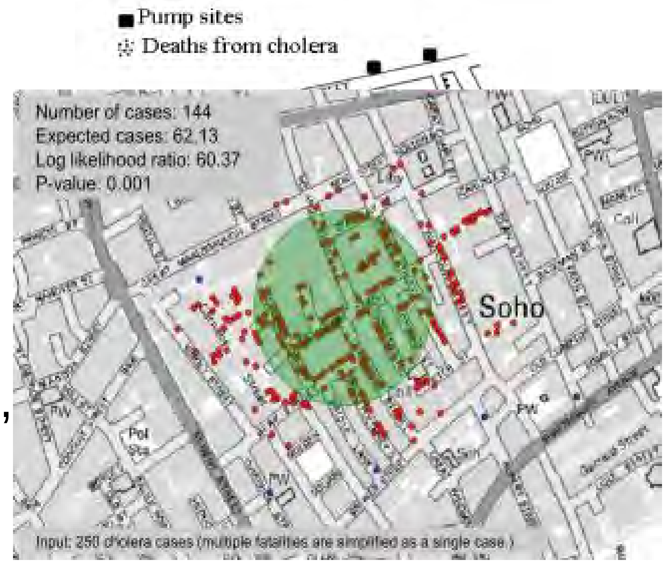
By The New York Times

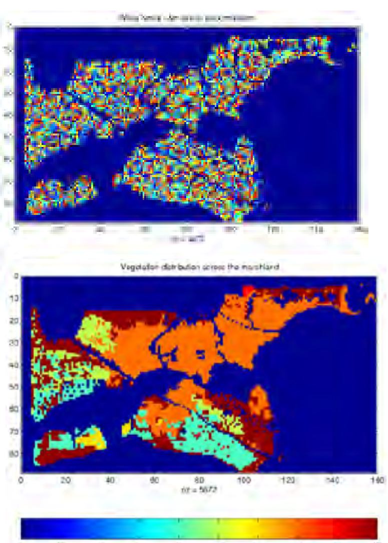
The Opera House Hotel is at the center of the outbreak. Edwin J. Torres for The New York Times

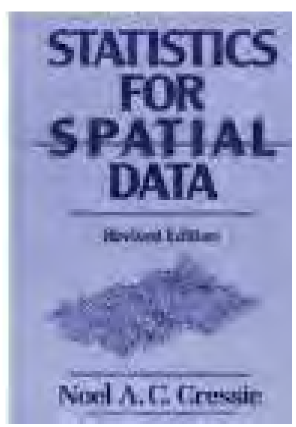
Spatial Statistics: Mathematical Concepts

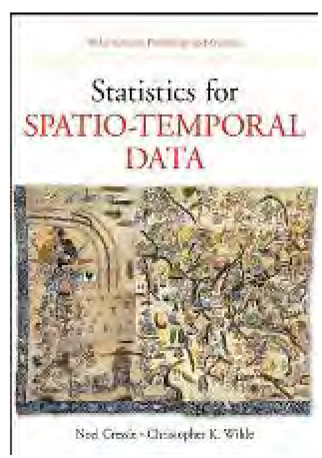
- Spatial Statistics
  - Quantify uncertainty, confidence, …
  - Is it significant?
  - Is it different from a chance event or rest of dataset?
    - e.g., SaTScan finds circular hot-spots

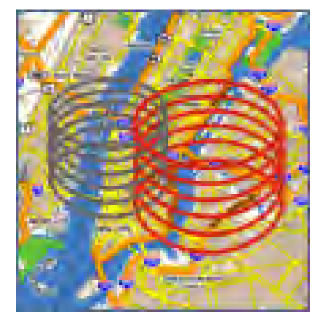
- Model Auto-correlation, Heterogeneity, Edge-effect,
  - Point Process, e.g., Ripley's K-functions, SatScan
  - Geo-statistics, e.g., Kriging, GWR
  - Lattice-based models











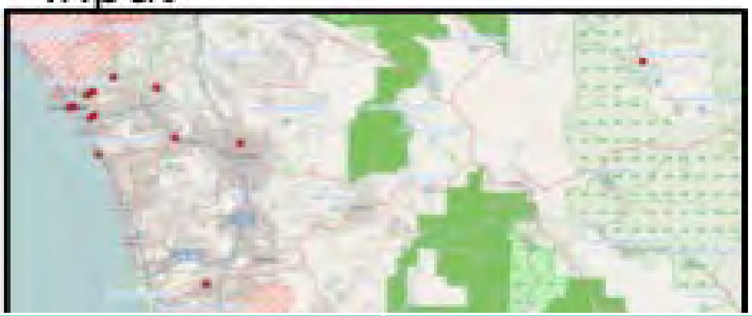
SaTScan™

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

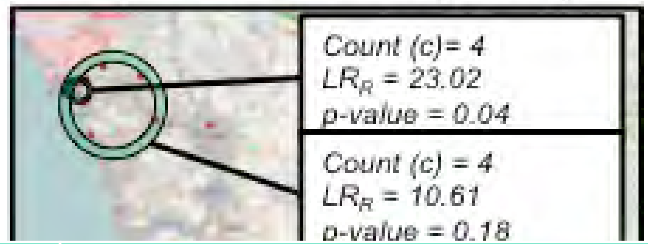
Semantic Gap between Spatial and Machine Learning

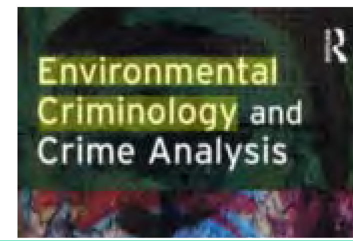
- Representation choices beyond Linear Algebra
- Environmental Criminology
  - Routine Activities Theory, Crime Pattern Theory, Doughnut Hole pattern
- Formulation: rings, where inside density is significantly higher than outside …

Input



Output: Ring Shaped Hotspot Detection (RHD)



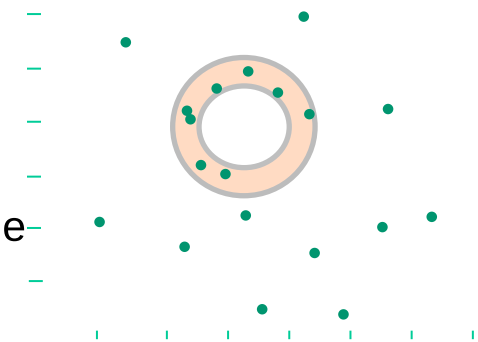


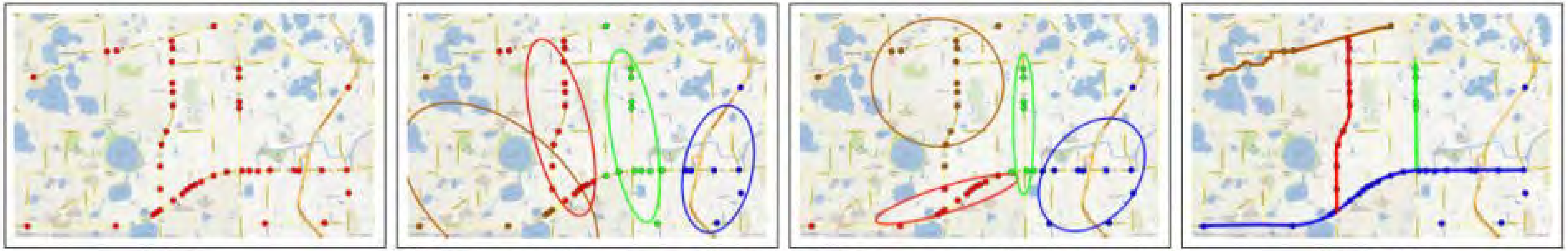
Mathematics	Concepts	Relationships
Sets	Set Theory	Member, set-union, set-difference, …
Vector Space	Linear Algebra	Matrix & vector operations
Euclidean Spaces	Geometry	Circle, Ring, Polygon, Line_String, Convex hull, …
Boundaries, Graphs, Spatial Graphs	Topology, Graph Theory, Spatial graphs, …	Interior,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

