

CS225: Spatial Computing

Introduction to Spatial Computing

Amr Magdy

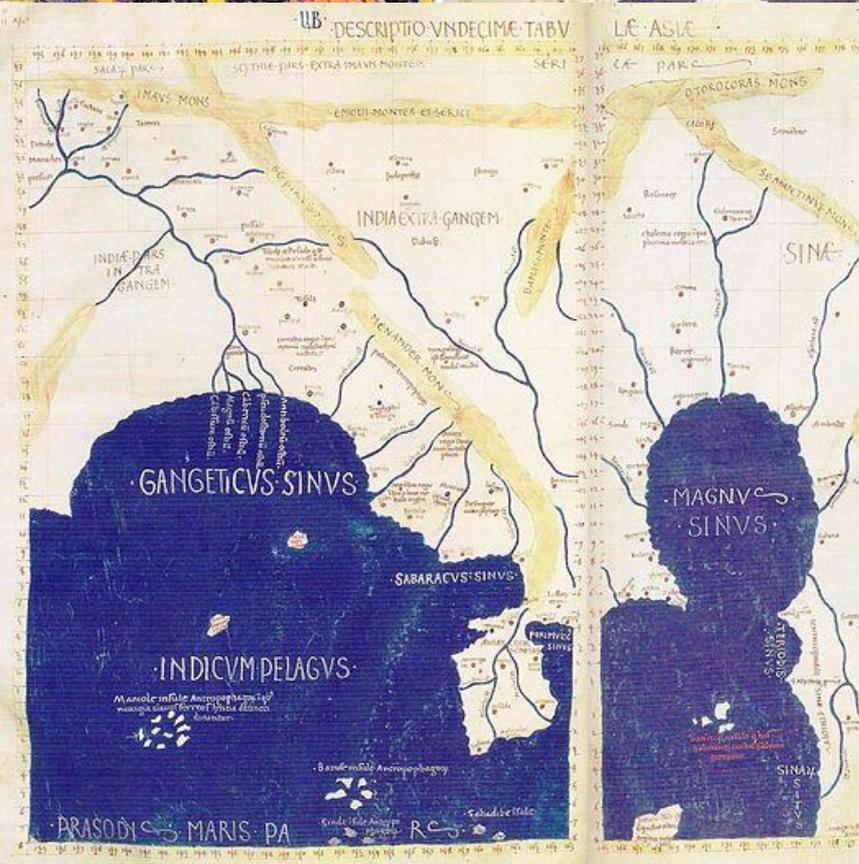
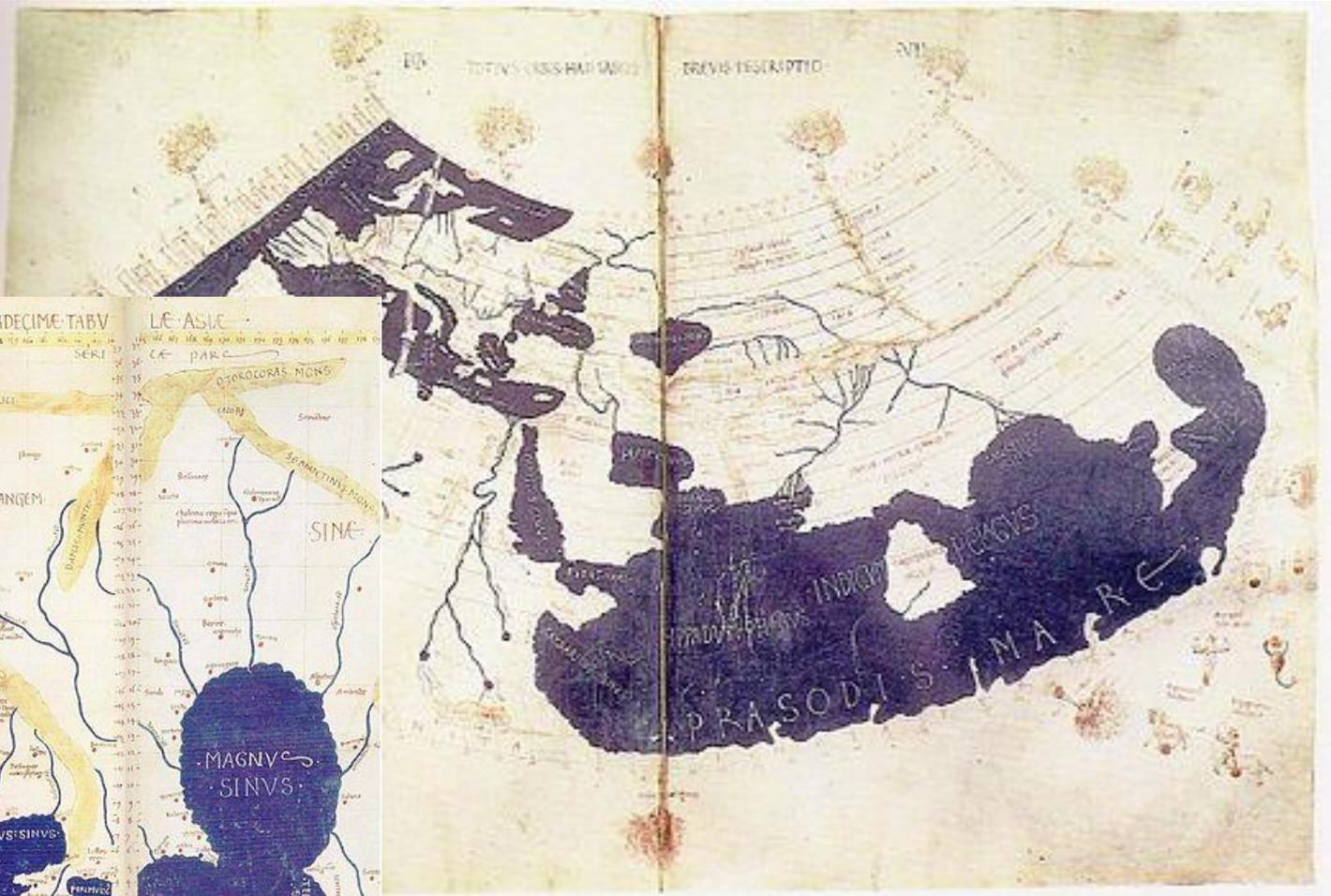
Computer Science and Engineering

www.cs.ucr.edu/~amr/

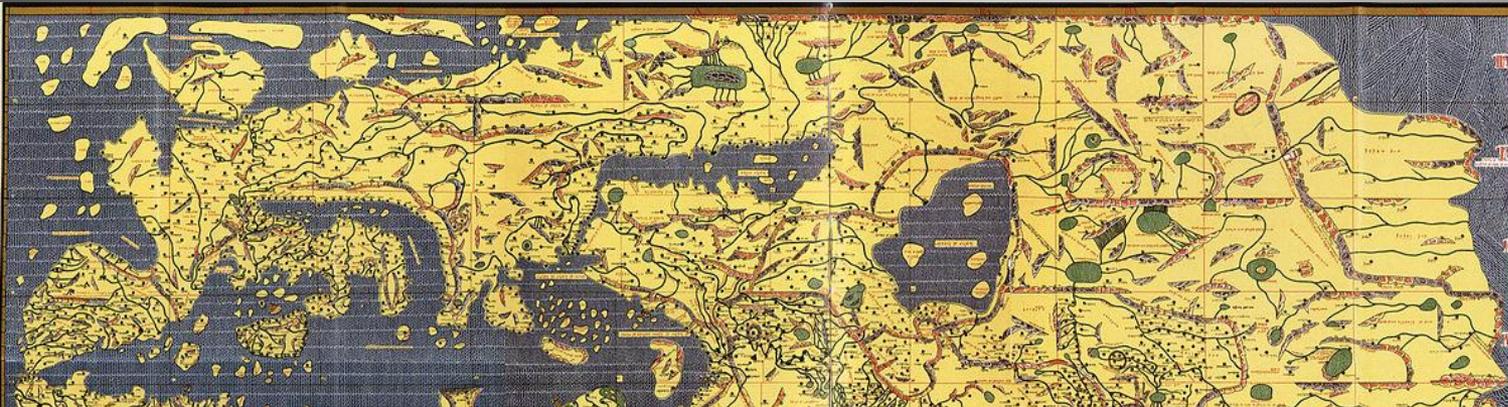
Once upon a
time...



Claudius Ptolemy (AD 90 – AD 168)

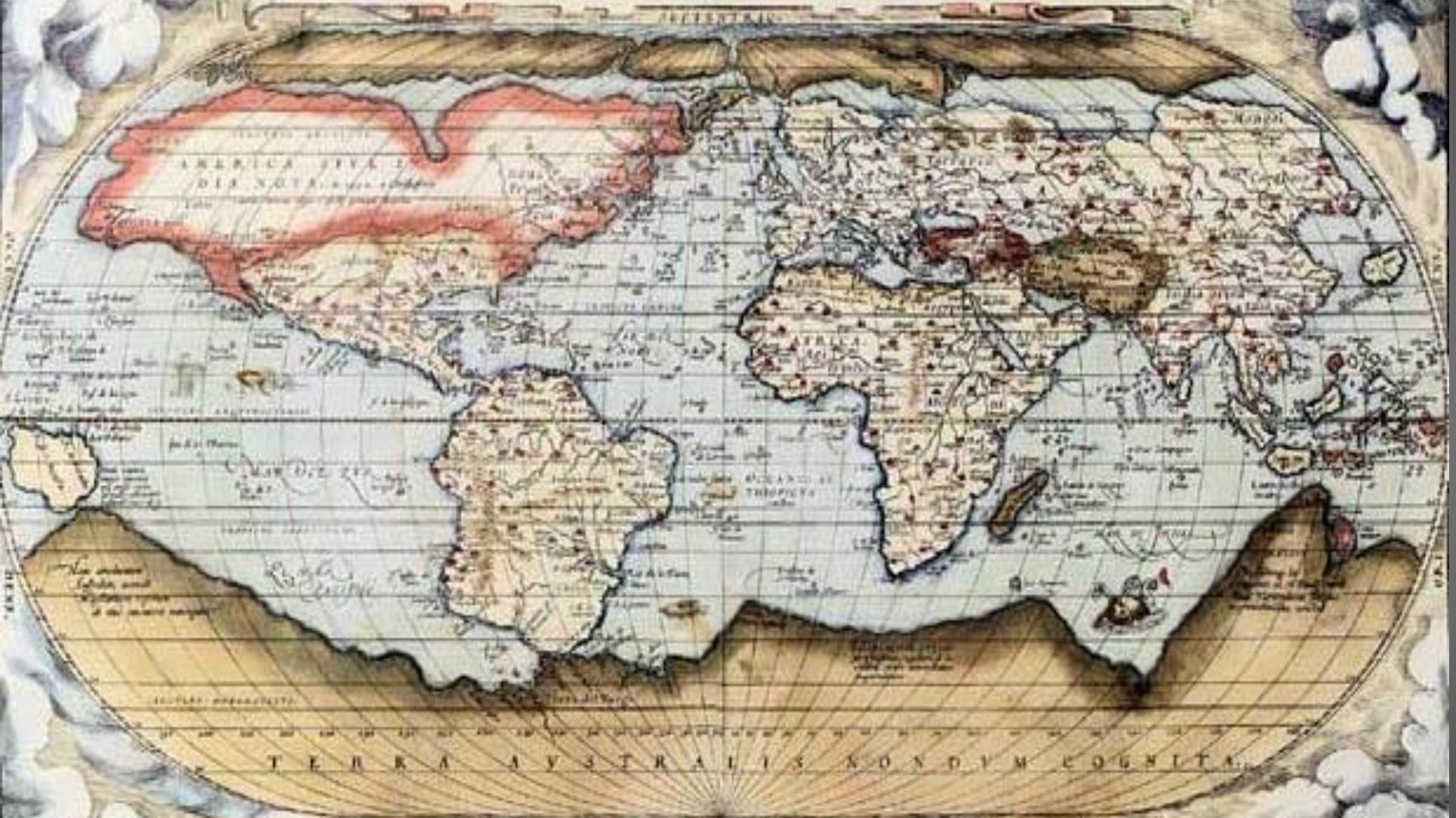


Al Idrisi (1099–1165)





