CS225: Spatial Computing

Introduction to Spatial Computing

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Once upon a time...
Claudius Ptolemy (AD 90 – AD 168)
TYPVS ORBIS TERRARVM

REXIDIS

QVID EI POTEST VIDERI MAGNUM IN REBUS HUMANIS, CVI AETERNITAS OMNIS TOTIVSQUE MUNDI NOTA SIT MAGNITUDO. CICERO.
Cholera cases in the London epidemic of 1854
Figure 3—Children under 15 years of age in 1940.
Figure 3—Children under 15 years of age in 1940.
Cool computer technology...!! Can I use it in my application?

I have BIG data. I need HELP...!!

Oh...!! But, it is not made for me. Can't make use of it as is.

My pleasure. Here it is.
Kindly let me understand your needs.

1969

Kindly let me get the technology you have.
HELP...!! I have BIG data. Your technology is not helping me. mmm...Let me check with my good friends there.

Cool Database technology...!! Can I use it in my application?

Oh...!! But, it is not made for me. Can't make use of it as is.

My pleasure. Here it is.
Kindly let me understand your needs

Kindly let me get the technology you have
HELP..!! Again, I have BIG data. Your technology is not helping me.

Let me check with my other good friends there.

Sorry, seems like the DBMS technology cannot scale more.

Cool Big Data technology..!! Can I use it in my application?

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The Era of Big Spatial Data
The Era of Big Spatial Data

Recent products are there....
What is Spatial Computing?
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  - [tentative] → emerging definition and field
  - Technologies could be software, hardware, or both
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  › Where am I?
    › On Earth, in a mall, in a campus, in a plaza, inside a human body…etc
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- What is in or around certain area(s)? (Spatial Analysis)
  - Situation after a natural disaster, changes over time, etc
  - Science, e.g., vegetation analysis, environment, ecology,…etc
  - Enterprise, e.g., agriculture, ride sharing, market research,…etc
Who use Spatial Computing?

- Hundreds of millions of people (if not billions)
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- Business
  - Estimated value by 2020: $600B
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Table 1. Members of the Federal Geographic Data Committee (FGDC)

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

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Major technologies and areas (past, present, & future)

- GPS
- Location Based Services
- Spatial Data Management Systems
- Geographic Information Systems
- Spatial Predictive Analysis (Spatial Statistics, or Spatial Data Mining)
- Virtual Globes and VGI (or CGI)
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Global Positioning Systems (GPS)

- Positioning ships
  - Latitude \( f(\text{compass, star positions}) \) → ancient and medieval civilizations
  - Longitude Prize (1714) → marine chronometer
Global Positioning Systems (GPS)

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

Trilateration


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

- Ocean Navigation
- Aircraft Navigation
- Aircraft landing
- Car navigation
- Spacecraft Navigation
- Space Weather (Ionosphere)
- Precision Agriculture
- Autonomous Nav
- Earthquake Displacements
- Airborne LIDAR/SAR
- Leveling
- Tsunami Warning
- Glacial Flow
- Weather Forecasting
- Satellite Orbit Determination
- Volcanic Hazards
- Seismic Hazard
- Hydrology
- Geodynamics
- Decadal Survey Missions
- Sea Level

Time Scale:
- Seconds
- Minutes
- Hours
- Days
- Months
- Years
- Decades
Future & Trends: Localization Indoors, Underground, & Underwater

- GPS works outdoors, but,
  - We are indoors 90% of time!
  - Ex. malls, hospitals, airports, …
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**TOP 10 LOCATION BASED SERVICES AT AIRPORTS**

1. Find Your Gate
2. Your Current Location
3. Find [Any Service]
4. Estimated Walking Times
5. Queue Management
6. Recommended Activities
7. People Flow Optimisation
8. Location Based Notifications
9. Location Based Offers
10. Find Customer Service

Get In-Store Notifications

[Diagram showing heatmaps and in-store analytics]
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  - Blue Tooth, Wi-Fi, …

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[Image: Get In-Store Notifications]
Future & Trends: Localization Indoors, Underground, & Underwater

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  - 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?


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

Services based on your location
- Location Sharing: Where am I? (street address, <latitude, longitude>)
- Directory: Where is the nearest gas station?
- Routes: What is the shortest path to reach there?
Trends: Next Generation Navigation

- Eco-Routing
- Best start time
- Road-capacity aware
Trends: Persistent Geo-Hazard Monitoring

- Environmental influences on our health & safety
  - air we breathe, water we drink, food we eat
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, ...etc
Major technologies and areas (past, present, & future)

› GPS
› Location Based Services
› **Spatial Data Management Systems**
› Geographic Information Systems
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Database Management Systems (DBMSs)
Spatial Database Management Systems (SDBMS)

- An SDBMS is a software module that:
  - Can work with an underlying database management system (DBMS)
  - Supports spatial data models, spatial abstract data types (ADTs) and a query language from which these ADTs are callable
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  - Supports spatial indexing, efficient algorithms for processing spatial operations, and domain specific rules for query optimization
SDBMS: Spatial Data Examples