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

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



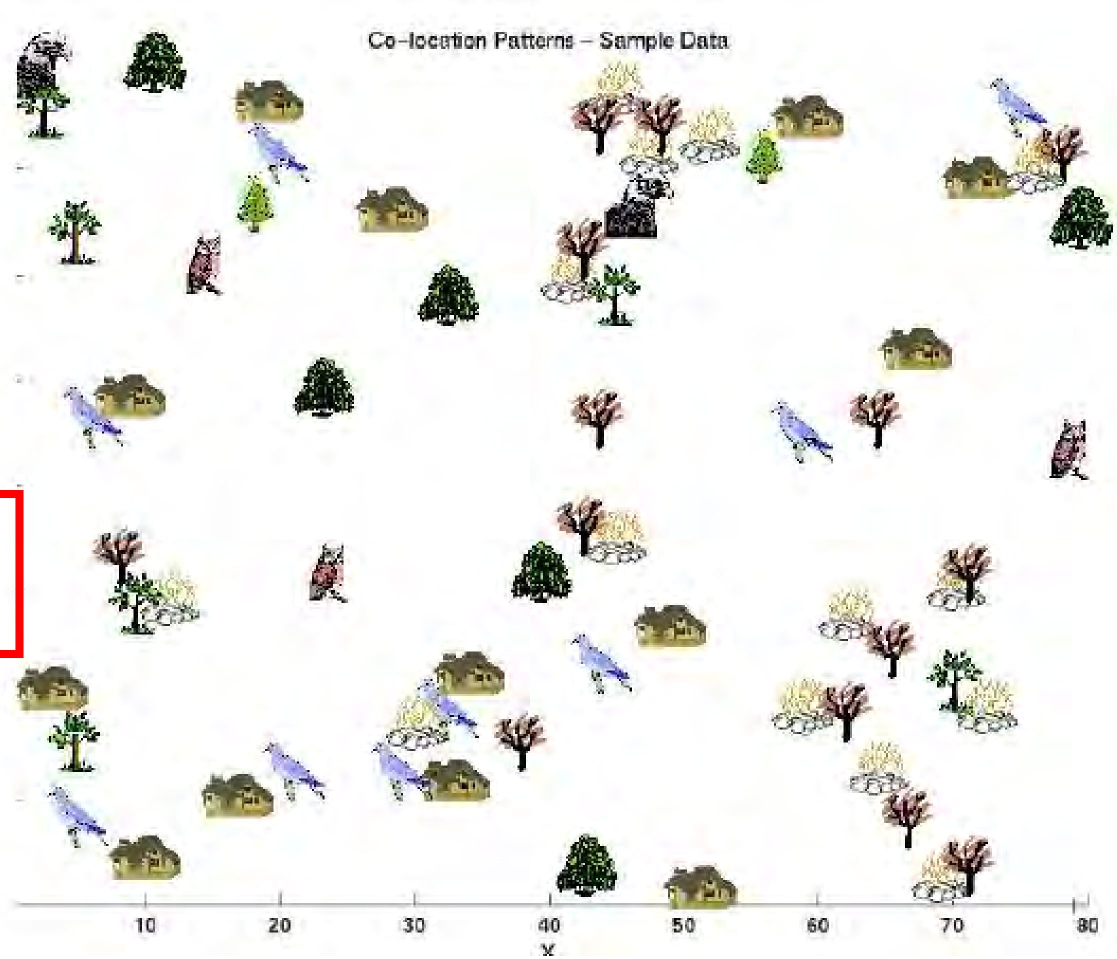


(a) Input (b) Crimestat K-means with Euclidean Distance (c) Crimestat K-means with Network Distance (d) KMR

Details: A K-Main Routes Approach to Spatial Network Activity Summarization, (w/ D. Oliver et al.) IEEE Transactions on Knowledge and Data Engineering, 26(6):1464-1478, 2014.

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, (w/ H. Yan et al.), IEEE Transactions on Knowledge and Data Engineering, 16(12), Dec. 2004.

Fast Algorithms to Mine Colocations from Big Data

Participation ratio pr(f_i, c) of feature f_i in colocation $c = \{f_1, f_2, \ldots, f_k\}$:

fraction of instances of f_i with feature $\{f_1, \ldots, f_{i-1}, f_{i+1}, \ldots, f_k\}$ nearby (i.e. within a given distance)

Participation index PI(c) = min{ pr(f_i, c) }

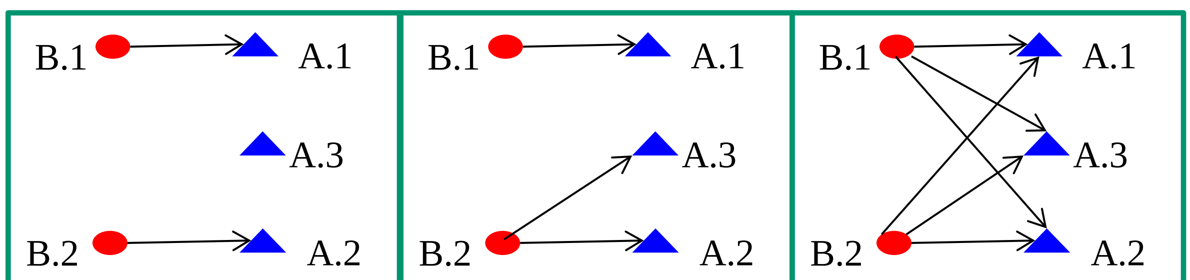
Properties:

(1) Computational: Non-monotonically decreasing like support measure

Allows scaling up to big data via pruning

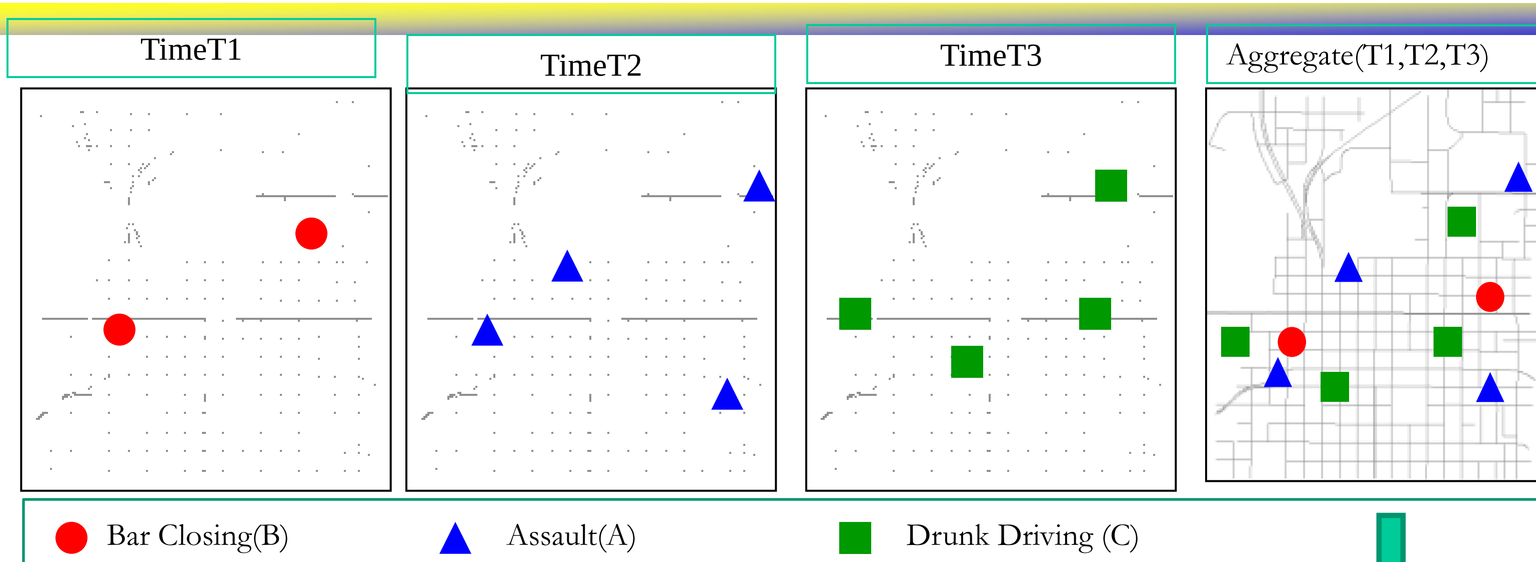
(2) Statistical: Upper bound on Cross-K function

- Comparison with Ripley's K-function (Spatial Statistics)

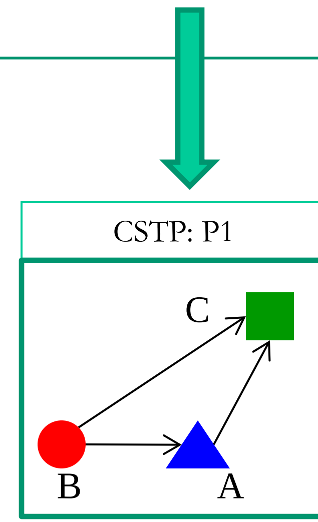


K-function (B → A)	2/6 = 0.33	3/6 = 0.5	6/6 = 1
PI (B → A)	2/3 = 0.66	1	1

Cascading spatio-temporal pattern (CSTP)