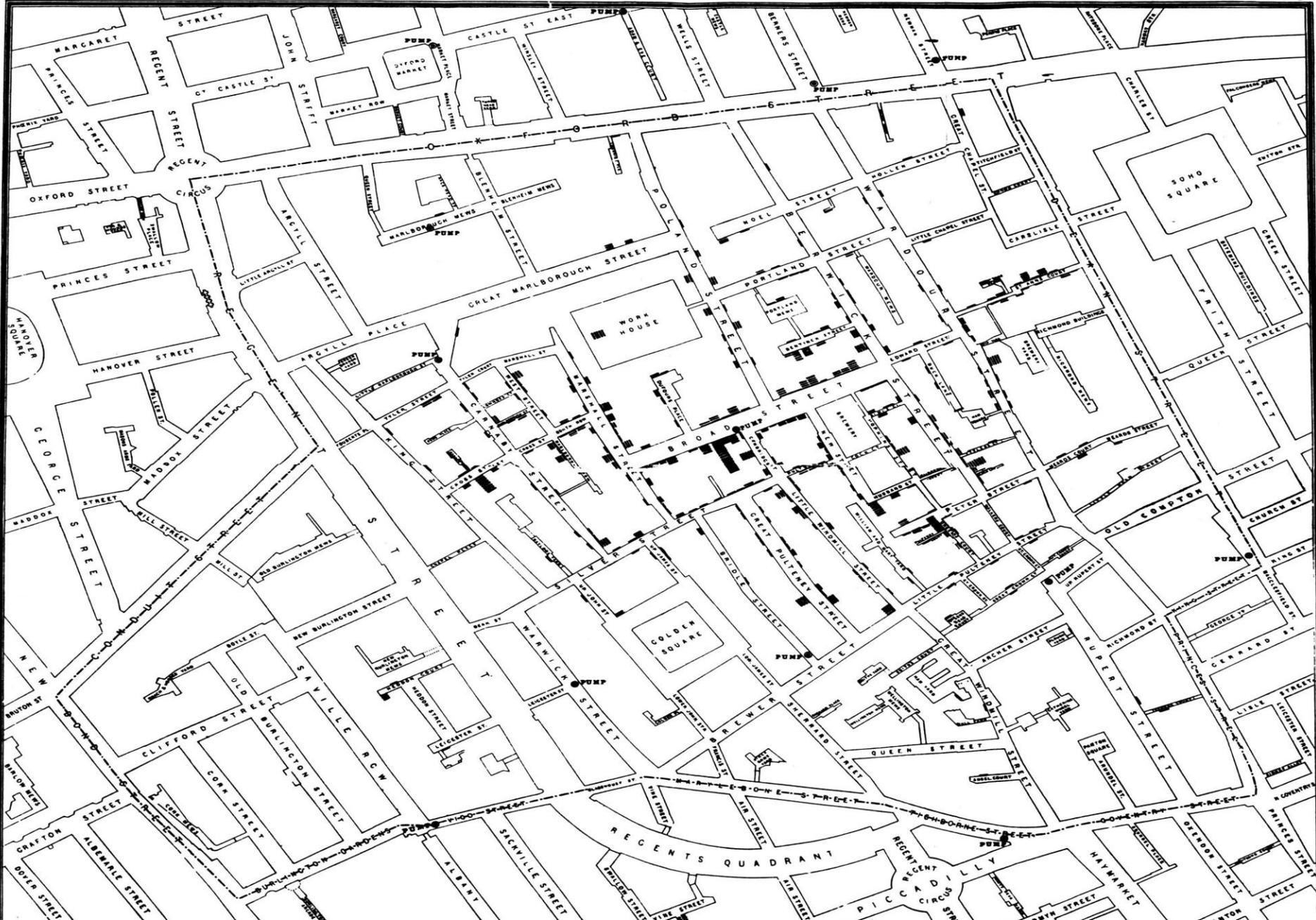
TYPVS ORBIS TERRARVM



TERRA AVSTRALIS NONDVM COGNITA

QVID EI POTEST VIDERI MAGNUM IN REBVS HVMANIS, CVI AETERNITAS OMNIS, TOTIVSQUE MVNDI NOTA SIT MAGNITVDO. CICERO:

Cholera cases in the London epidemic of 1854



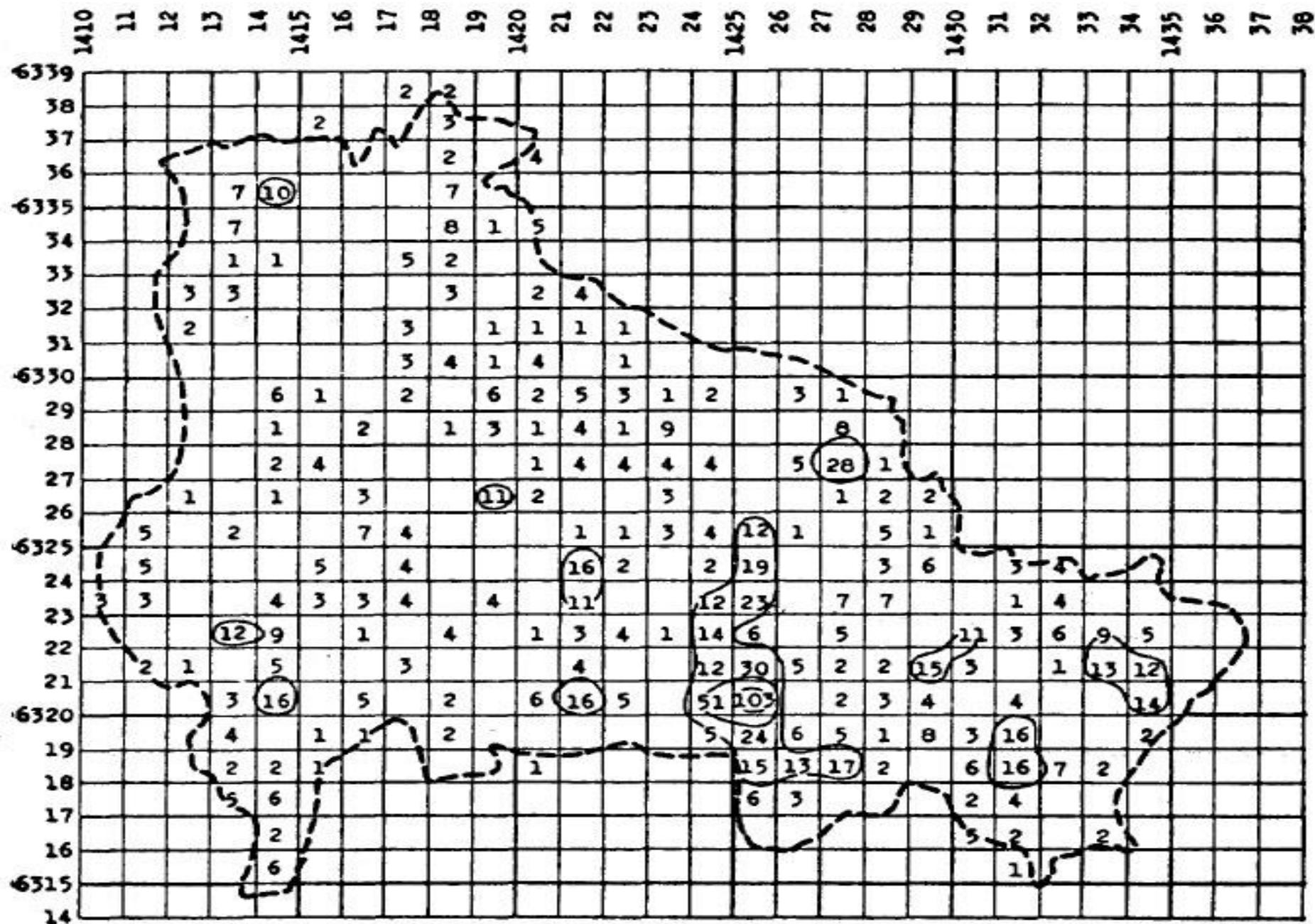


FIGURE 3—Children under 15 years of age in 1940.

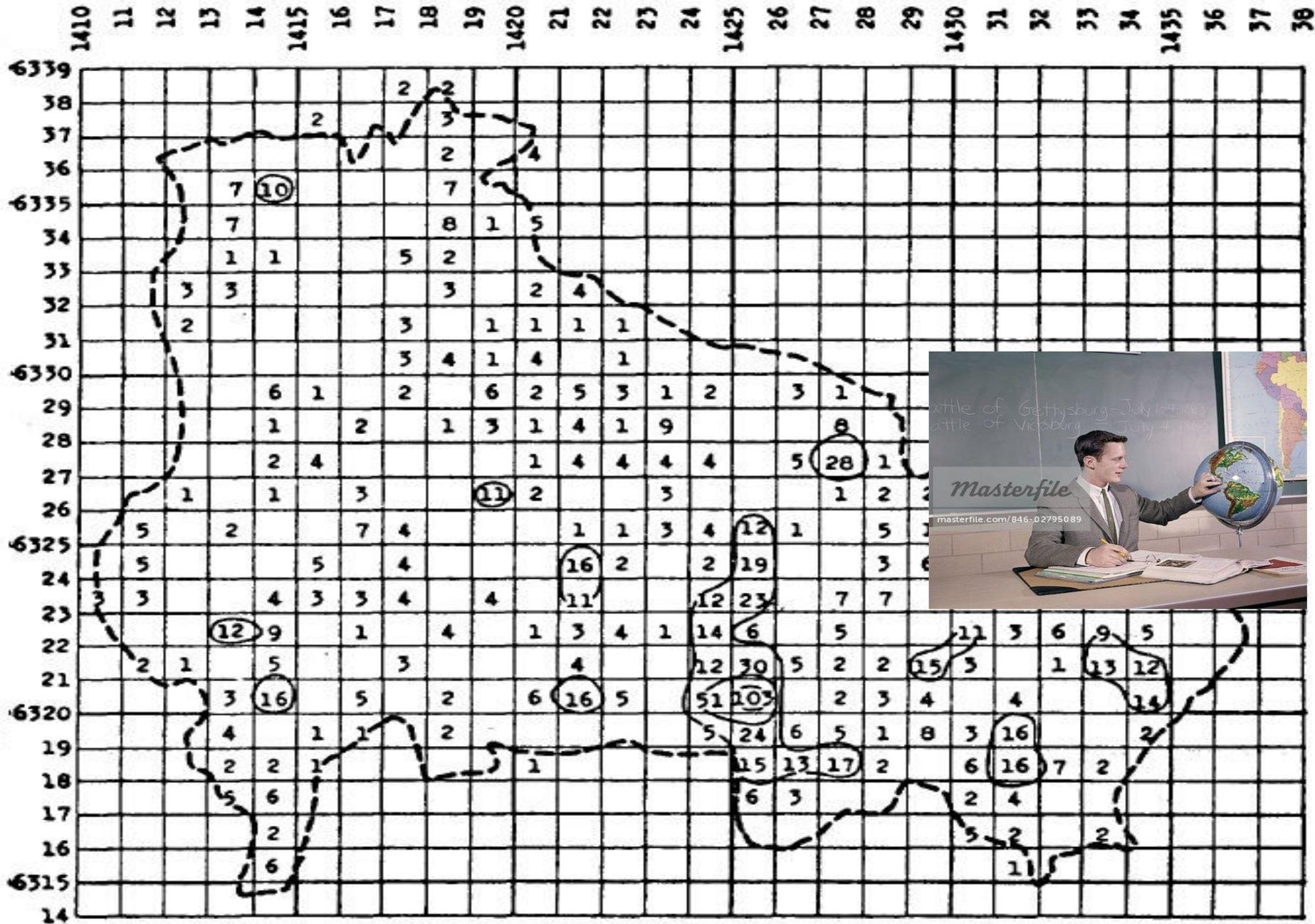
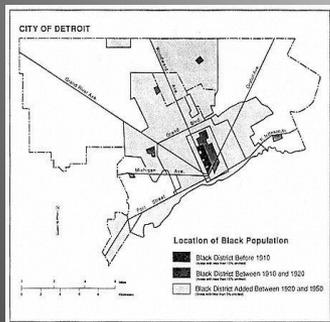
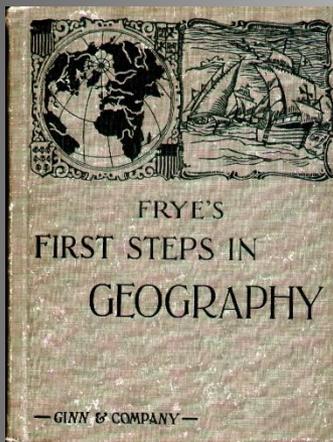


FIGURE 3—Children under 15 years of age in 1940.