- Examples of non-spatial data
  - Names, phone numbers, email addresses of people

- Examples of spatial data
  - Census Data
  - NASA satellites imagery - terabytes of data per day
  - Weather and climate data
  - Rivers, farms, ecological impact
  - Medical imaging
SDBMS: Non-Spatial vs. Spatial Queries

- Non-spatial queries
  - List the names of all bookstore with more than ten thousand titles
  - List the names of ten customers, in terms of sales, in the year 2001

- Spatial Queries
  - List the names of all bookstores with ten miles of Minneapolis
  - List all customers who live in Tennessee and its adjoining states
Components of an SDBMS

- Spatial data model
- Query language
- Query processing
- File organization and indexes
- Query optimization, etc.
SDBMS Example

Consider a spatial dataset with:
- County boundary (dashed white line)
- Census block - name, area, population, boundary (dark line)
- Water bodies (dark polygons)
- Satellite Imagery (gray scale pixels)
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Storage in a SDBMS table:
```sql
create table census_blocks (
    name string,
    area float,
    population number,
    boundary polygon);
```
SDBMS Example

- A row in the table `census_blocks`
- Boundary has a spatial data type that can be manipulated by the query language, query processor, indexes, etc
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- Boundary has a spatial data type that can be manipulated by the query language, query processor, indexes, etc
- Query: Select * FROM census_blocks C, factory F WHERE Overlap(C.boundary, F. boundary)
Spatial beyond Databases

- Distributed systems
  - Hadoop, Spark, Impala, … etc
Challenges: Privacy vs. Utility

- Check-in risks: Stalking, GeoSlavery, Others know that you are not home, etc
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- Ex: Girls Around me App (3/2012)

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)
Fitness tracking app Strava gives away location of secret US army bases

Data about exercise routes shared online by soldiers can be used to pinpoint overseas facilities

Latest: Strava suggests military users ‘opt out’ of heatmap as row deepens
Challenges: Security vs. Utility

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Alex Hern

Location-based threats: How cybercriminals target you based on where you live

Corporate • Network • Security Tips • SophosLabs • Cryptowall • Geomalware • Locky • Phishing • Ransomware • Sophos Home • Spam • TorrentLocker
Challenges: Security vs. Utility

- Important questions:
  - Who gets my data?
  - Who do they give it to?
  - What promises do I get?
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Involved groups:
- Civil Society
- Economic Entities
- Public Safety
- Policy Makers
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  - Public Safety
  - Policy Makers

- Agreements and disagreements
  - Agreements: E911, emergency alerts
  - Controversial: traffic monitoring
Spatial beyond GeoSpatial

- Examples:
  - Human bodies
  - VLSI
  - Universe
Spatial beyond GeoSpatial

Examples:
- Human bodies
- VLSI chips and boards
- Universe
- Indoor and virtual spaces

Challenges:
- What are the reference system?
  - On Mars? Outside Milkyway galaxy? In augmented reality spaces?
  - Is it one for all humans? Or personalized?
- Accuracy
- 3D+ scalability
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Geographic Information Systems (GIS)

- Software packages for working with maps and geographic information.
  - Creating and using maps
  - Compiling geographic data
  - Analyzing mapped info
  - Sharing and discovering geographic information
How different GIS from SDBMS?
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- SDBMS can be used by applications other than GIS
  - Astronomy, location-based services, brain informatics, etc
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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
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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

- In the spatial space, statistical independence assumptions do not always hold.
- Spatial Statistics
  - Hot spot detection
  - Spatial auto-correlation
  - Spatial-constrained clusters
  - Spatial uncertainty, confidence, etc.
Detecting Spatial Patterns

- Arson crimes in San Diego in 2013
  - Total 33 cases (red dots on the map)
  - Activity Area is appr. 3000 sq. miles.
  - Arsonist caught in top green ring²

![Input Map](image1)

![SaTScan output](image2)

![Significant Ring Detection](image3)

**Green:** Rings with LR >10 & p-value < 0.20

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**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**

- $LR_R = 23.02$
  - p-value = 0.04
- $LR_R = 10.61$
  - p-value = 0.18
- $LR_R = 27.74$
  - p-value = 0.01
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- LBS accessibility
- Visualization
- Volunteering (or Crowdsourcing) geo information
- Education
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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
Map Orientation and Projections

- Mapping a 3D globe on a flat 2D plane
  - https://www.youtube.com/watch?v=kIID5FDi2JQ
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Readings and Credits

Readings

› CACM Article: https://cacm.acm.org/magazines/2016/1/195727-spatial-computing/fulltext
› Supp. book, Ch. 1
› Spatial Computing Lectures: https://www.youtube.com/watch?v=ftwWfB7JWaQ&list=PLq_27Uv53bDm3hyXd5QWG-N8L4Vgvcy9J&index=1

Credits:

› Prof. Ahmed Eldawy and Prof. Mohamed Mokbel tutorial
› Prof. Shashi Shekhar book slides
  › http://www.spatial.cs.umn.edu/Book/slides/
  › http://www.edugrabs.com/components-of-dbms/