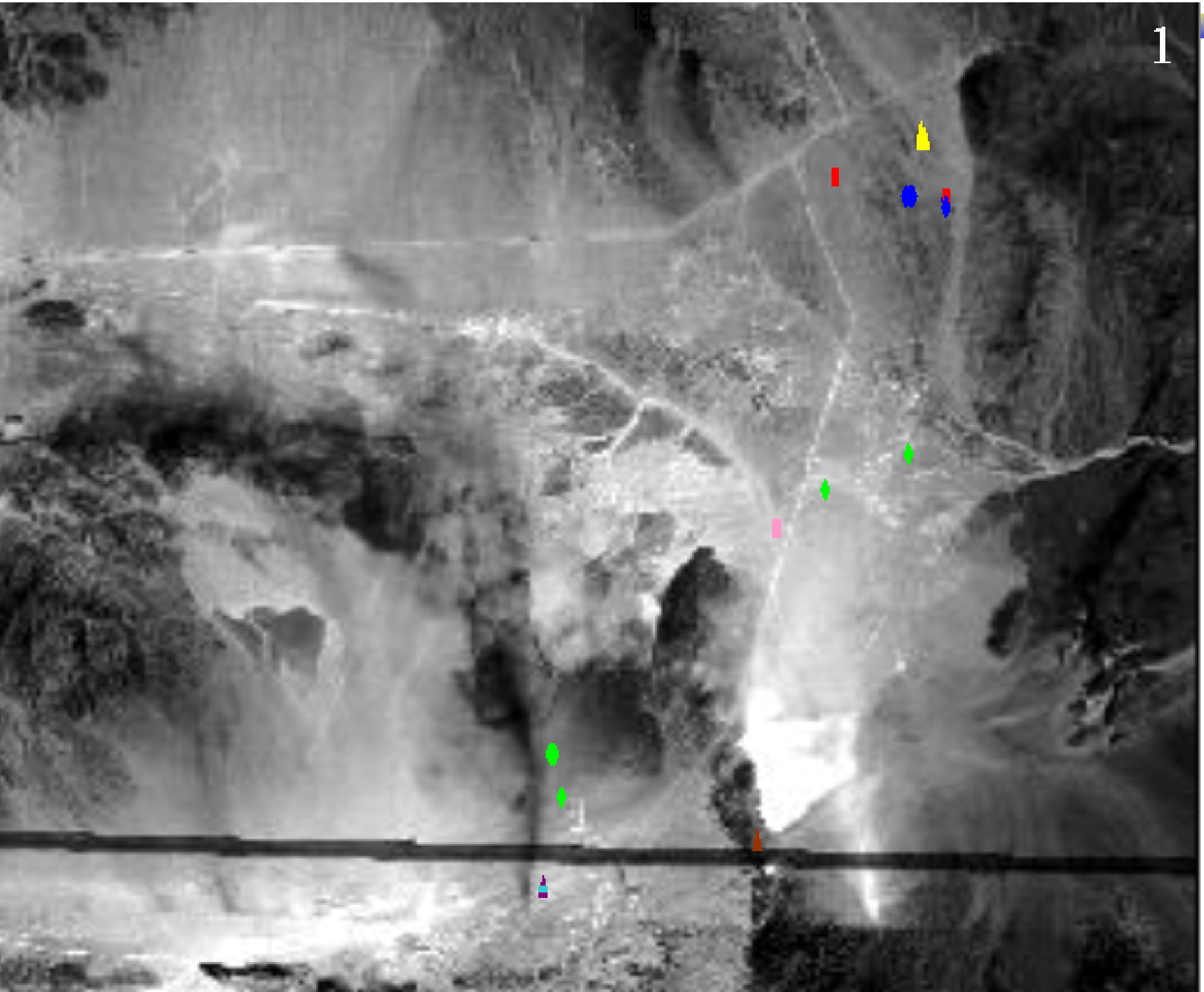


- *Input:* Urban Activity Reports
- *Output: CSTP*
  - *Partially ordered* subsets of ST event types.
  - Located together in space.
  - Occur in *stages* over time.
- Applications: Public Health, Public Safety, …



Details: Cascading Spatio-Temporal Pattern Discovery, (w/ P. Mohan et al.), IEEE Transactions on Knowledge and Data Engineering, 24(11), Nov. 2012.

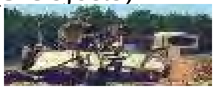
MDCOP Motivating Example : Input



- Manpack stinger (2 Objects)

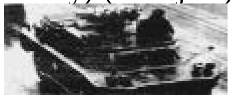
- M1A1_tank (3 Objects)

- M2_IFV (3 Objects)



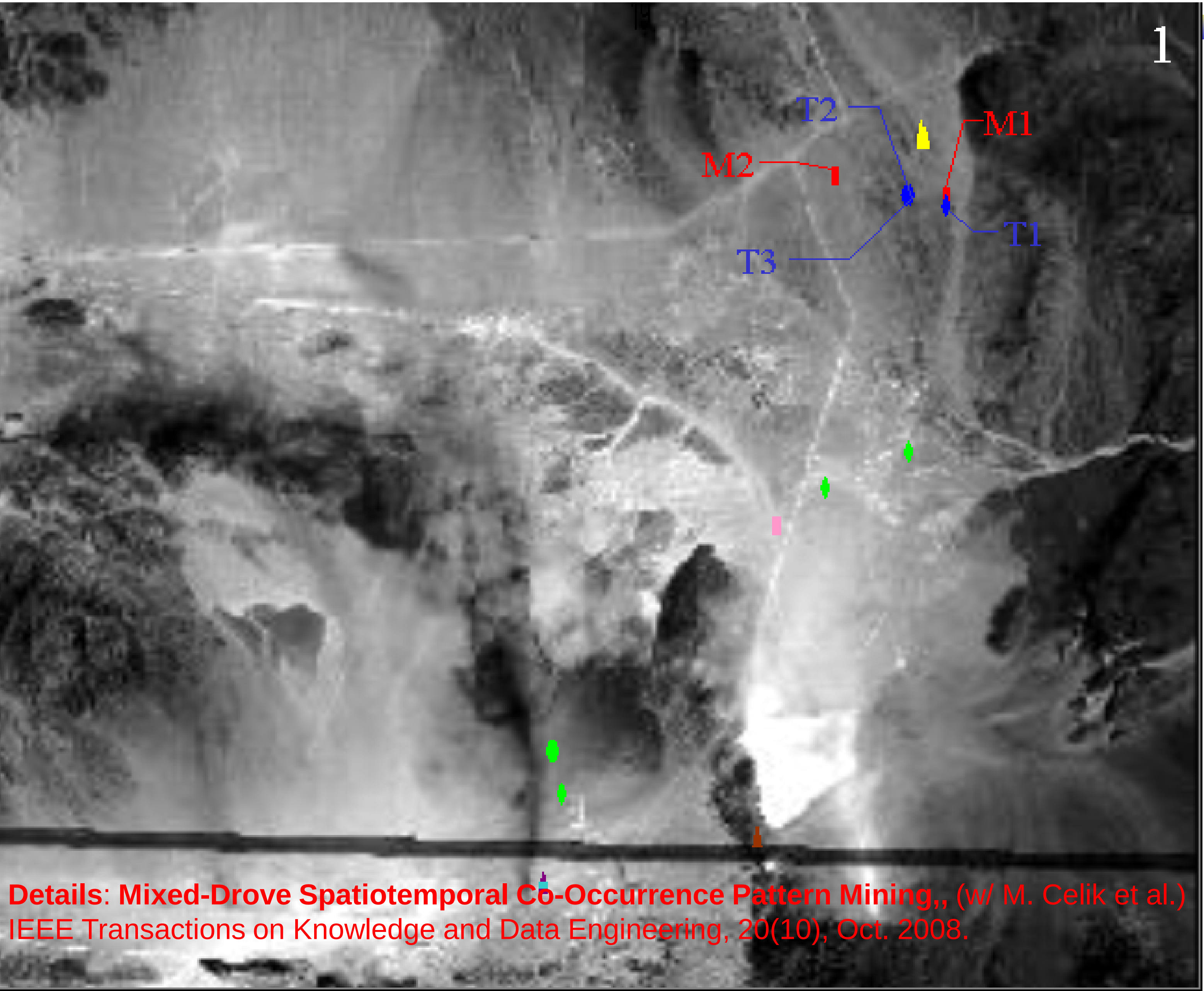
- Field_Marker (6 Objects)
- T80_tank (2 Objects)

- BRDM_AT5 (enemy) (1 Object)



- BMP1 (1 Object)

MDCOP Motivating Example : Output

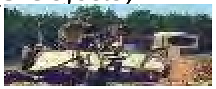


Details: **Mixed-Drove Spatiotemporal Co-Occurrence Pattern Mining,**, (w/ M. Celik et al.)
IEEE Transactions on Knowledge and Data Engineering, 20(10), Oct. 2008.

Manpack stinger
(2 Objects)

M1A1_tank
(3 Objects)

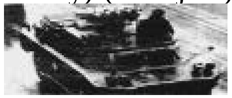
M2_IFV
(3 Objects)



Field_Marker
(6 Objects)

T80_tank
(2 Objects)

BRDM_AT5
(enemy) (1 Object)



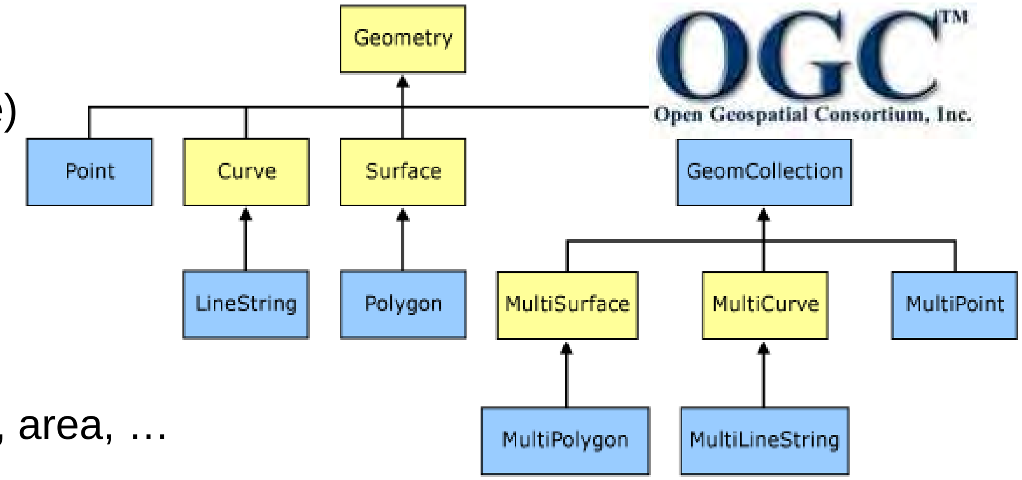
BMP1
(1 Object)