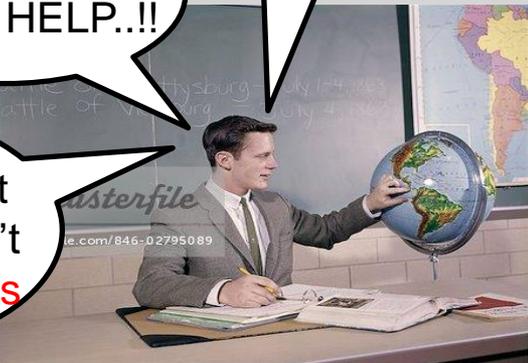




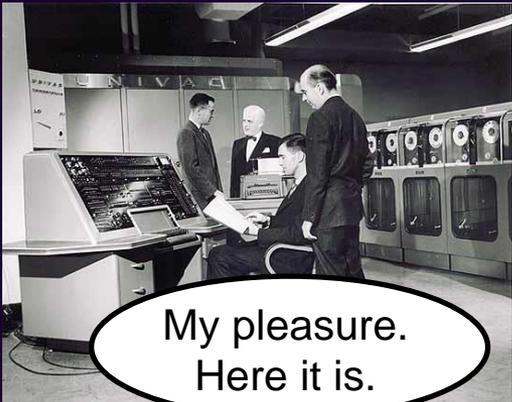
Cool **computer** technology..!!
Can I use it in my application



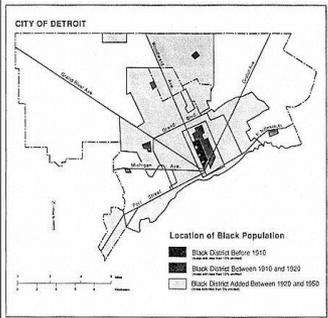
I have **BIG** data.
I need **HELP**..!!



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

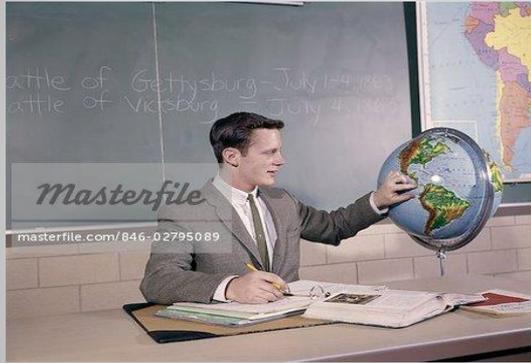


My pleasure. Here it is.



masterfile.com/846-02793618

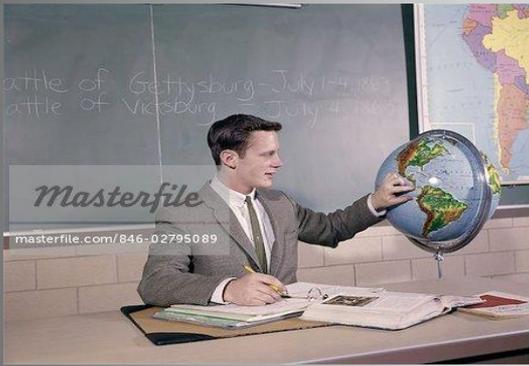




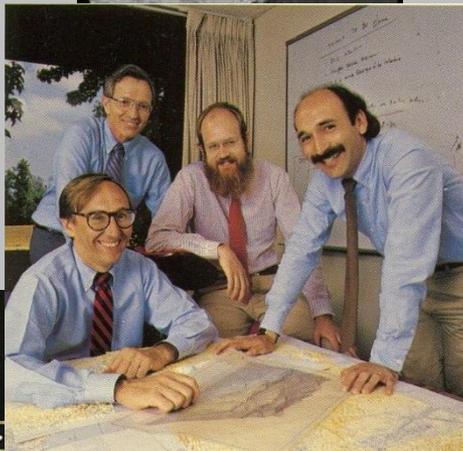
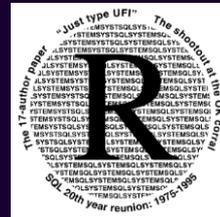
Kindly let me understand your needs

1969

Kindly let me get the technology you have



ESRI



DATABASE MANAGEMENT SYSTEMS



Informix

SQL



ESRI



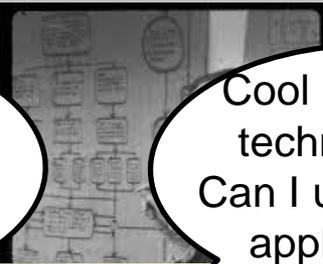
AIRLINE BOOKING



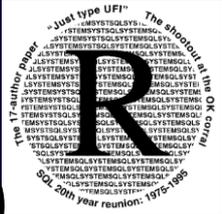
Banking



mmm...Let me check with my good friends there.



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



My pleasure. Here it is.

HELP..!! I have **BIG** data. Your technology is not helping me



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Informix

SQL



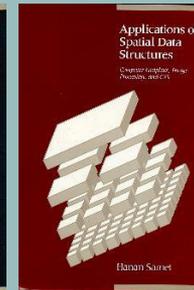
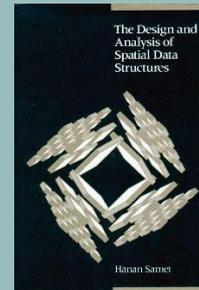
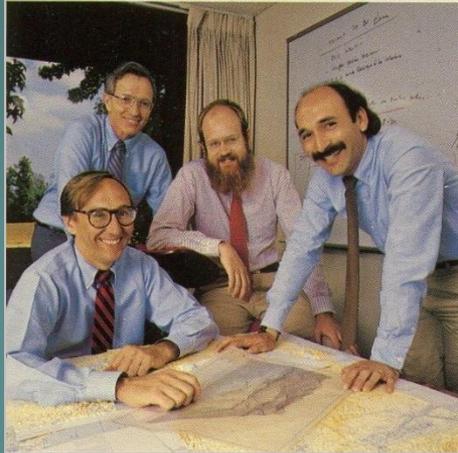
ESRI

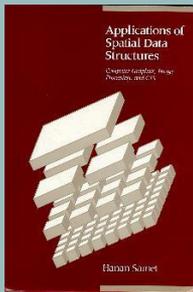
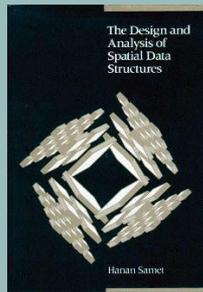
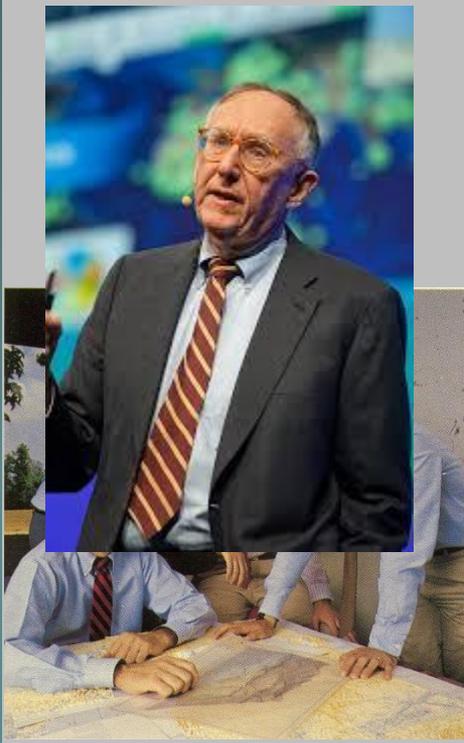


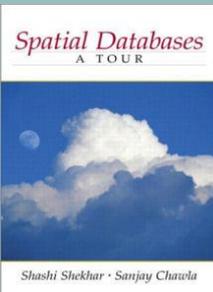
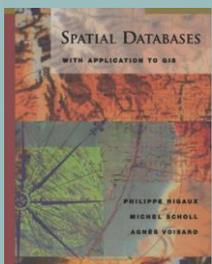
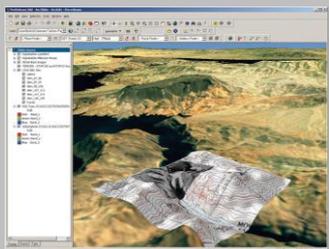
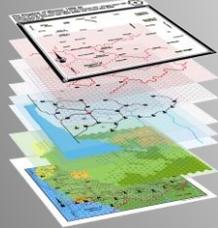
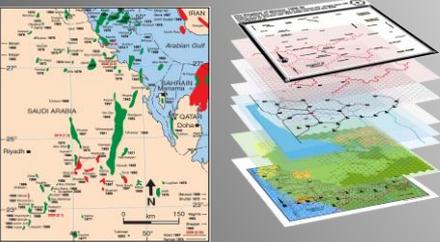
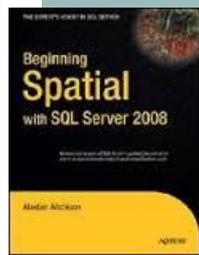
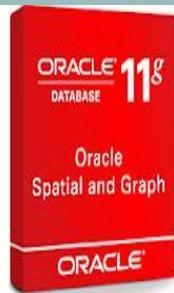
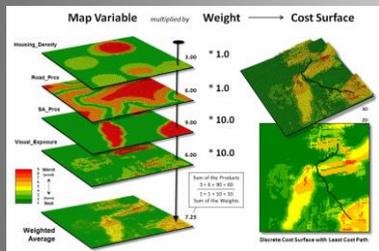


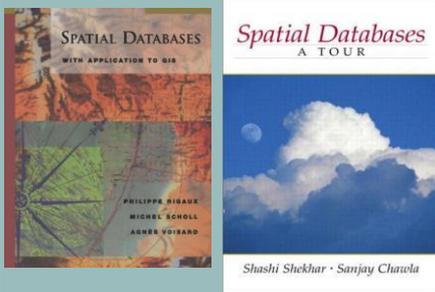
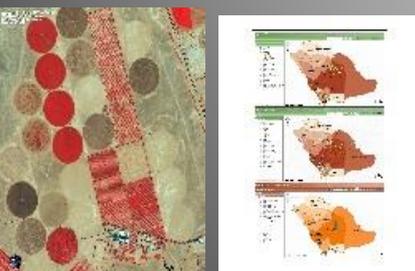
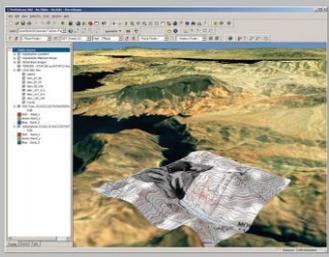
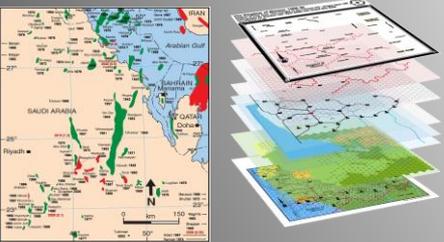
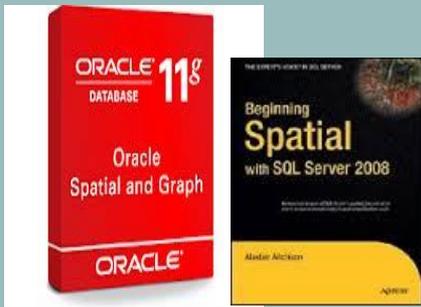
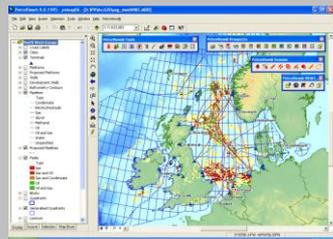
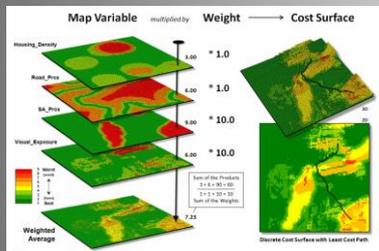
Kindly let me understand your needs

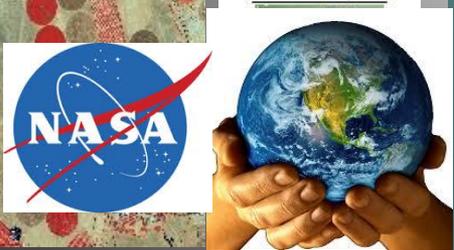
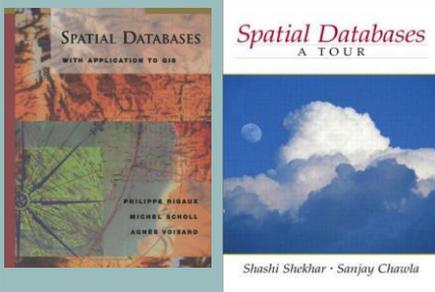
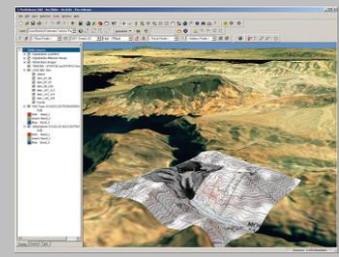
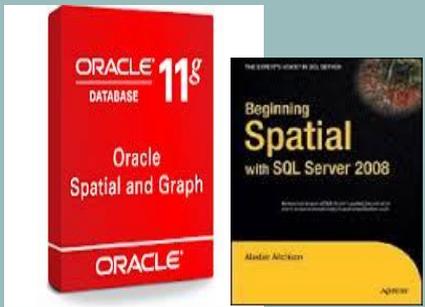
Kindly let me get the technology you have











Let me check with my **other** good friends there.

