From GPS and Google Maps to Spatial Computing

IEEE Intl. Conf. on Contemporary Computing (ICS), JIIT, Delhi, India, Aug., 2015

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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
Research Theme 1: Spatial Databases

Parallelize Range Queries

Evacuation Route Planning
- only in old plan
- Only in new plan
- In both plans

Shortest Paths

Storing graphs in disk blocks

ROUTE PREFERENCE
Minimize:
- TRAVEL TIME
- DISTANCE
- FUEL
- GREENHOUSE GASES
Theme 2: Spatial Data Mining

Location Prediction: nesting sites
- Nest locations
- Distance to open water
- Vegetation durability
- Water depth

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

Co-location Patterns

Spatial Concept Aware Summarization

Output: SaTScan

- $L_R = 23.02$, p-value = 0.04
- $L_R = 10.61$, p-value = 0.18
- $L_R = 27.74$, p-value = 0.01
Recent Professional Activities

- Spatial Computing Visioning Workshop
- Computing Community Consortium (CCC)
- Geoinformatica Journal
- Symposium on Spatial and Temporal Database 2011
- GIScience Conference 2012
Sources


- With few slides on work from presenter’s group
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 through understanding spaces and places
  • Examples: localization, navigation, site selection, mapping,
  • Examples: spatial context, situation assessment (distribution, patterns), …
## The Changing World of Spatial Computing

<table>
<thead>
<tr>
<th></th>
<th>Last Century</th>
<th>Last Decade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map User</td>
<td>Well-trained few</td>
<td>Billions</td>
</tr>
<tr>
<td>Mappers</td>
<td>Well-trained few</td>
<td>Billions</td>
</tr>
<tr>
<td>Software, Hardware</td>
<td>Few layers, e.g., Applications: Arc/GIS, Databases: SQL3/OGIS</td>
<td>Almost all layers</td>
</tr>
<tr>
<td>User Expectations &amp; Risks</td>
<td>Modest</td>
<td>Many use-case &amp; Geo-privacy concerns</td>
</tr>
</tbody>
</table>
It is widely used by Government!

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

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

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

New Ways to Exploit Raw Data May Bring Surge of Innovation, a Study Says
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
### 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 Faler, 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 Keyes, Texas A&M University
- Craig A. Knoblock, Information Sciences Institute
- Hank Korth, Lehigh University
- Benjamin Kuipers, University of Michigan
- Vinil 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
- Shaochen 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, ESRI
- 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
- Jada DePalacios, Naval Postgraduate School
- Joe Eisenberg, Computer Science and Telecommunications Board (CSTB)
- Tom Erickson, IBM
- Erwin Gianchandani, CCC
- Eric Hoel, 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

- Nabih Adam, DHS
- Vijay Atluri, NSF
- David Balshaw, NIH/NEHS
- Budhendra Bhaduri, ORNL
- Kelly Crews, NSF
- Beth Driver, NGA
- Walton Fehr, USDOT
- Myron Gutmann, NSF
- Susanne Hambrusch, NSF
- Michelle Heacock, NIH/NEHS
- Clifford Jacobs, NSF
- Farnam Jahanian, NSF
- Todd Johansen, NGA
- Thomas Johnson, NGA
- Henry Kelly, OSTP
- Alicia Lindauer, USDDE
- Keith Marzullo, NSF
- John L. Schnase, NASA
- Jim Shire, Army Research
- Raju Vatsavai, ORNL
- Eric Vessey, NSA
- Howard D. Wactlar, NSF
- Tandy Warnow, NSF
- Nicole Weyant, 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
- Ourl 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: Avidah 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 \( f(\text{compass, star positions}) \)
  - Longitude: dead-reckoning \( \Rightarrow \) marine chronometer
  - Longitude prize (1714), accuracy in nautical miles

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

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[Diagram: Trilateration](http://en.wikipedia.org/wiki/Global_Positioning_System)

[Diagram: Trilateration](http://answers.oreilly.com/topic/2815/how-devices-gather-location-information/)
Trends: Localization Indoors and Underground

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

- 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

<table>
<thead>
<tr>
<th>Static</th>
<th>Time-Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which is the shortest travel time path from downtown Minneapolis to airport?</td>
<td>Which is the shortest travel time path from downtown Minneapolis to airport?</td>
</tr>
<tr>
<td></td>
<td>Time in a work day?</td>
</tr>
</tbody>
</table>
Q: What is the cost of Path <A,C,D> with start-time t=1? Is it 3 or 4?

Snapshots of a Graph

<table>
<thead>
<tr>
<th>Path</th>
<th>T = 0</th>
<th>T = 1</th>
<th>T = 2</th>
<th>T = 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;A,C,D&gt;</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>&lt;A,B,D&gt;</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Lagrangian Graph

Spatio-temporal Graphs: Computational Challenges

**Ranking changes over time**

Violates stationary assumption in Dynamic Programming

<table>
<thead>
<tr>
<th>Time</th>
<th>Preferred Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:30am</td>
<td>Via Hlawatha</td>
</tr>
<tr>
<td>8:30am</td>
<td>Via Hiawatha</td>
</tr>
<tr>
<td>9:30am</td>
<td>via 35W</td>
</tr>
<tr>
<td>10:30am</td>
<td>via 35W</td>
</tr>
</tbody>
</table>

**Waits, Non FIFO Behavior**

Violate assumption of Dijkstra/A*

<table>
<thead>
<tr>
<th>Time</th>
<th>Route</th>
<th>Flight Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30am</td>
<td>via Detroit</td>
<td>6 hrs 31 mins</td>
</tr>
<tr>
<td>9:10am</td>
<td>direct flight</td>
<td>2 hrs 51 mins</td>
</tr>
<tr>
<td>11:00am</td>
<td>via Memphis</td>
<td>4 hrs 38 mins</td>
</tr>
<tr>
<td>11:30am</td>
<td>via Atlanta</td>
<td>6 hrs 28 mins</td>
</tr>
<tr>
<td>2:30pm</td>
<td>direct flight</td>
<td>2 hrs 51 mins</td>
</tr>
</tbody>
</table>

*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
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
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
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 ...