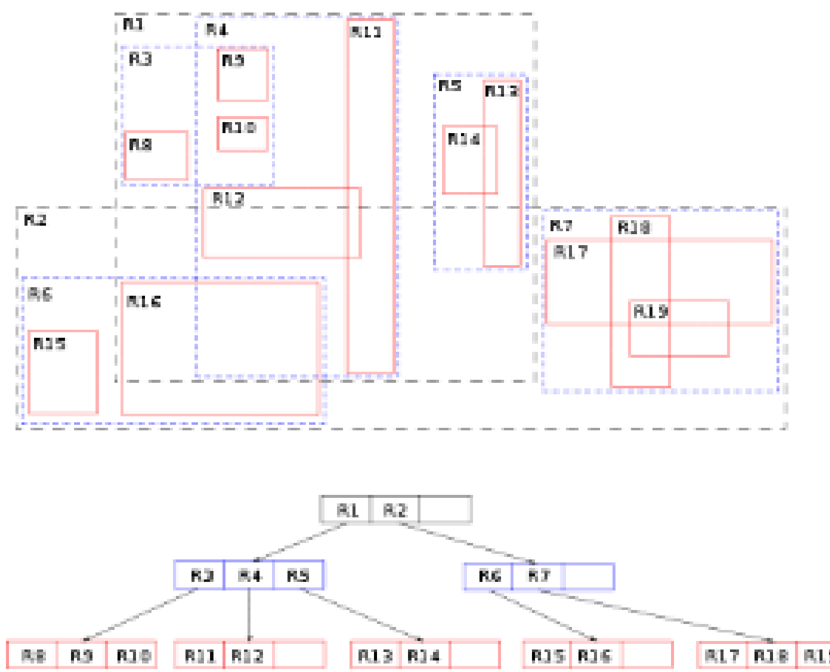
Outline

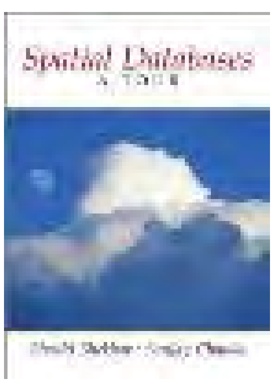
- Introduction
- GPS
- Location Based Services
- Spatial Statistics
- Spatial Database Management Systems
  - Scalability => Privacy
- Virtual Globes
- Geographic Information Systems
- Conclusions

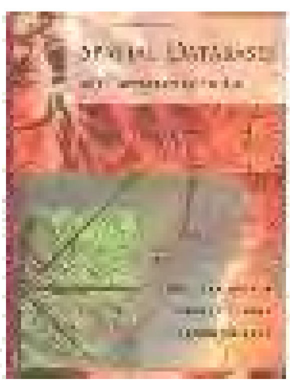
Spatial Databases for Geometry

- 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

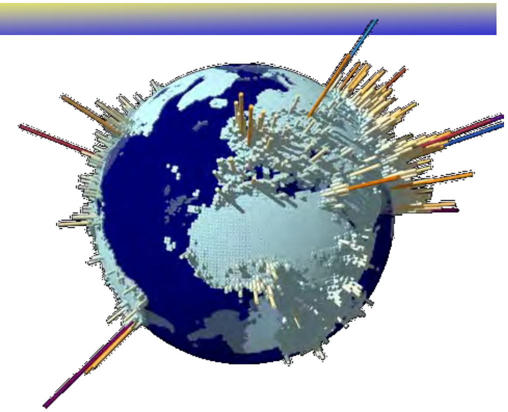
http://illumemagazine.com/zine/articleDetail.php?FBI-GPS-Tracking-and-Invasion-of-Privacy-13346

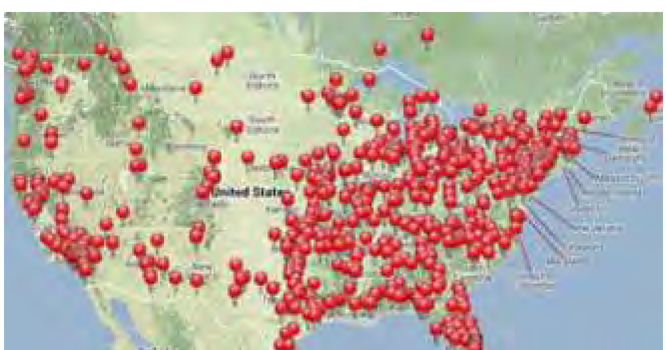
Outline

- Introduction
- GPS
- Location Based Services
- Spatial Statistics
- Spatial Database Management Systems
- Virtual Globes & VGI
  - Quilt => Time-travel & Depth
- Geographic Information Systems
- Conclusions

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/





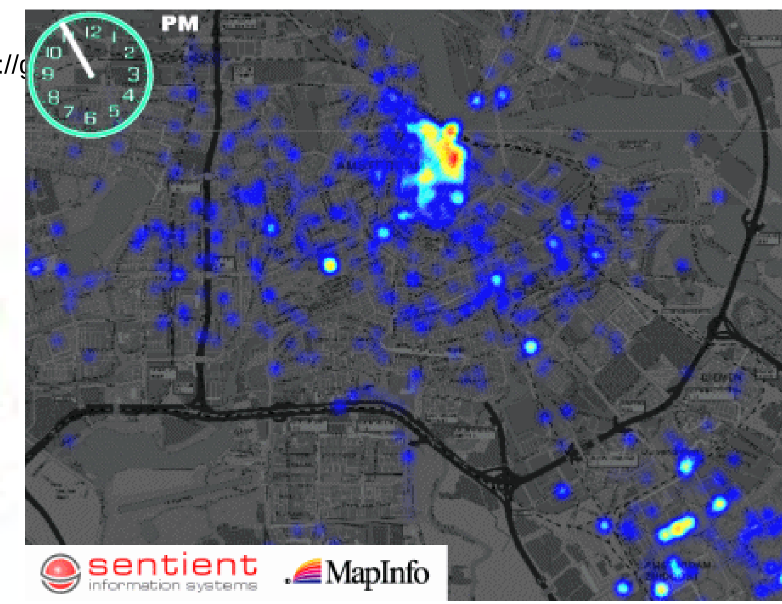
Virtual Globes in GIS Education

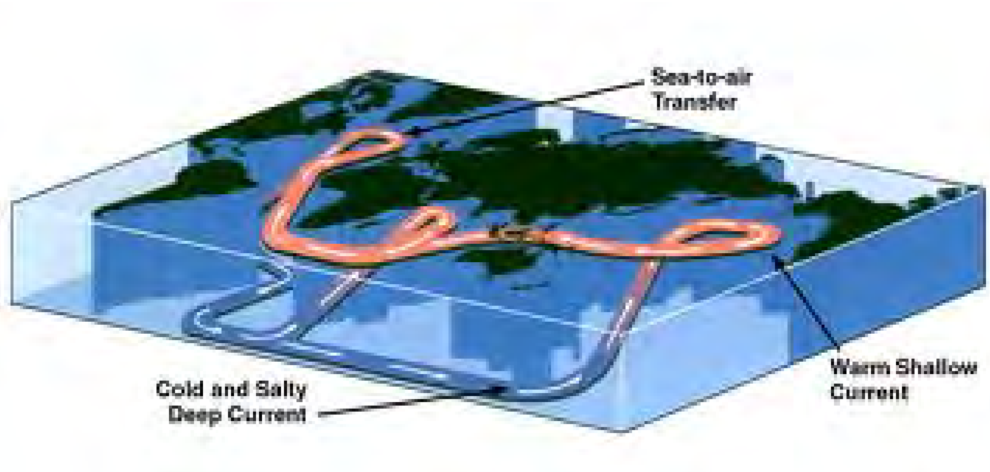
- Coursera MOOC: From GPS and Google Earth to Spatial Computing
  - 21,844 students from 182 countries (Fall 2014)
  - 8 modules, 60 short videos, in-video quizzes, interactive examinations, …
  - 3 Tracks: curious, concepts, technical
  - Flipped classroom in UMN on-campus course

Opportunities: Time-Travel and Depth in Virtual Globes

- Virtual globes are snapshots
- How to add time? depth?
  - Ex. Google Earth Engine, NASA NEX
  - 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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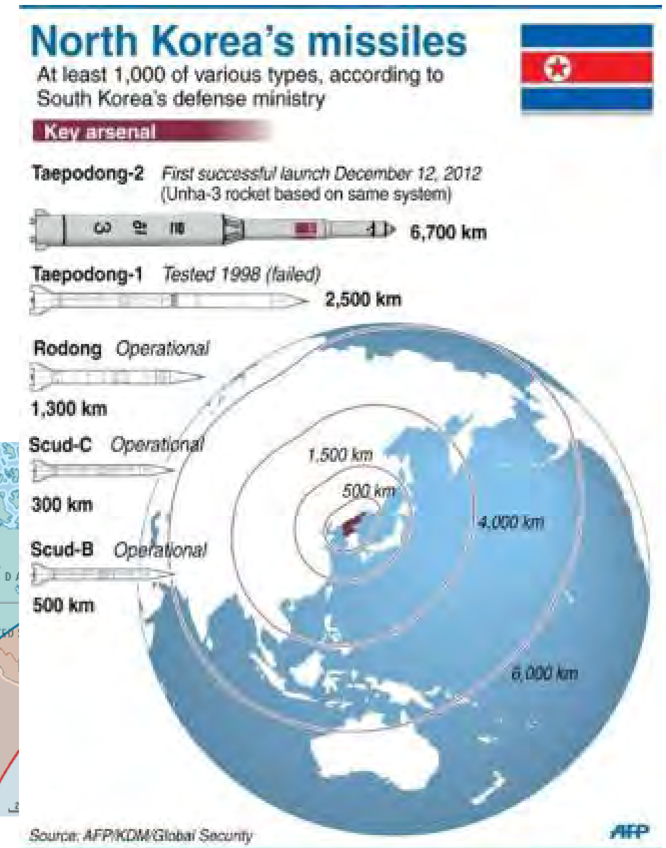
- Spatial Database Management Systems
- Virtual Globes
- Geographic Information Systems
  - Geo => Beyond Geo
- Conclusions

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.
  - Q? How to model time? Spatio-temporal?
- Reference Systems
  - Which countries in North Korea missile range?
  - 3D Earth surface displayed on 2D plane
  - Spherical coordinates vs. its planar projections
  - Q? What are reference systems for time?