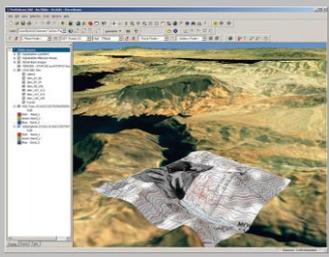
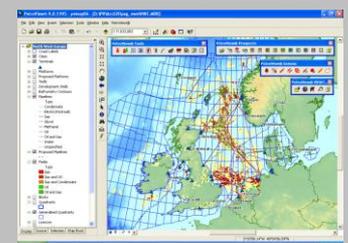
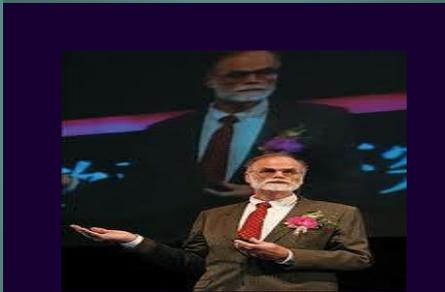
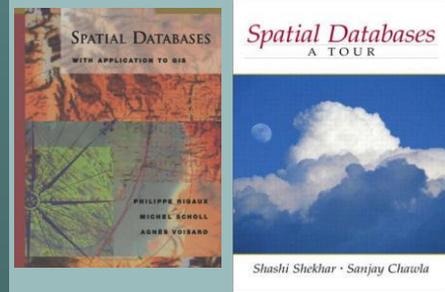
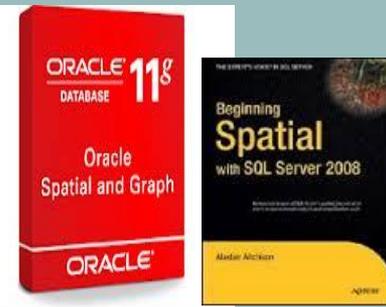
Cool **Big Data** technology..!!
Can I use it in my application?

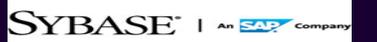
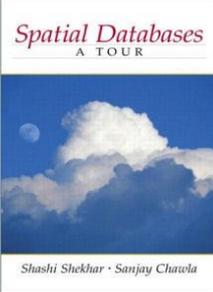
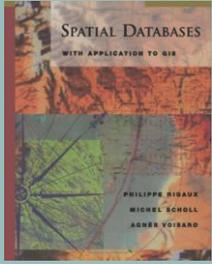
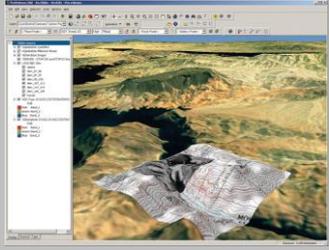
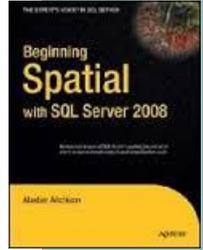
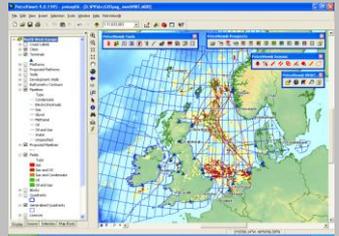
My pleasure.
Here it is.

HELP..!! Again,
I have **BIG** data.
Your technology is
not helping me

Sorry, seems like
the DBMS
technology cannot
scale more

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



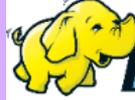




Kindly let me understand your needs

facebook  MapReduce

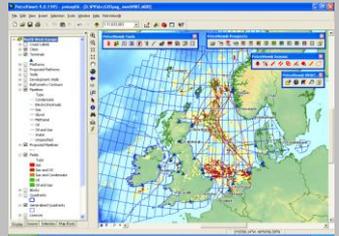
 amazon web services™ EC2

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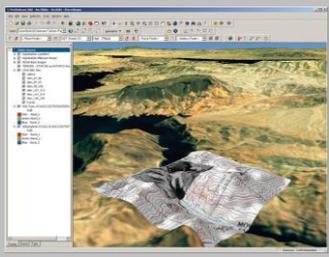
cloudera® IMPALA Spark 



 ArcGIS
ESRI



PostGIS
Geospatial Objects for PostgreSQL 



ORACLE 11g
DATABASE
Oracle Spatial and Graph
ORACLE

Beginning Spatial
with SQL Server 2008
Mehmet Akhavan

ORACLE®

IBM DB2

Microsoft SQL Server



idrisi  

SPATIAL DATABASES
WITH APPLICATION TO GIS
PHILIPPA ZIOGAK
MIRIAM SARGAL
ANDRÉ VOISARD

Spatial Databases
A TOUR
Shashi Shekhar - Sanjay Chavala

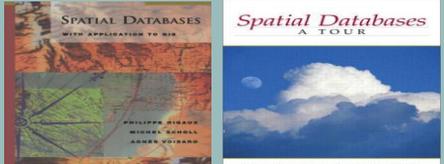
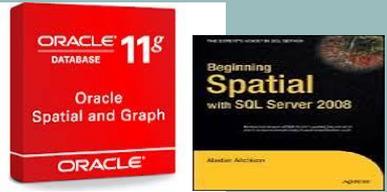
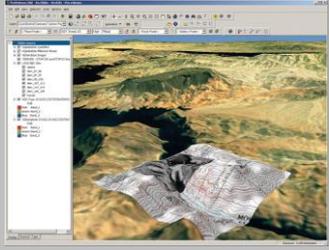
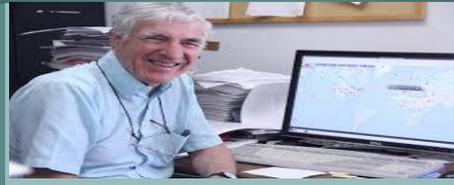
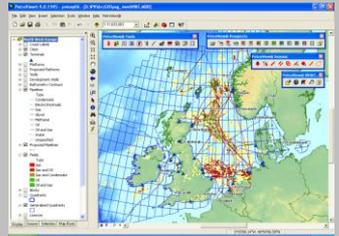
 PostgreSQL
the world's most advanced open source database

MySQL

SYBASE™ | An SAP Company



The Era of Big Spatial Data



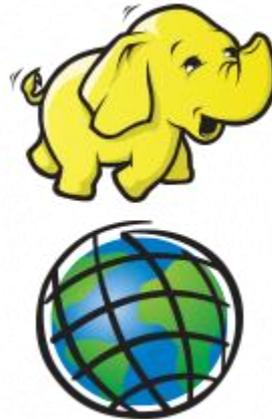
The Era of Big Spatial Data

Recent products are there....



GeoSpark

The GeoSpark logo consists of the word "GeoSpark" in a bold, black, sans-serif font. The letter "o" in "Geo" is replaced by a small globe icon.



Hadoop-GIS

Spatial Big Data Solutions

The Hadoop-GIS logo features the text "Hadoop-GIS" in a grey, sans-serif font, with the tagline "Spatial Big Data Solutions" in a green, italicized, sans-serif font below it.



What is Spatial Computing?



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- › A field that innovates a set of technologies and techniques to combine spatial information with computing technologies

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 - ▶ [tentative] → emerging definition and field
 - ▶ Technologies could be software, hardware, or both

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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?



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(McKinsey Global Institute, 2011 report on Big Data)

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Table I. 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)

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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)

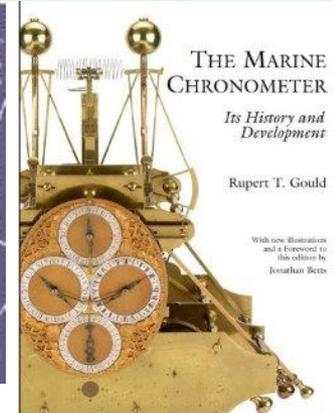
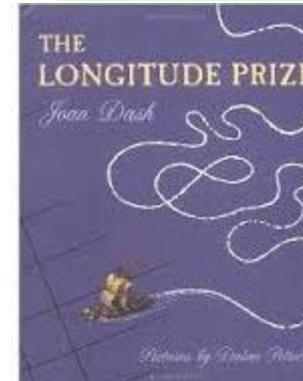
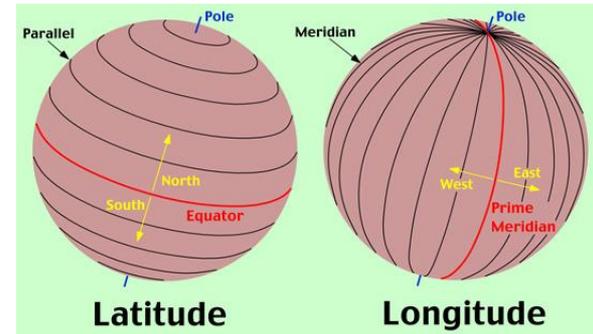
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Global Positioning Systems (GPS)

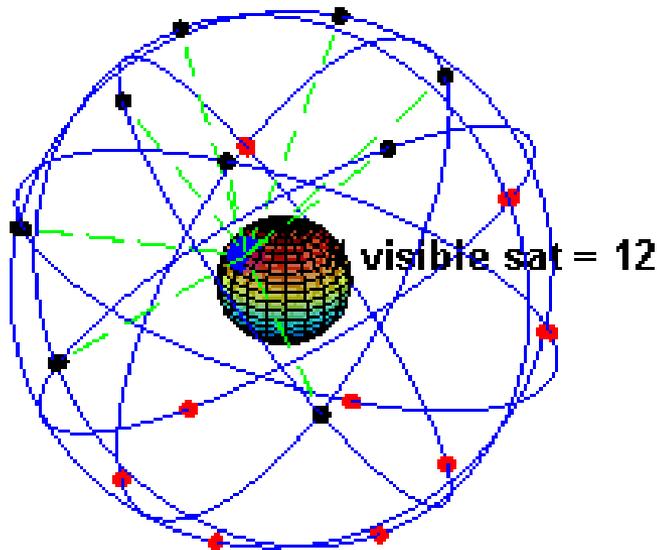
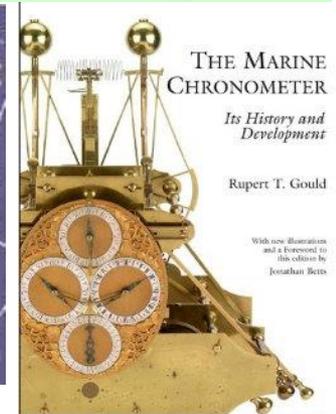
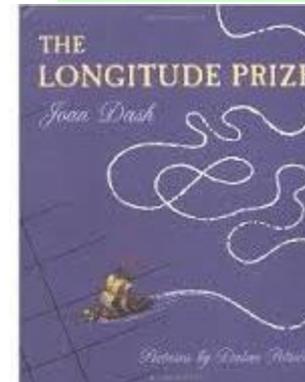
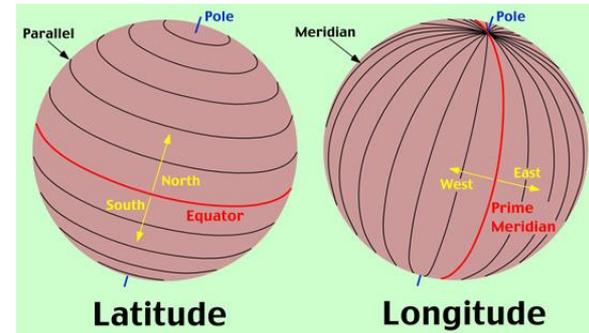
- › Positioning ships
 - › Latitude (compass, star positions) → ancient and medieval civilizations
 - › Longitude Prize (1714) → marine chronometer