<table>
<thead>
<tr>
<th>Mathematics</th>
<th>Concepts</th>
<th>Relationships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sets</td>
<td>Set Theory</td>
<td>Member, set-union, set-difference, ...</td>
</tr>
<tr>
<td>Vector Space</td>
<td>Linear Algebra</td>
<td>Matrix &amp; vector operations</td>
</tr>
<tr>
<td>Euclidean Spaces</td>
<td>Geometry</td>
<td>Circle, Ring, Polygon, Line_String, Convex hull, ...</td>
</tr>
<tr>
<td>Boundaries, Graphs,</td>
<td>Topology, Graph Theory, Spatial graphs, ...</td>
<td>Interior, boundary, Neighbor, inside, surrounds, ..., Nodes, edges, paths, trees, ... Path with turns, dynamic segmentation, ...</td>
</tr>
</tbody>
</table>

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

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)

<table>
<thead>
<tr>
<th>( K)-function (B → A)</th>
<th>2/6 = 0.33</th>
<th>3/6 = 0.50</th>
<th>6/6 = 1.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI (B → A)</td>
<td>2/3 = 0.66</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
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

- 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)

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• Introduction
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• 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

![Table 4.2: Geo-privacy Policy Conversation Starters](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
• 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)
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 sources?

http://googleblog.blogspot.com/2013/05/a-picture-of-earth-through-time.html
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• 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?
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?

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

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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, ...

  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

- Petaflop
- Compute Intensity
- Global Climate Models
- Earth Futures, e.g., Nexus of Food-Energy-Water Security, (Compare policy alternatives)
- Google Earth Engine

Data Intensity

Petabyte
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 4th 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
INPUT:

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

OUTPUT:

<table>
<thead>
<tr>
<th>Time</th>
<th>Preferred Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:30am</td>
<td>Via Hiawatha</td>
</tr>
<tr>
<td>8:30am</td>
<td>Via Hiawatha</td>
</tr>
<tr>
<td>9:30am</td>
<td>Via 35W</td>
</tr>
<tr>
<td>10:30am</td>
<td>Via 35W</td>
</tr>
</tbody>
</table>
Panel: Spatio-Temporal (ST) Computing Questions

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Challenge: Lagrangian Frame of Reference

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

<table>
<thead>
<tr>
<th>Path</th>
<th>T = 0</th>
<th>T = 1</th>
<th>T = 2</th>
<th>T = 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;A,C,D&gt;</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>&lt;A,B,D&gt;</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
Challenges

Non Stationarity ranking of paths

<table>
<thead>
<tr>
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<th>Preferred Routes</th>
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<tbody>
<tr>
<td>7:30am</td>
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<td>9:30am</td>
<td>via 35W</td>
</tr>
<tr>
<td>10:30am</td>
<td>via 35W</td>
</tr>
</tbody>
</table>

Non FIFO Behavior

<table>
<thead>
<tr>
<th>Time</th>
<th>Route</th>
<th>Flight Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30am</td>
<td>via Detroit</td>
<td>6 hrs 31 mlns</td>
</tr>
<tr>
<td>9:10am</td>
<td>direct flight</td>
<td>2 hrs 51 mlns</td>
</tr>
<tr>
<td>11:00am</td>
<td>via Memphis</td>
<td>4 hrs 38 mlns</td>
</tr>
<tr>
<td>11:30am</td>
<td>via Atlanta</td>
<td>6 hrs 28 mlns</td>
</tr>
<tr>
<td>2:30pm</td>
<td>direct flight</td>
<td>2 hrs 51 mlns</td>
</tr>
</tbody>
</table>

*Flight schedule between Minneapolis and Austin (TX)*

- Violation of stationary assumption dynamic programming
- Violates the no wait assumption of Dijkstra/A*
Panel: Spatio-Temporal (ST) Computing Questions

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Naïve Solution (1/2)

Snapshot Model

Time expanded Graph (TEG)
Naïve Solution (1/2)

Snapshot Model

Time aggregate graph (TAG)
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?
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Observation:

- Earliest arrival time series is FIFO in nature.
Travel-Time vs. Earliest Arrival Time

**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.

Candidate Paths between A and D

- \( <A, C, D> \)
- \( <A, B, D> \)
- \( <A, B, E, D> \)

Path Functions for time [0, 3]

- \([4477]\) for \( <A, C, D> \)
- \([6666]\) for \( <A, B, D> \)
- \([9999]\) for \( <A, B, E, D> \)

The ranking changes at \( t=2 \). Thus \( t=2 \) becomes a **Critical time point**.

- **Path ranking cannot change at non critical-time-points.**
Panel: Spatio-Temporal (ST) Computing Questions

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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)