Original

The Economist

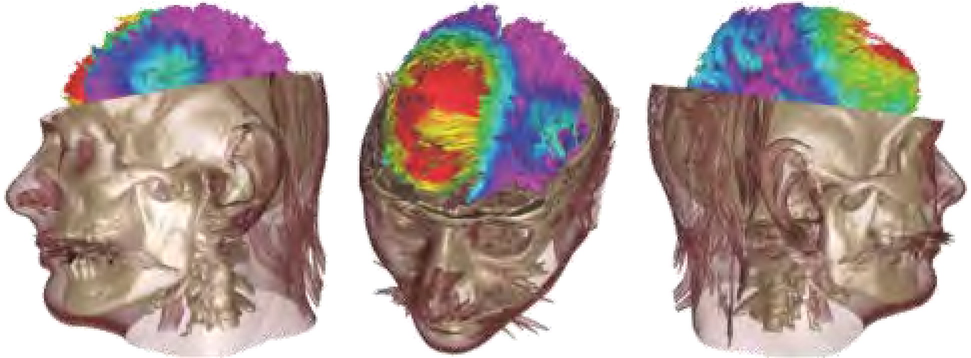
Correction

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.

Outline

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Nexus of Food, Energy, Water Security

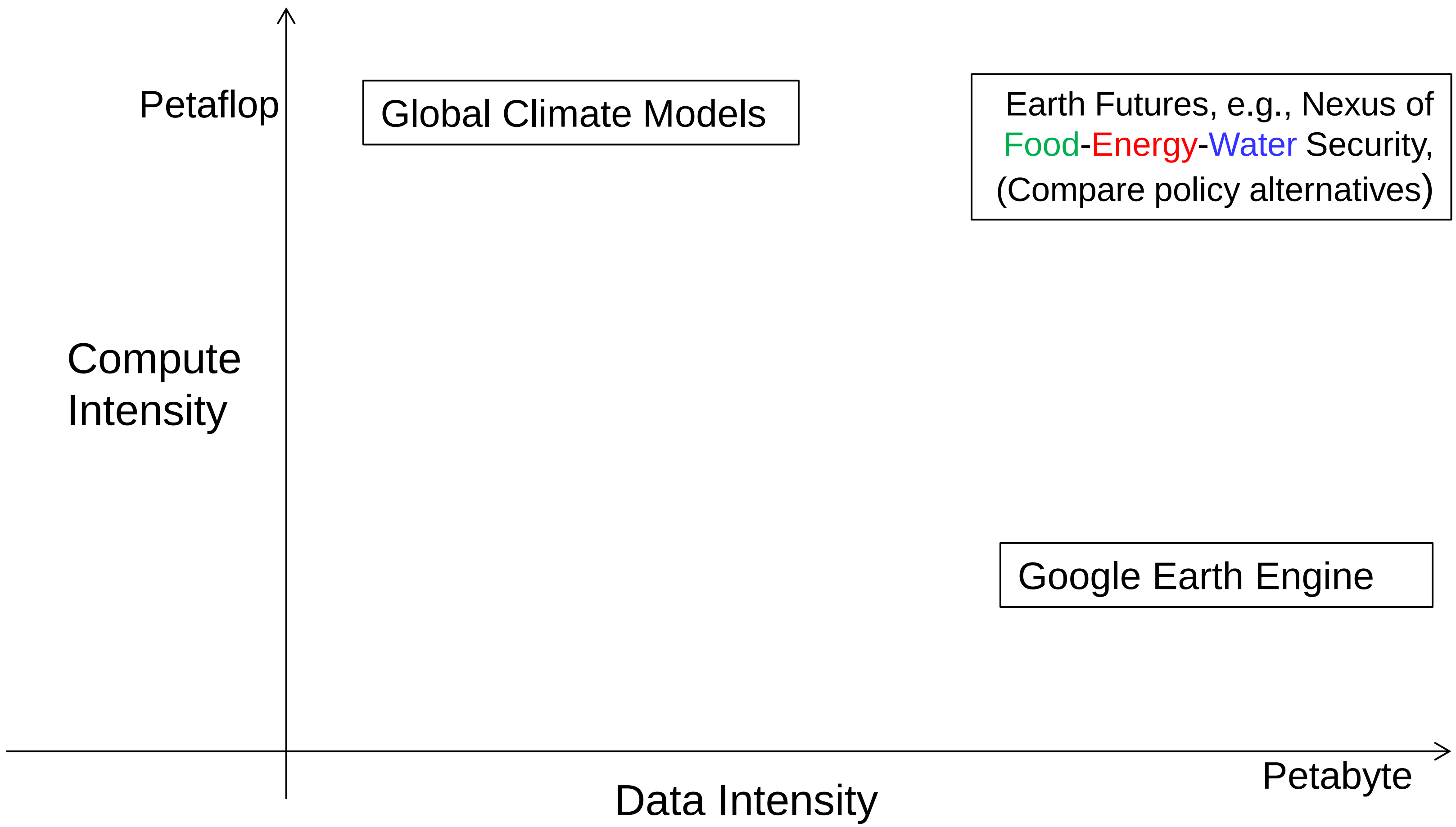
- USA:
  - NSF: INFEWS, \$70M in FY16
  - Reports from OSTP, NIC, USDOE, …

- Spatial computing is essential
  - Water census (USGS)
  - Local sourcing, virtual water trade
  - Precision Agriculture, …

- Excerpt "Satellites provide the big picture", **Science**, 349(6249):684-685, Aug. 14th, 2015.

Satellite observations have revolutionized our understanding of hydrology, water availability, and global change, while catalyzing modern advances in weather, flood, drought, and fire prediction in ways that would not have occurred with relatively sparse ground-based measurements alone. Earth-observing satellites provide the necessary "big-picture" spatial coverage, as well as the regional-to-global understanding essential for improving predictive models and informing policy-makers, resource managers, and the general public.

High-Capability Computing & Future of Virtual Globes



Recommendations

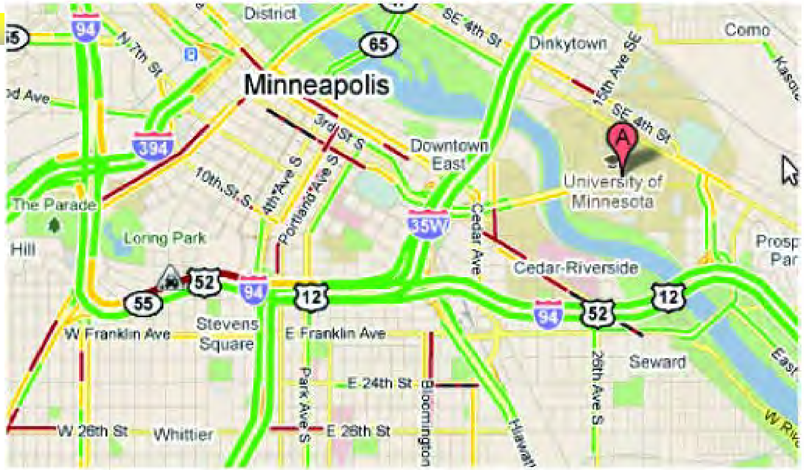
- Spatial Computing has transformed our society
  - It is only a beginning!
  - It promises an astonishing array of opportunities in coming decade
- However, these will not materialize without support
- Universities
  - Institutionalize spatial computing
    - GIS Centers, a la Computing Centers of the 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

Panel: Spatio-Temporal (ST) Computing Questions

- 13. What is missing from … research agenda? What can be achieved in … 5 years?
- 7. What are the major obstacles … ?
- 6. What are promising data models for managing ST data?
- 8. Is it appropriate to model the temporal domain as 4^{th} dimension?
- 4. What are the latest advances in ST computing?
- 14. What is the way to educate the next generation workforce with ST knowledge?

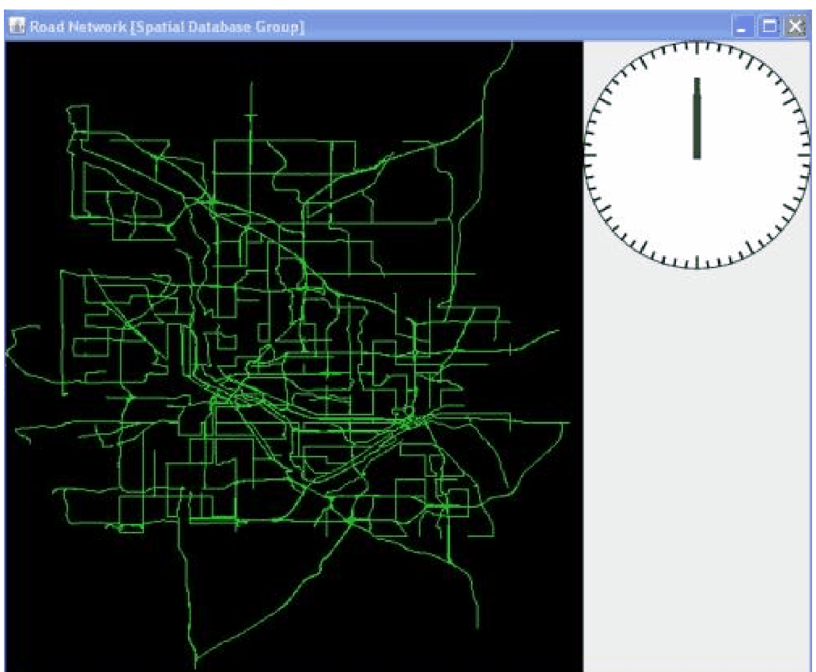
Source: A Critical-Time-Point Approach to All-Start-Time Lagrangian Shortest Paths: A Summary of Results, Proceedings of the Symposium on Spatial and Temporal Databases, Springer LNCS 6849, 2011:74-91. (Complete results accepted for IEEE Transactions on Knowledge and Data Eng.)