Global Positioning Systems (GPS)

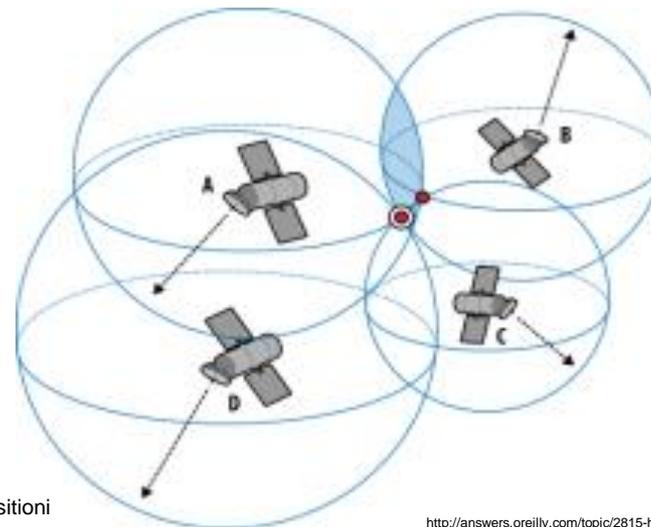
- › Positioning ships
 - › Latitude f(compass, star positions) → ancient and medieval civilizations
 - › Longitude Prize (1714) → marine chronometer

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

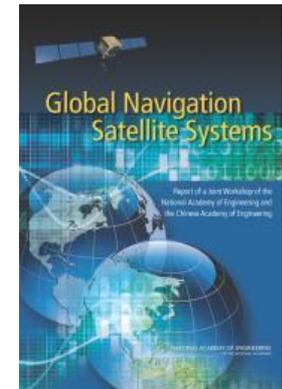


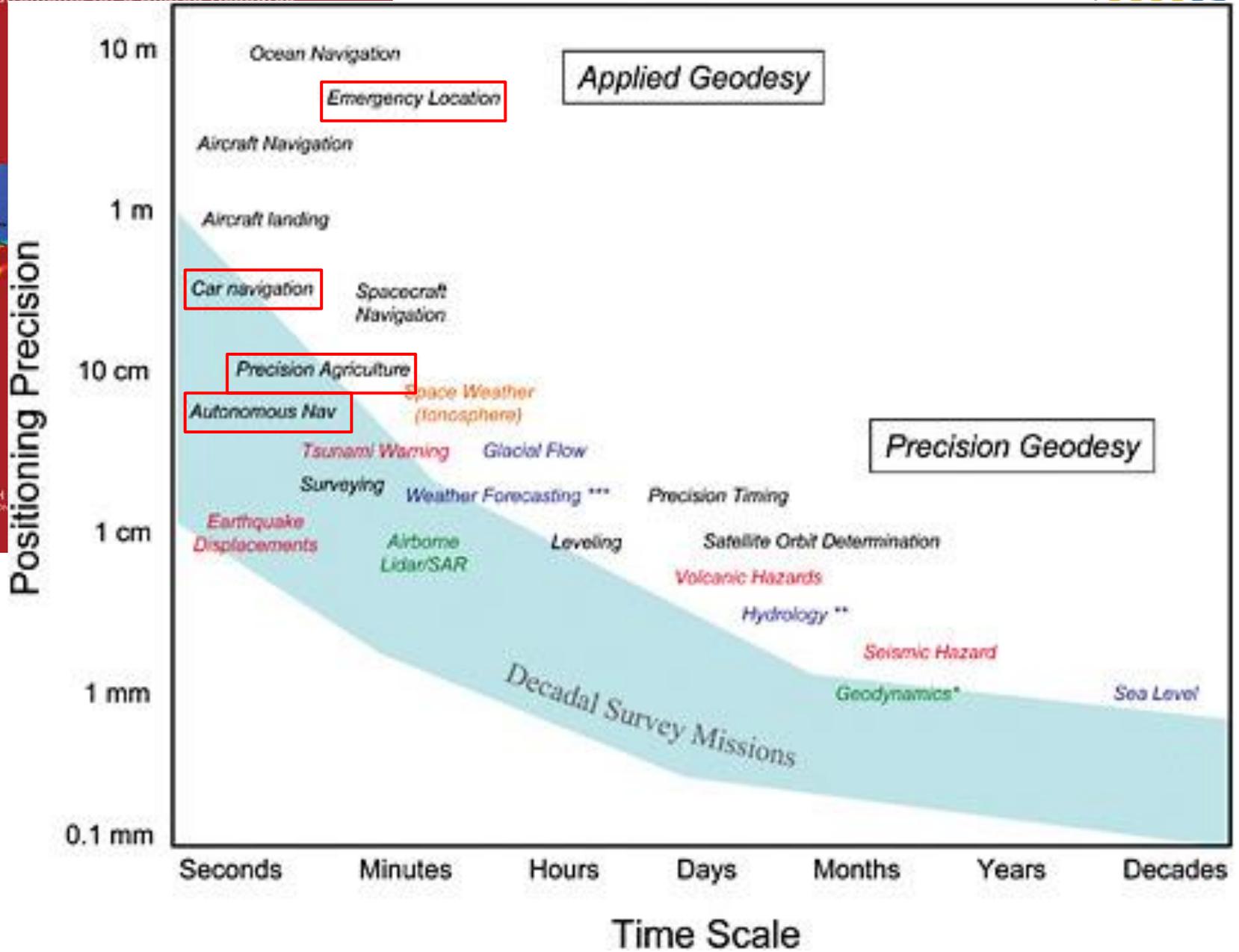
http://en.wikipedia.org/wiki/Global_Positioning_System

Trilateration



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





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 | #6 RECOMMENDED ACTIVITIES |
| #2 YOUR CURRENT LOCATION | #7 PEOPLE FLOW OPTIMISATION |
| #3 FIND [ANY SERVICE] | #8 LOCATION BASED NOTIFICATIONS |
| #4 ESTIMATED WALKING TIMES | #9 LOCATION BASED OFFERS |
| #5 QUEUE MANAGEMENT | #10 FIND CUSTOMER SERVICE |



Get In-Store Notifications



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 - › Blue Tooth, Wi-Fi, ...

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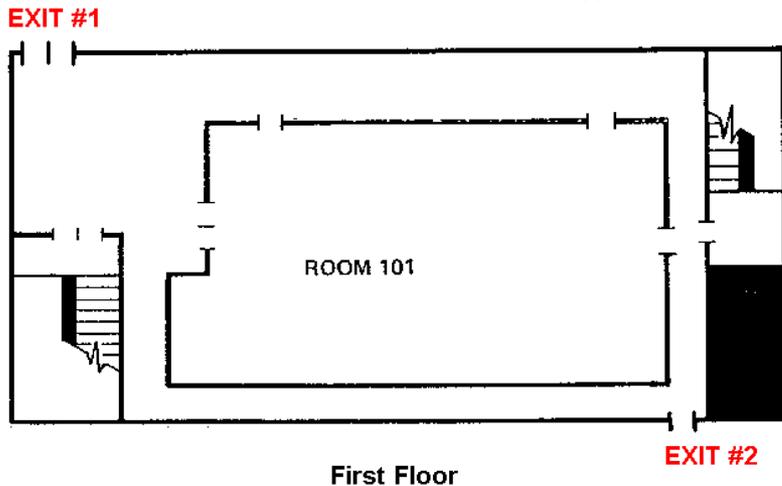
<http://www.mobilefringe.com/products/square-one-shopping-center-app-for-iphone-and-android/>

- › 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 ?



Get In-Store
Notifications

WiFi Localization



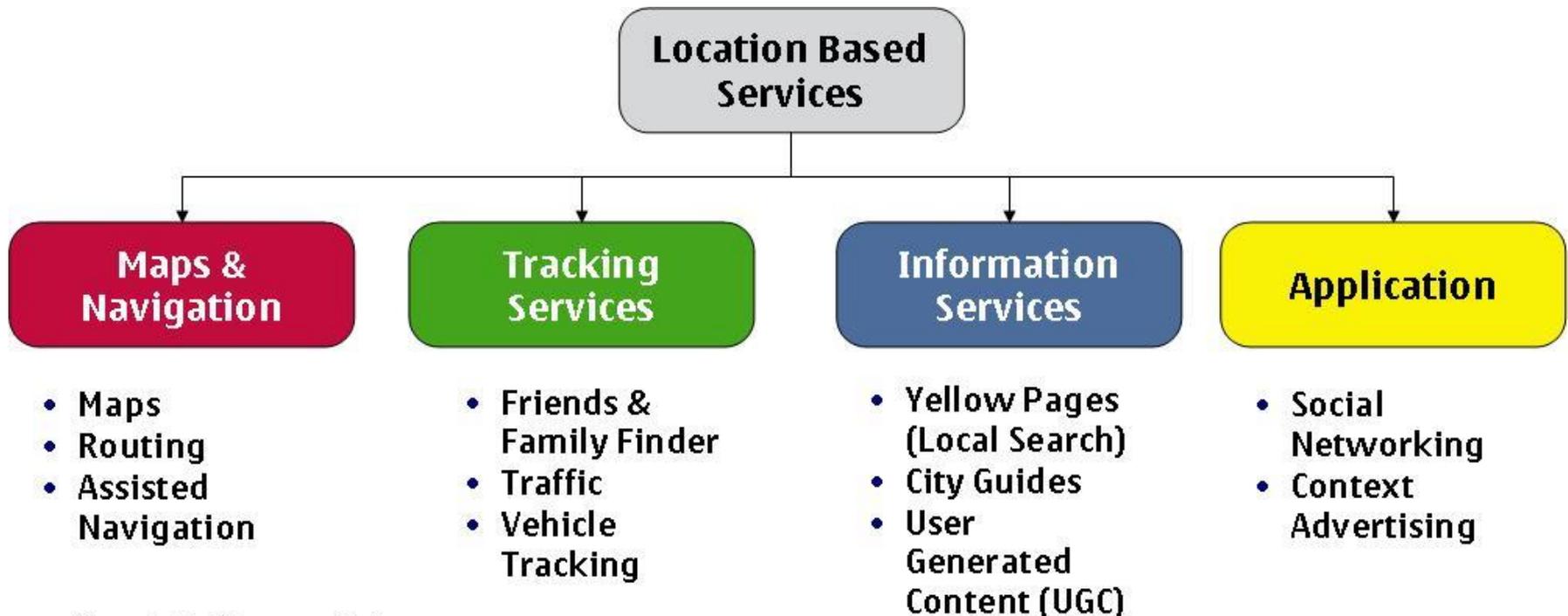
Major technologies and areas (past, present, & future)



- › 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)