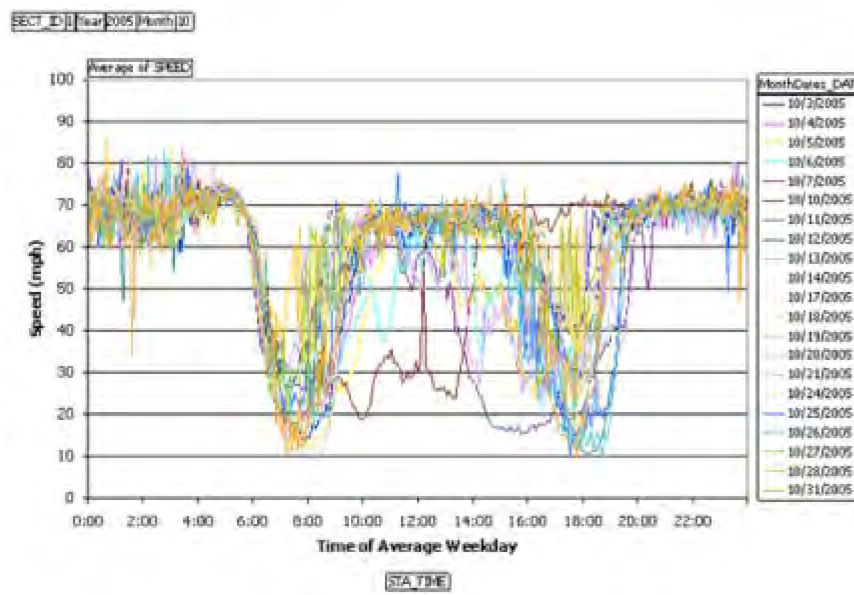
Dynamic Nature of Transportation Network



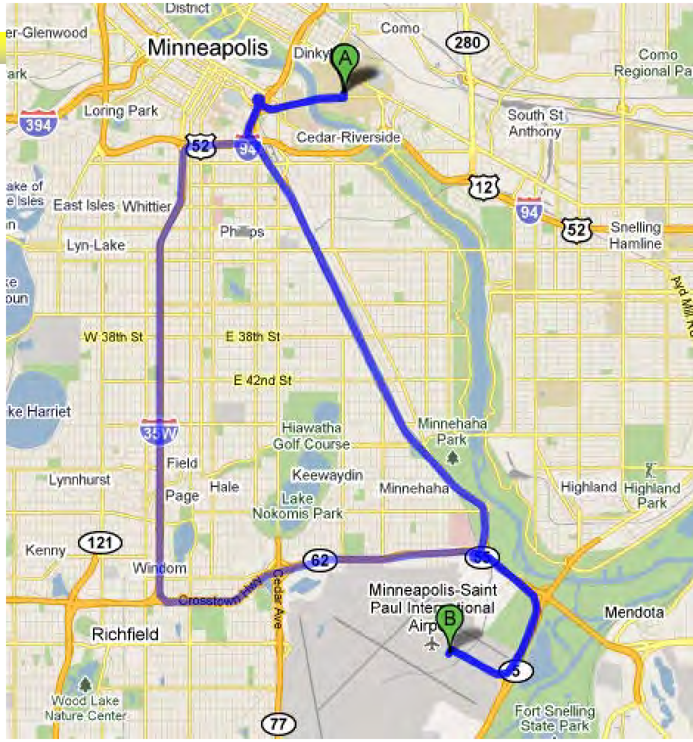
Traffic during non-rush hours

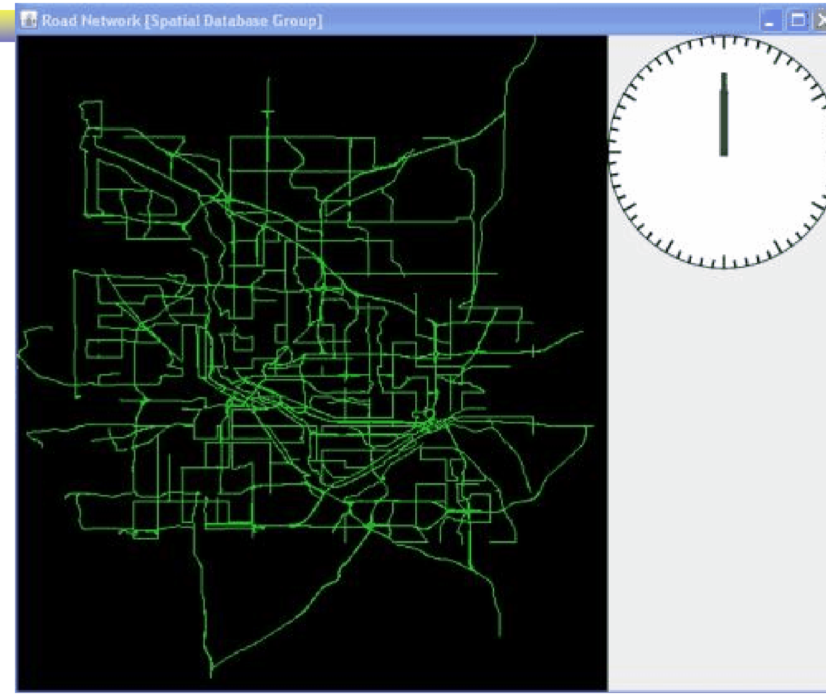
Traffic during Rush hours





Problem Instance





INPUT:

- **Source:** University of Minnesota
- **Destination:** MSP Airport
- **Time Interval** 7:00am --- 12:00noon

OUTPUT:

Time	Preferred Routes
7:30am	Via Hiawatha
8:30am	Via Hiawatha
9:30am	via 35W
10:30am	via 35W

Panel: Spatio-Temporal (ST) Computing Questions

- 13. What is missing from … research agenda? What can be achieved in … 5 years?
- 7. What are the major obstacles … ?
- 6. What are promising data models for managing ST data?
- 8. Is it appropriate to model the temporal domain as 4^{th} dimension?
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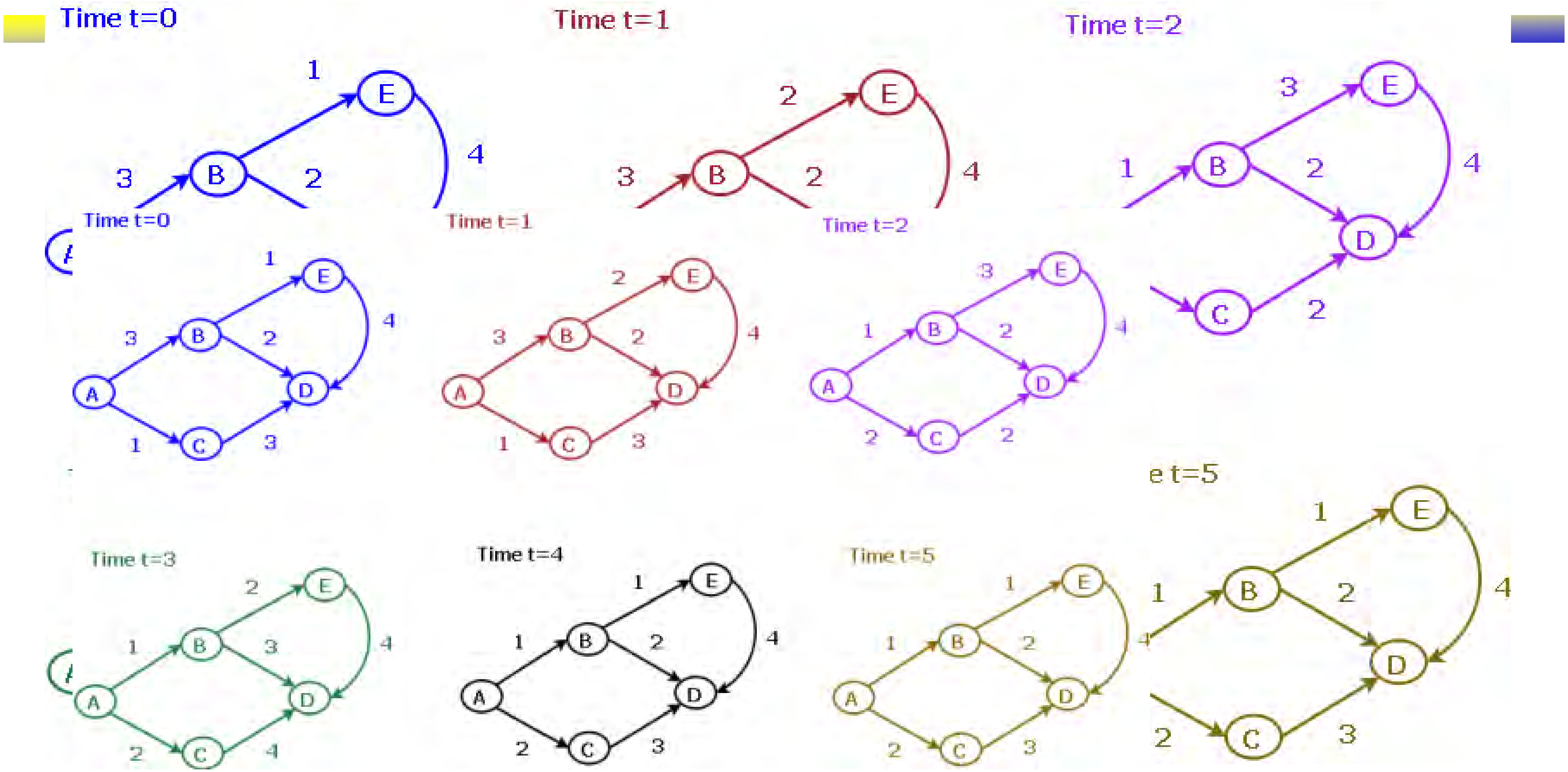
- 14. What is the way to educate the next generation workforce with ST knowledge?

Challenge: Lagrangian Frame of Reference



Q? What is cost of Path <A,C,D> start time=2 ?
➢Is it 4 or 5 ??