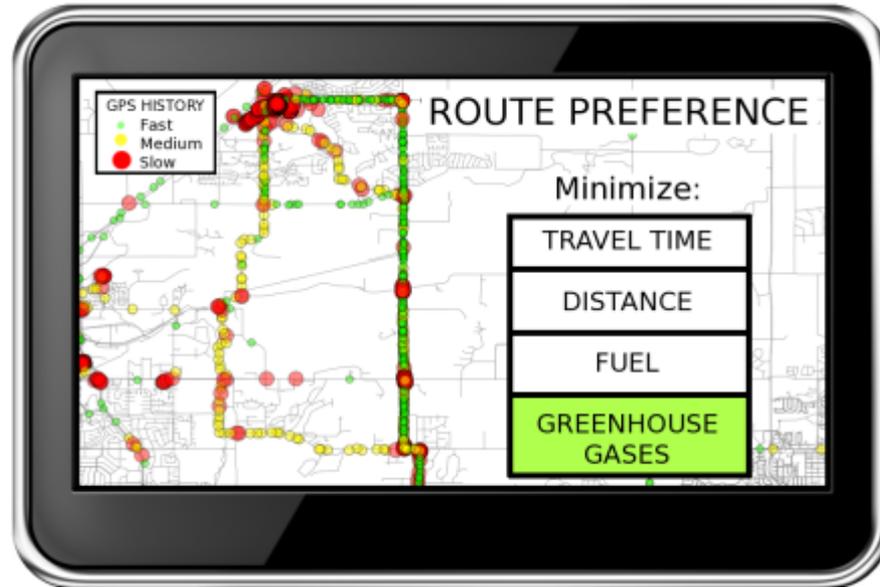
Location Based Services

- › 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



UCR



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

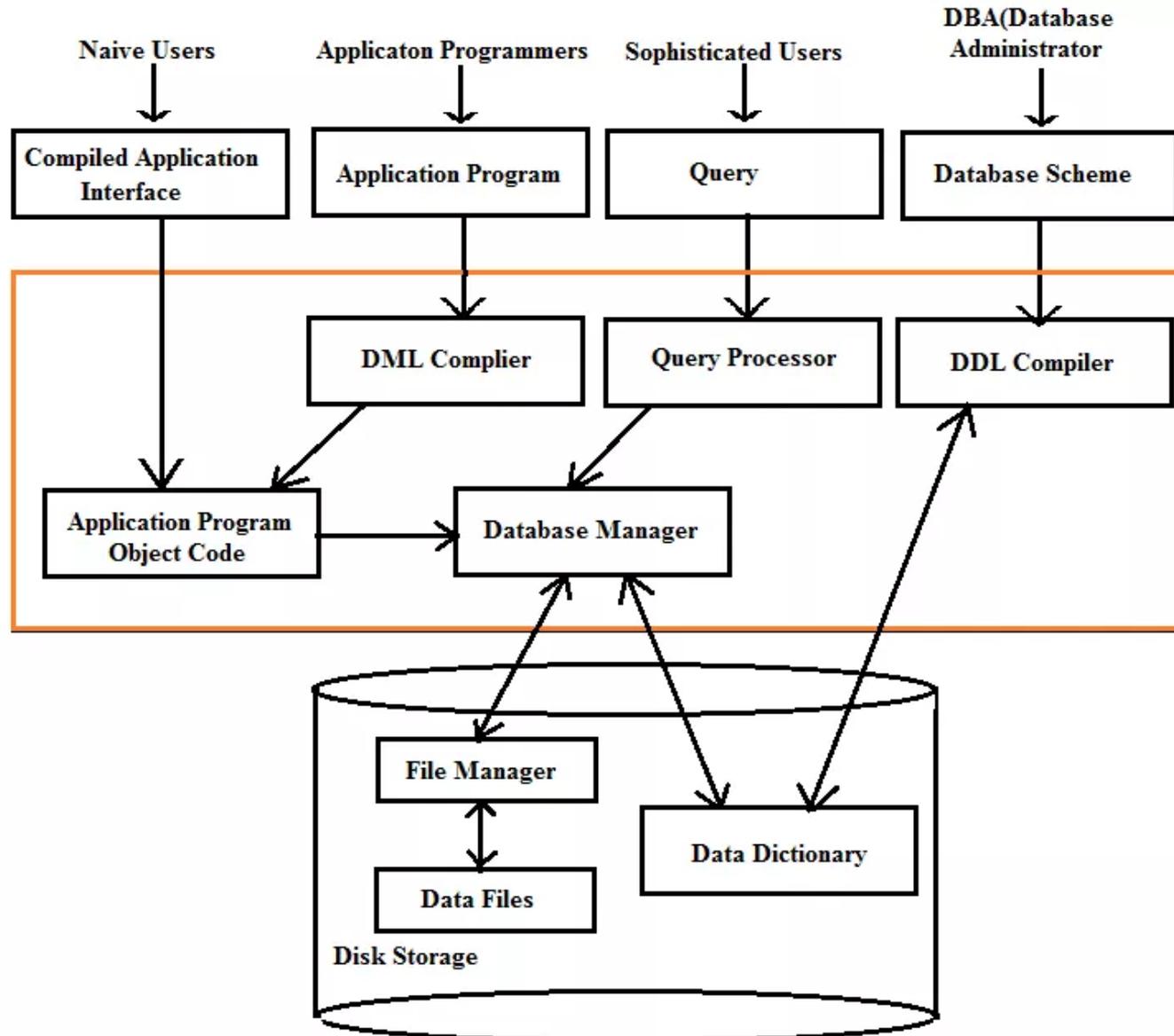


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Database Management Systems (DBMSs)



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

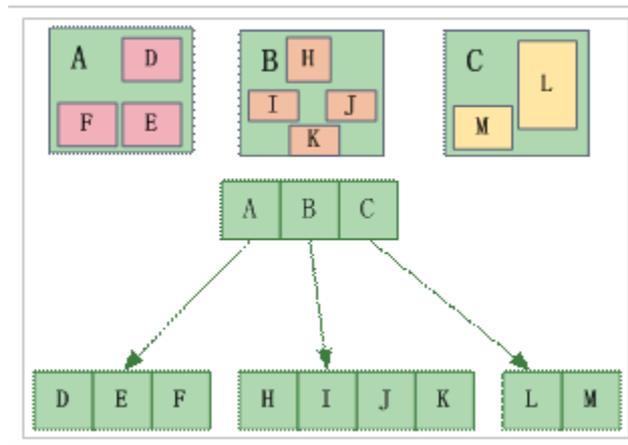
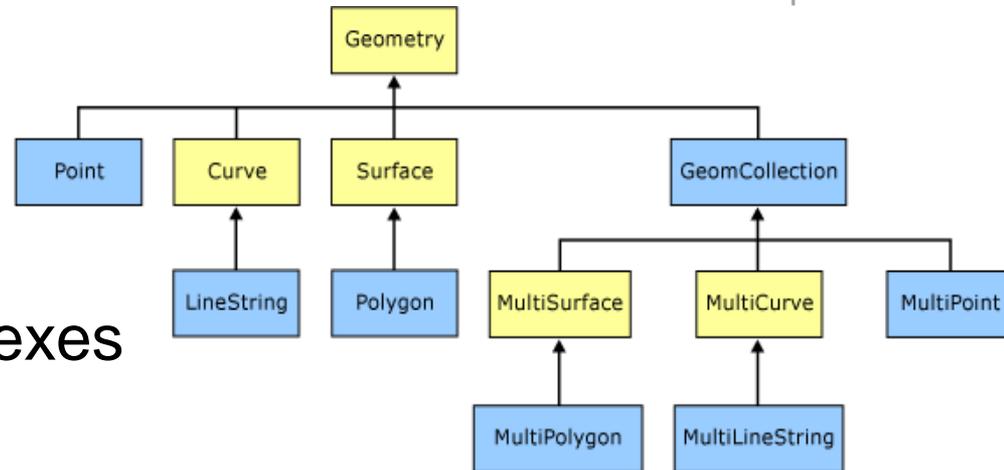


- › Non-spatial queries
 - › List the names of all bookstore with more than ten thousand titles
 - › List the names of ten customers, in terms of sales, in the year 2001

- › 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:

```
create table census_blocks (
```

```
name          string,
```

```
area          float,
```