Path	T = 0	T = 1	T = 2	T = 3
<A,C,D>	4	3	5	4
<A,B,D>	6	5	4	3

Challenges

Non Stationarity ranking of paths

Time	Preferred Routes
7:30am	Via Hiawatha
8:30am	Via Hiawatha
9:30am	via 35W
10:30am	via 35W

➢ Violation of stationary assumption dynamic programming

Non FIFO Behavior

Time	Route	Flight Time
8:30am	via Detroit	6 hrs 31 mins
9:10am	direct flight	2 hrs 51 mins
11:00am	via Memphis	4 hrs 38mins
11:30am	via Atlanta	6 hrs 28 mins
2:30pm	direct flight	2 hrs 51 mins

*Flight schedule between Minneapolis and Austin (TX)

➢ Violates the no wait assumption of Dijkstra/A*

Panel: Spatio-Temporal (ST) Computing Questions

- 13. What is missing from … research agenda? What can be achieved in … 5 years?
- 7. What are the major obstacles … ?
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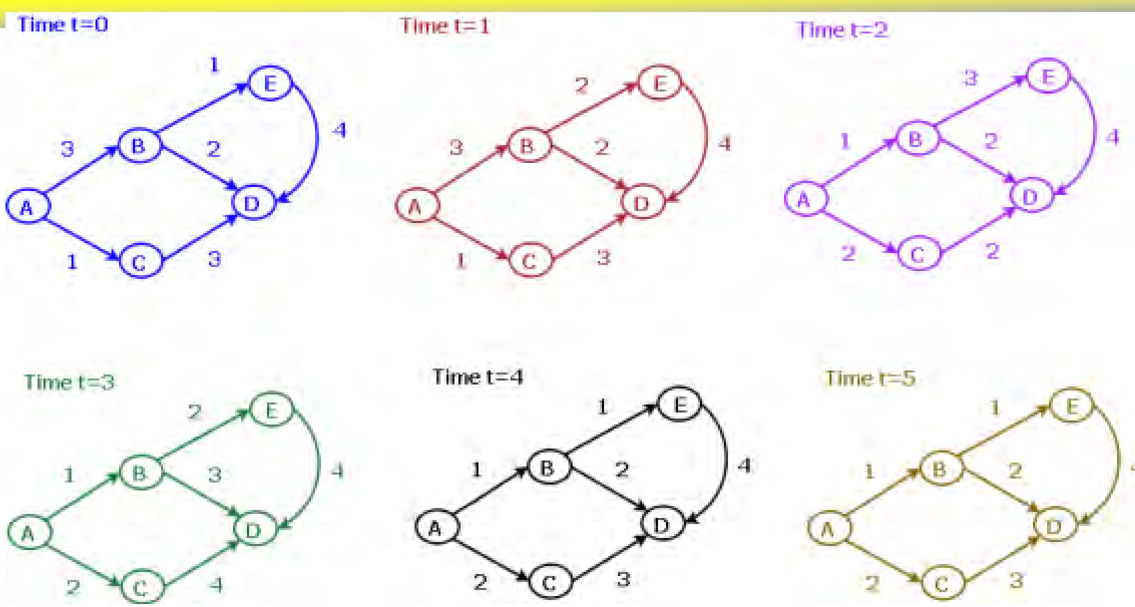
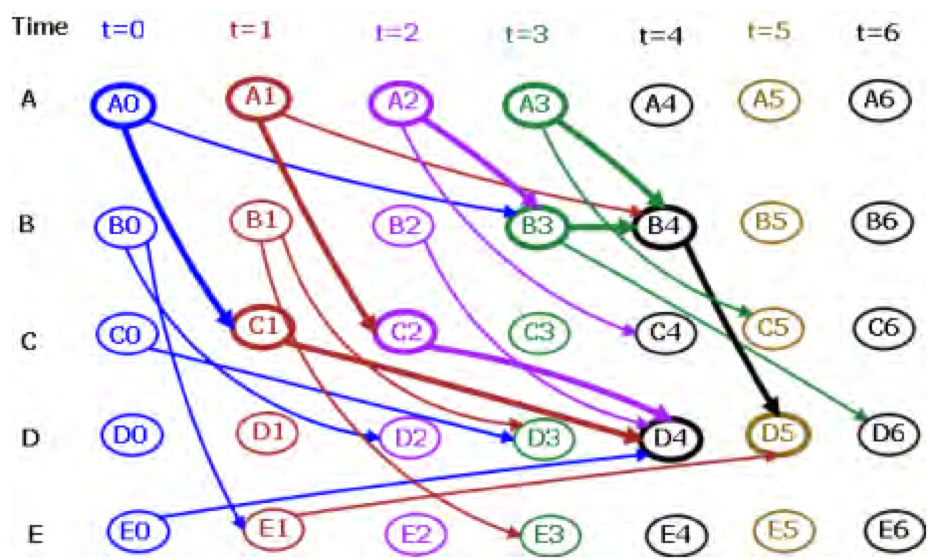
- 8. Is it appropriate to model the temporal domain as 4^{th} dimension?
- 4. What are the latest advances in ST computing?
- 14. What is the way to educate the next generation workforce with ST knowledge?

Naïve Solution (1/2)

Snapshot Model

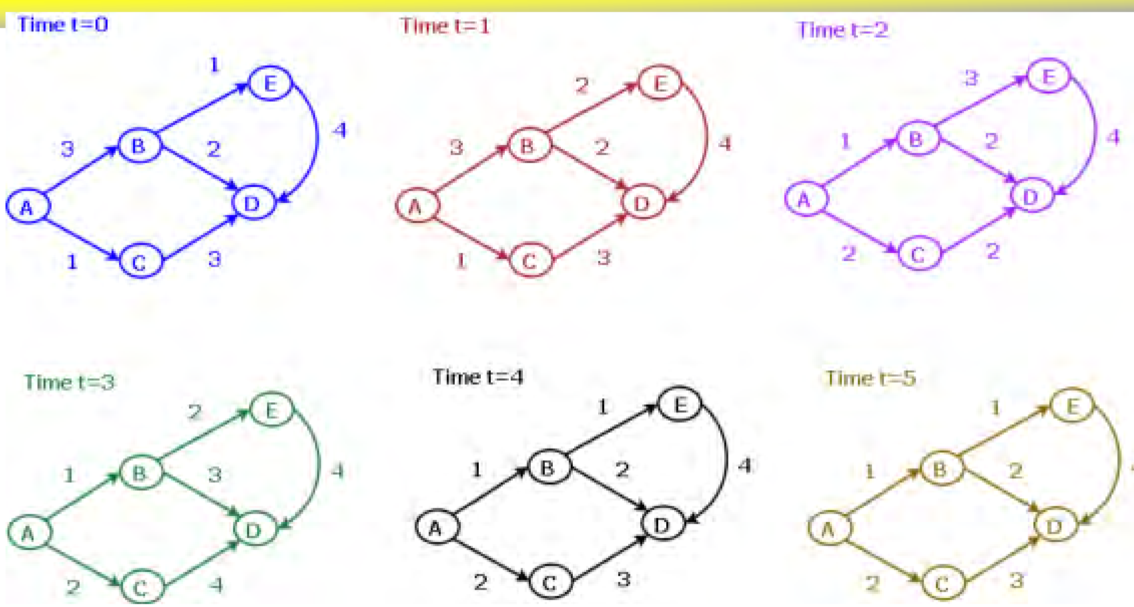


Time expanded Graph (TEG)

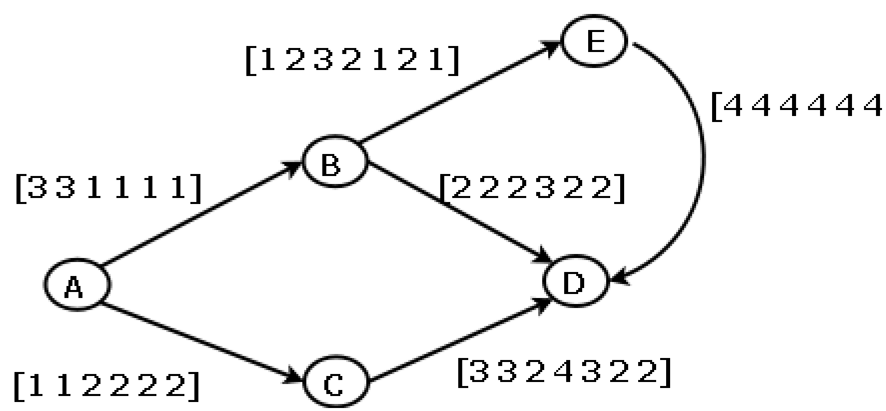


Naïve Solution (1/2)