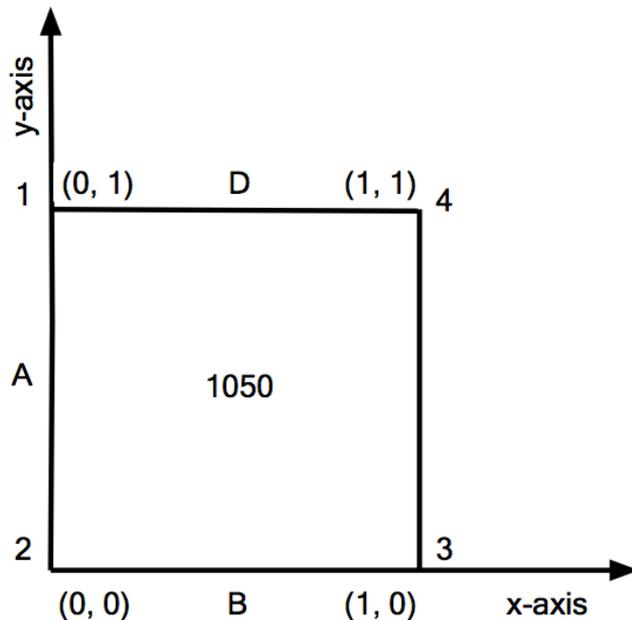
```
population    number,
```

```
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

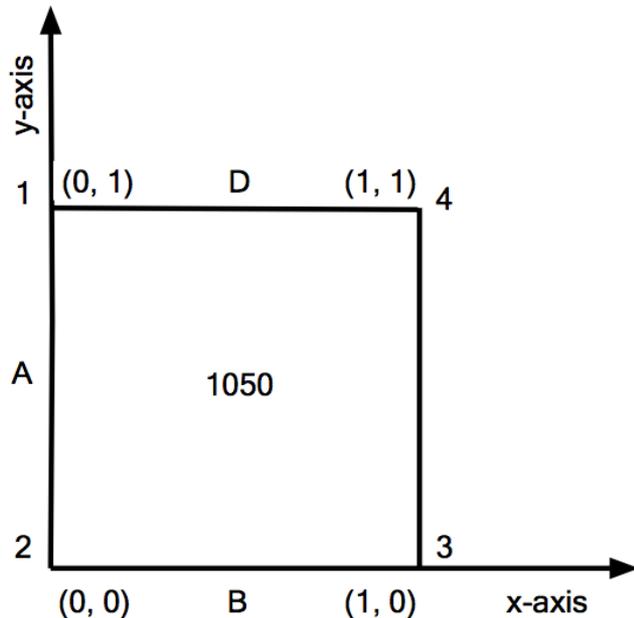


Census_blocks

Name	Area	Population	Boundary
1050	1	1839	Polyline ((0,0), (0,1), (1,1), (1,0))

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
- › Query: `Select * FROM census_blocks C, factory F WHERE Overlap(C.boundary, F. boundary)`



Census_blocks

Name	Area	Population	Boundary
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Spatial beyond Databases



- › Distributed systems
 - › Hadoop, Spark, Impala, ...etc

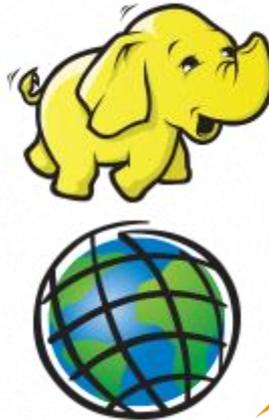
Spatial beyond Databases



GeoSpark



rasdaman
raster data manager



Hadoop-GIS
Spatial Big Data Solutions



geomesa



GeoTrellis



Challenges: Privacy vs. Utility



- › Check-in risks: Stalking, GeoSlavery, Others know that you are not home, etc

Challenges: Privacy vs. Utility

- ▶ Check-in risks: Stalking, GeoSlavery, Others know that you are not home, etc
- ▶ 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](#))



Challenges: Security vs. Utility

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GPS

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**

Alex Hern



Challenges: Security vs. Utility

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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?

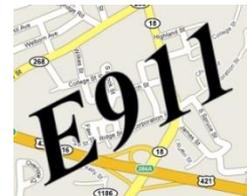
Challenges: Security vs. Utility

- ▶ Important questions:
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 - ▶ Policy Makers

Challenges: Security vs. Utility



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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

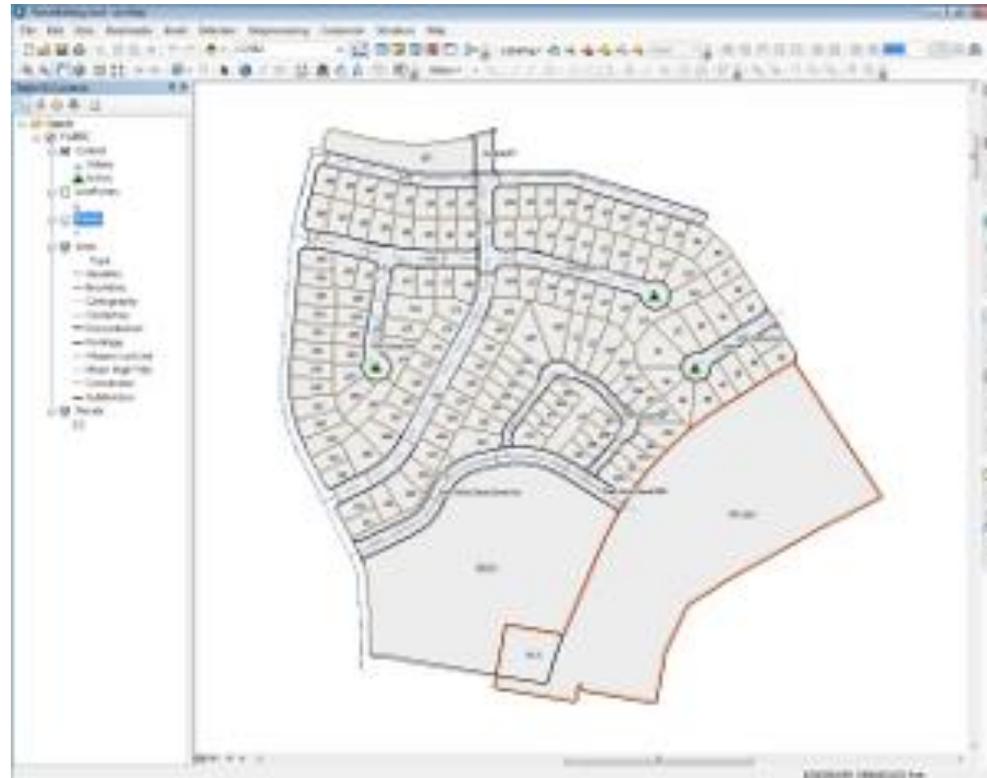
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Geographic Information Systems (GIS)

- 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?



How different GIS from SDBMS?



- › GIS uses SDBMS to store, search, and query spatial data

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

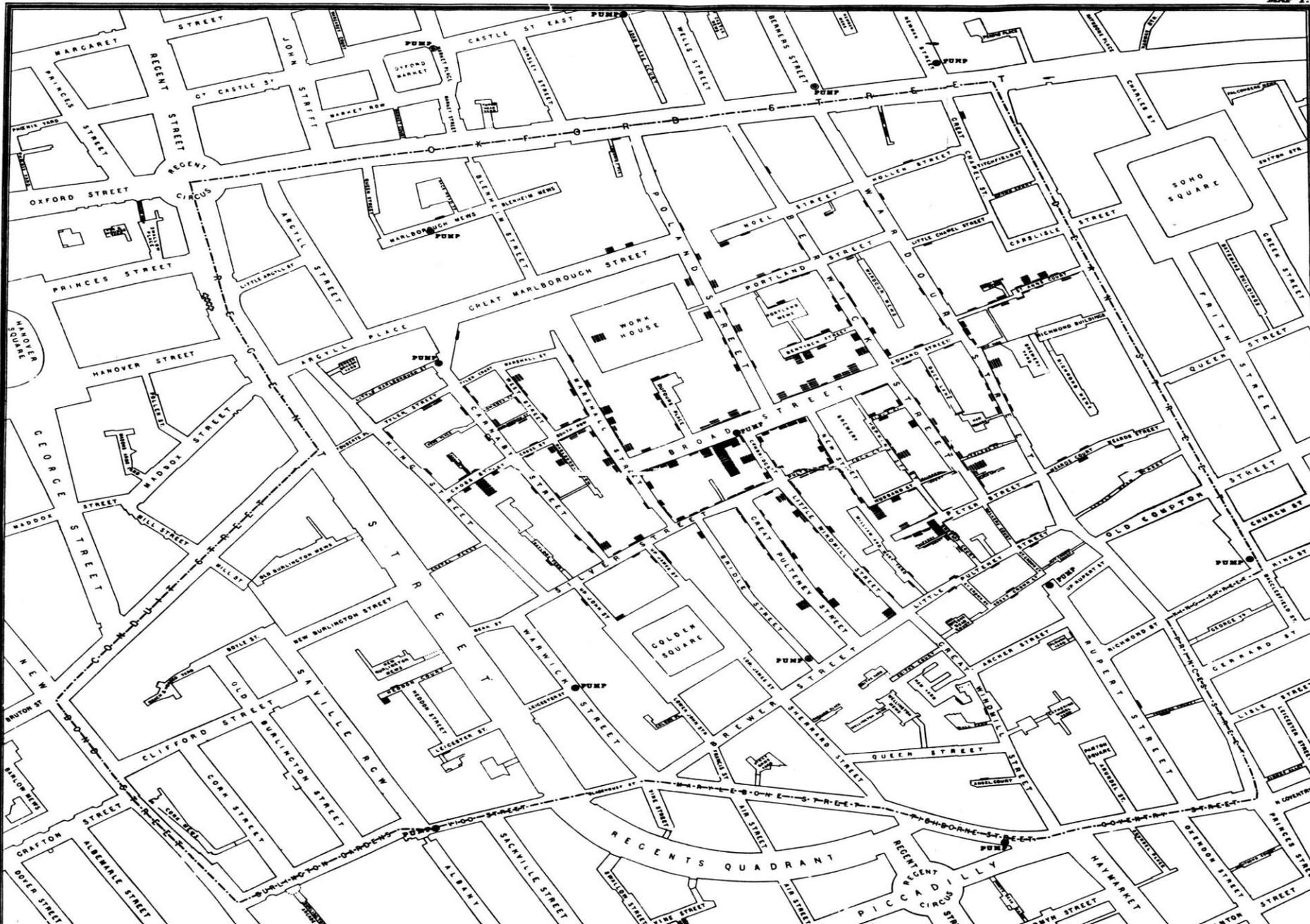
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Cholera cases in the London epidemic of 1854