Snapshot Model



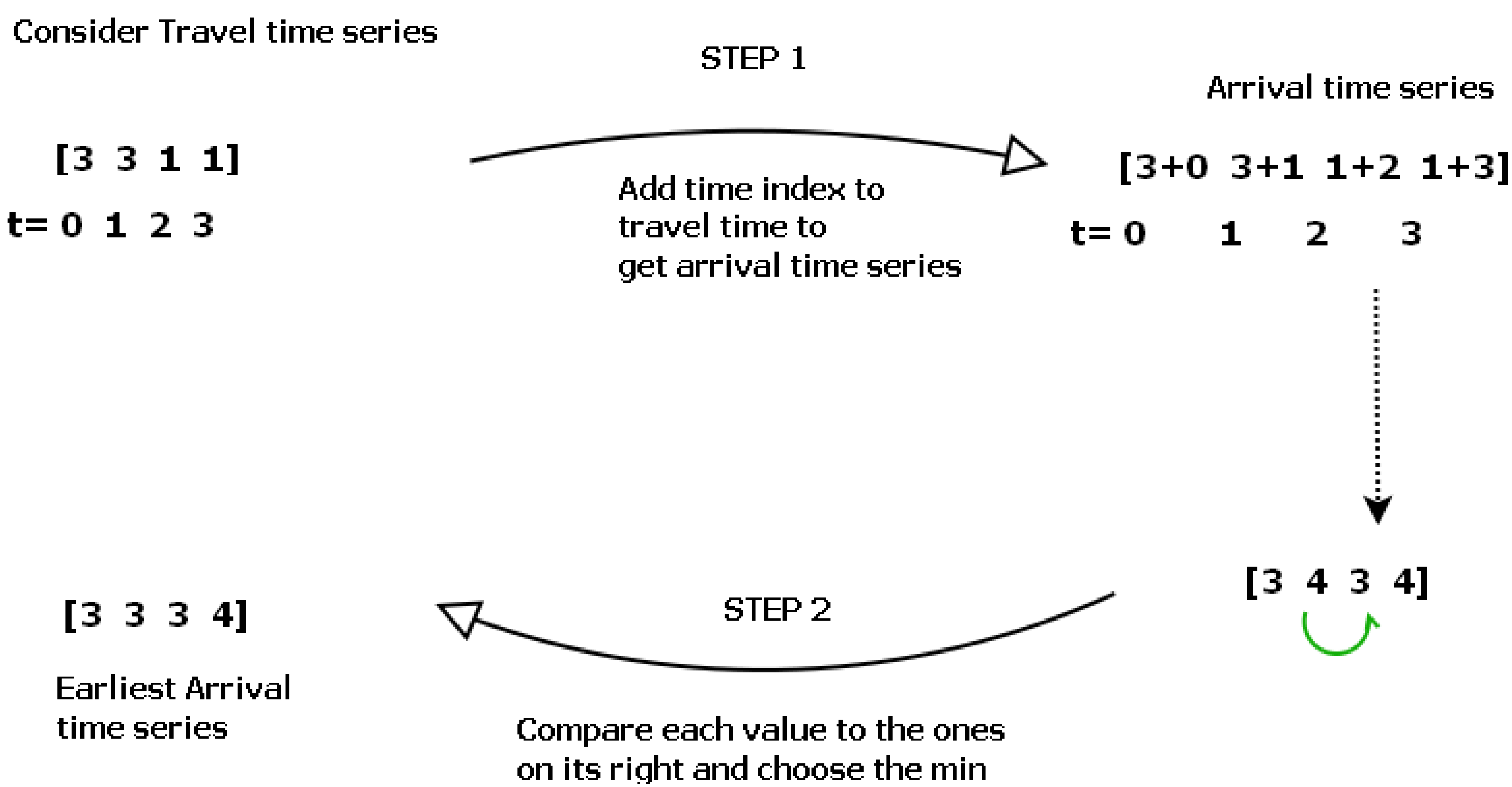
Time aggregate graph (TAG)



Panel: Spatio-Temporal (ST) Computing Questions

- 13. What is missing from … research agenda? What can be achieved in … 5 years?
- 7. What are the major obstacles … ?
- 6. What are promising data models for managing ST data?
- 8. Is it appropriate to model the temporal domain as 4^{th} dimension?
- 4. What are the latest advances in ST computing?
- 14. What is the way to educate the next generation workforce with ST knowledge?

Handling Non-FIFO Behavior (Earliest Arrival Time Series Transformation)

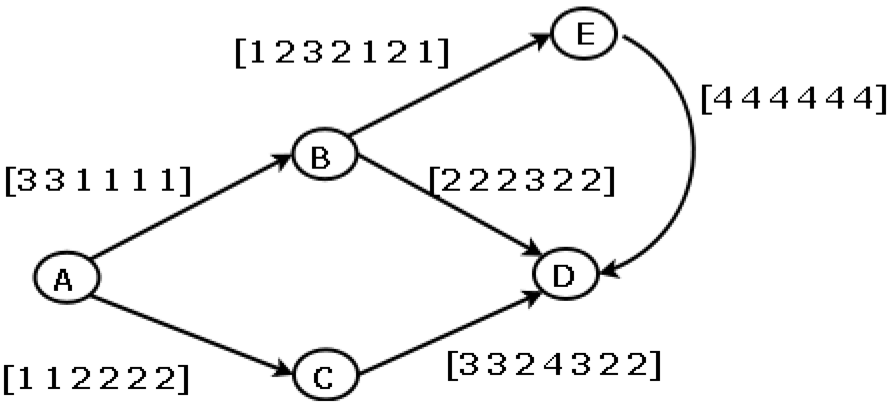


Observation:

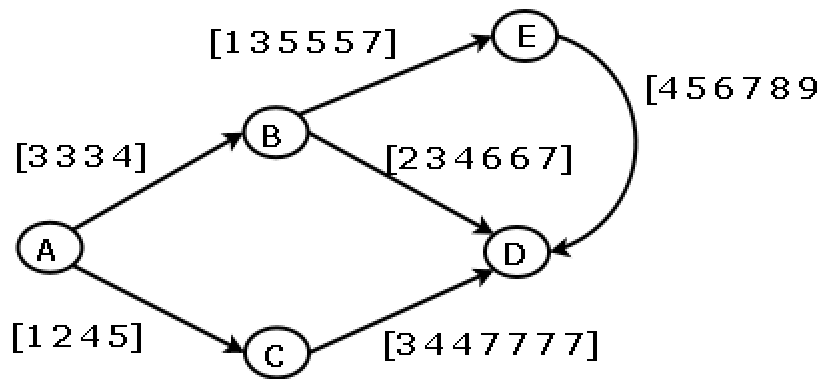
- Earliest arrival time series is FIFO in nature.

Travel-Time vs. Earliest Arrival Time

Travel-Time-Series



Earliest Arrival Time -Series

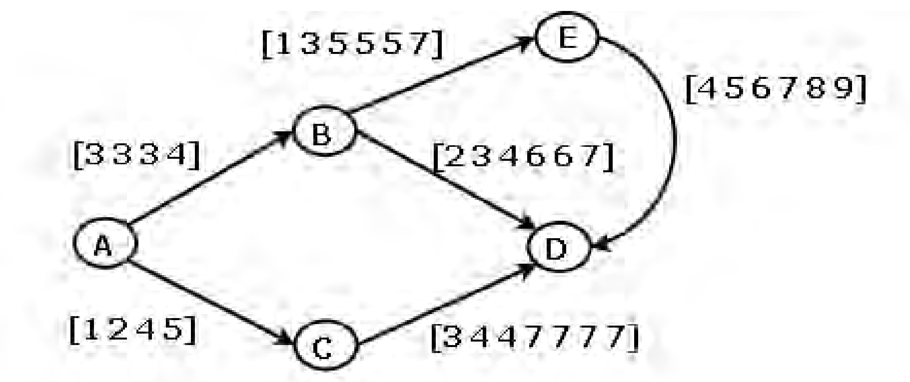


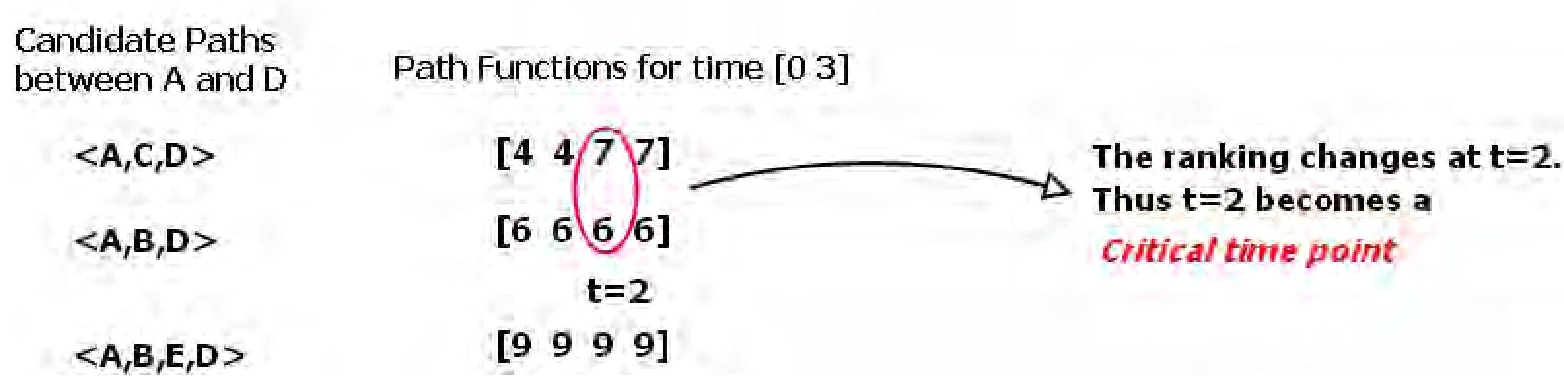
Observation:

- Earliest arrival time series is FIFO in nature.
- Computing fastest path is easier with earliest arrival time-series
-

Basic concepts for *Critical-time-point*

- **Non-critical times:** Path ranking can’t change.
- ***Critical-time-points:*** *Time point where path ranking may* change.





- **Path ranking cannot change at *non critical-time-points.***

Panel: Spatio-Temporal (ST) Computing Questions

- 13. What is missing from … research agenda? What can be achieved in … 5 years?
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Q13. ST Education

- Tutorials
- Articles in Encyclopedia of GIS
  - Springer's (M. Yuan, K. Stewart, …) , AAG's
- Survey Papers, book chapters
- Books
  - Choro-chronous (EU project), Moving Object Databases (Guting), Trajectory Processing (Y. Zheng), …
- Courses
- Degree programs
  - Interdisciplinary graduate programs
  - NSF NRT (previously IGERT)