MAP 1.

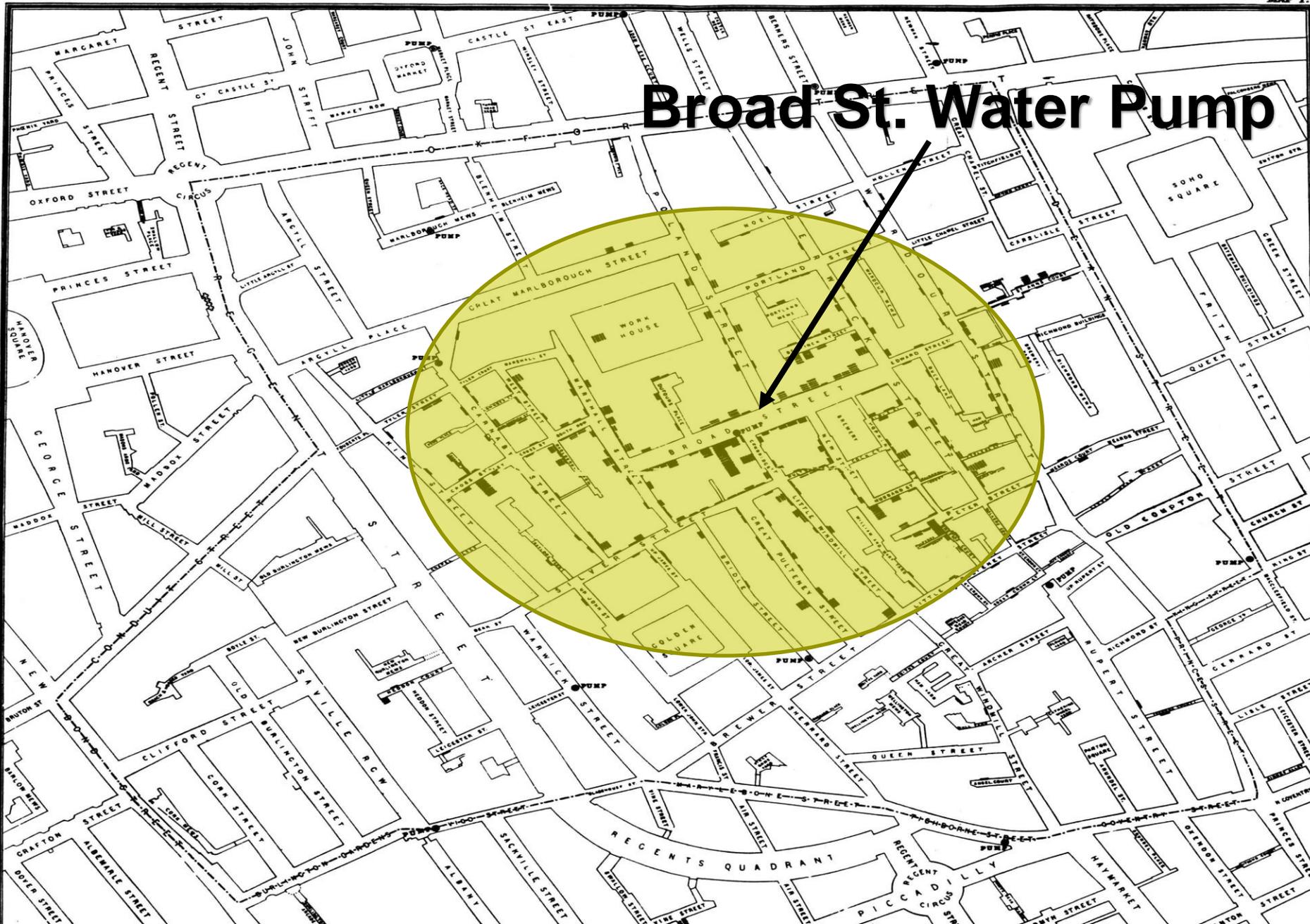


Cholera cases in the London epidemic of 1854



Cholera cases in the London epidemic of 1854

MAP 1.



Broad St. Water Pump

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

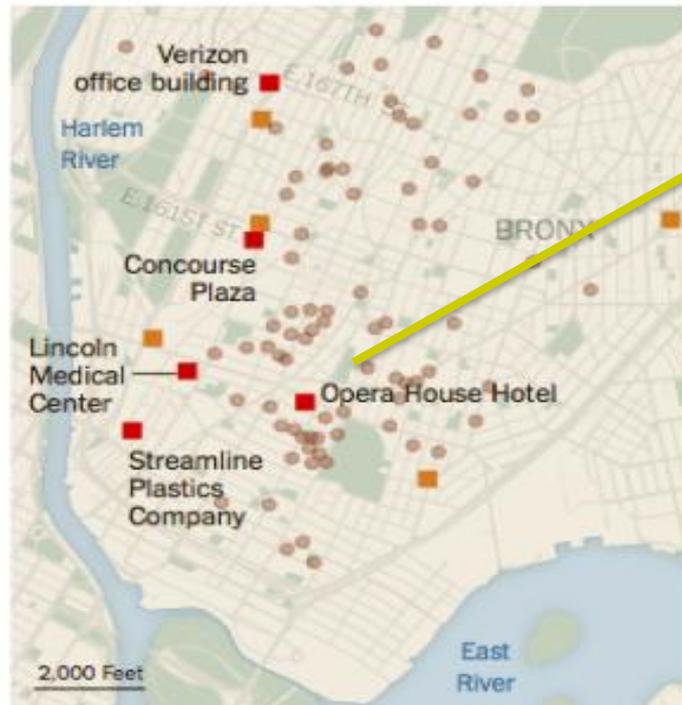
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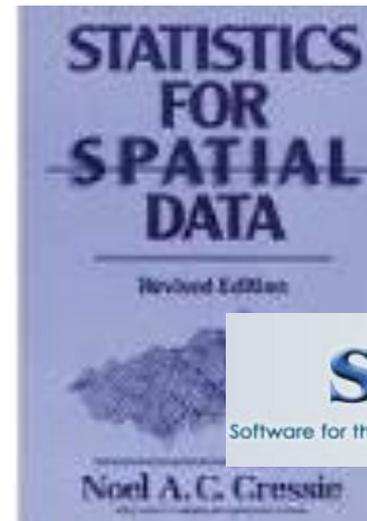
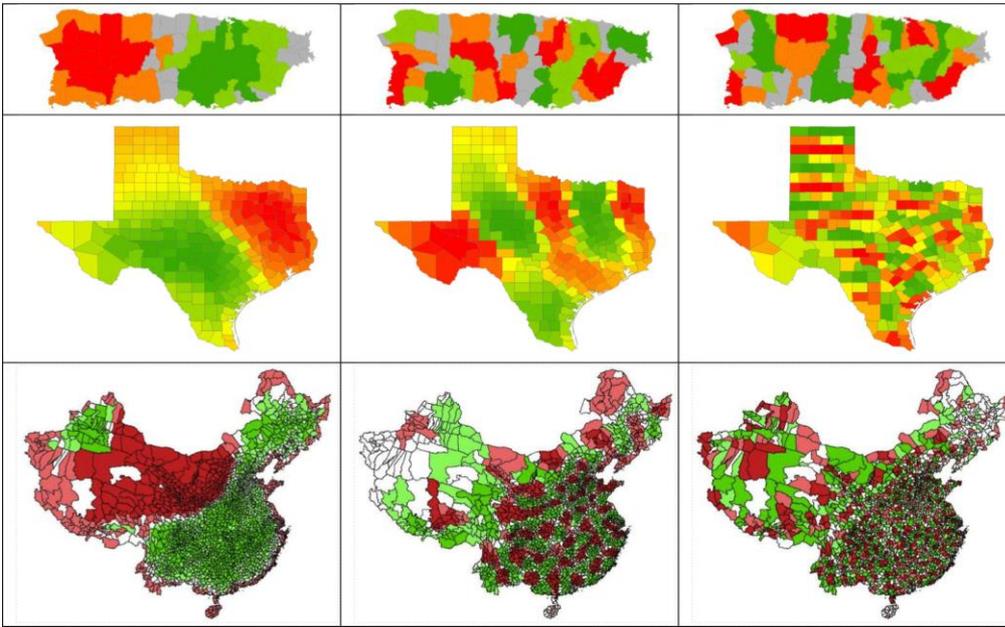
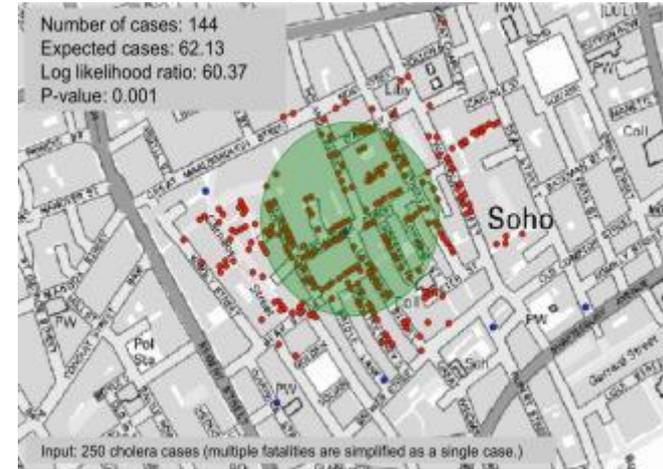
By The New York Times



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

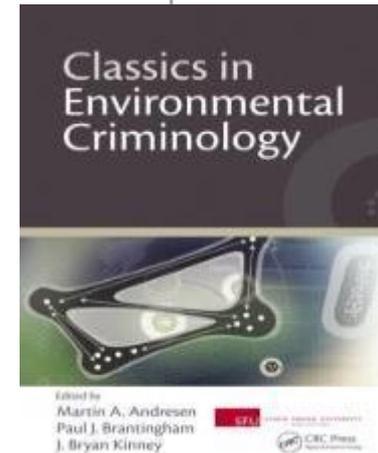
Spatial Statistics

- › 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

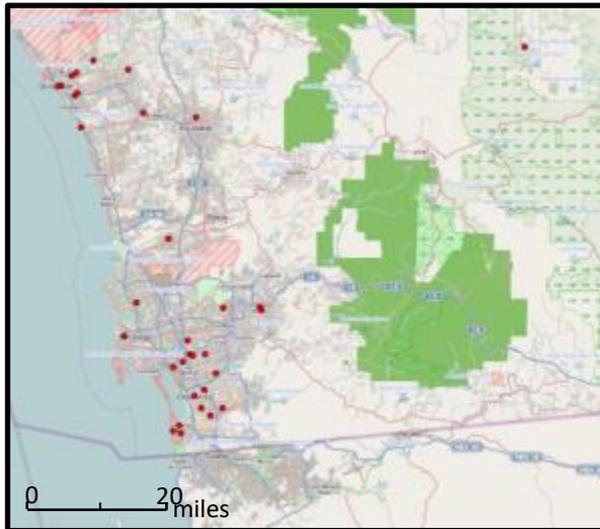


Detecting Spatial Patterns

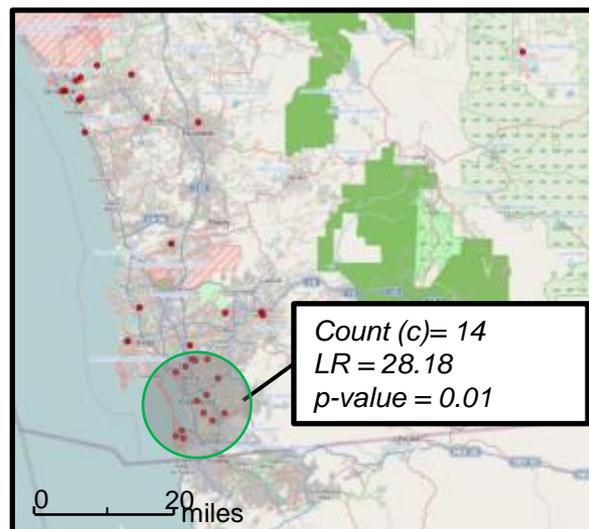
- › Arson crimes in San Diego in 2013
 - › Total 33 cases (red dots on the map)
 - › Activity Area is appr. 3000 sq. miles.
- › Arsonist caught in top green ring²



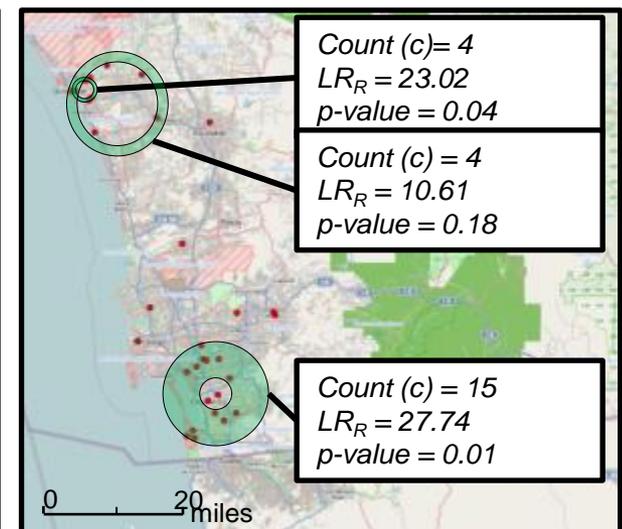
Input



SaTScan output



Significant Ring Detection

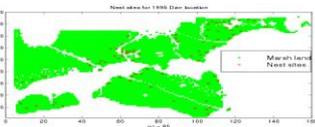


Green: Rings with $LR > 10$ & $p\text{-value} < 0.20$

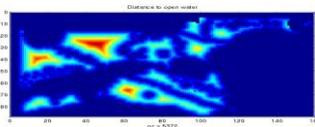
- (1) <http://www.sandiego.gov/police/services/statistics/index.shtml>
- (2) <http://www.nbcsandiego.com/news/local/Suspected-Arson-Grass-Fires-Oceanside-Mesa-Drive-Foussat-Road-218226321.html>
- (3) Ring-Shaped Hot-Spot Detection: A Summary of Results, IEEE Intl. Conf. on Data Mining, 2014.

Location Prediction: nesting sites

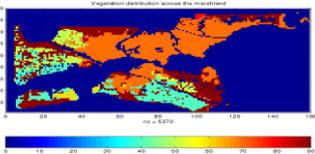
Nest locations



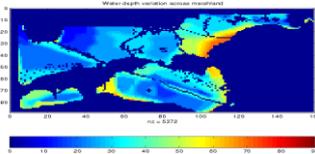
Distance to open water



Vegetation durability



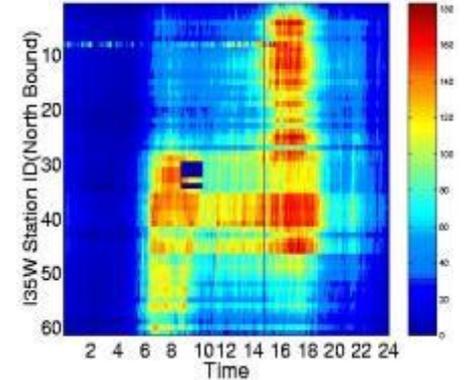
Water depth



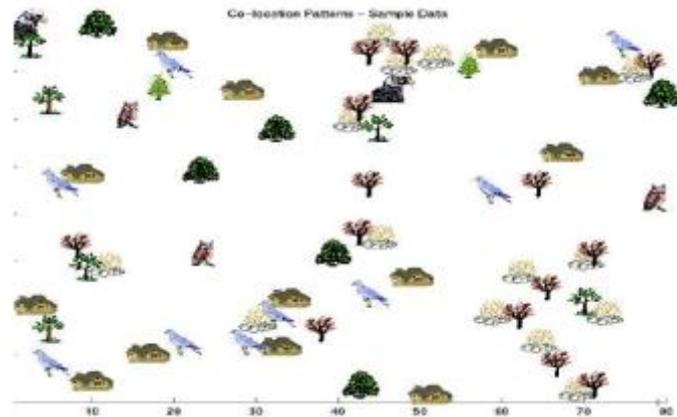
Spatial outliers: sensor (#9) on I-35



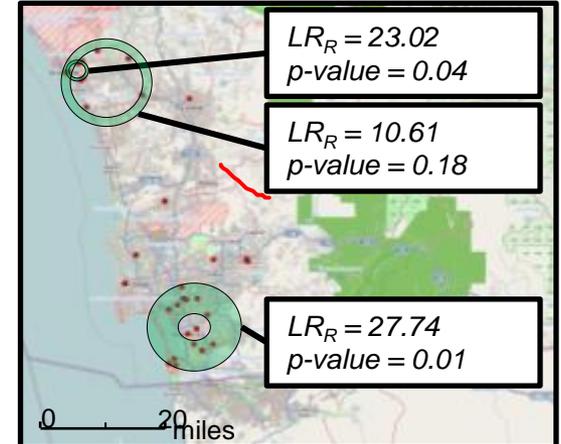
Average Traffic Volume (Time v.s. Station)



Co-location Patterns



Spatial Concept Aware Summarization



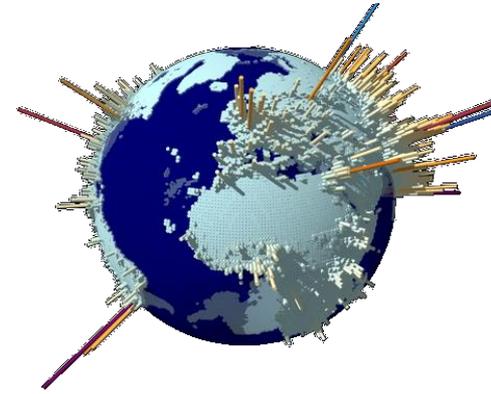
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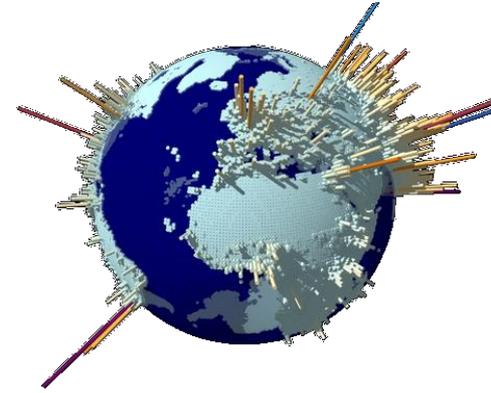
Virtual Globes and VGI (or CGI)

- › 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



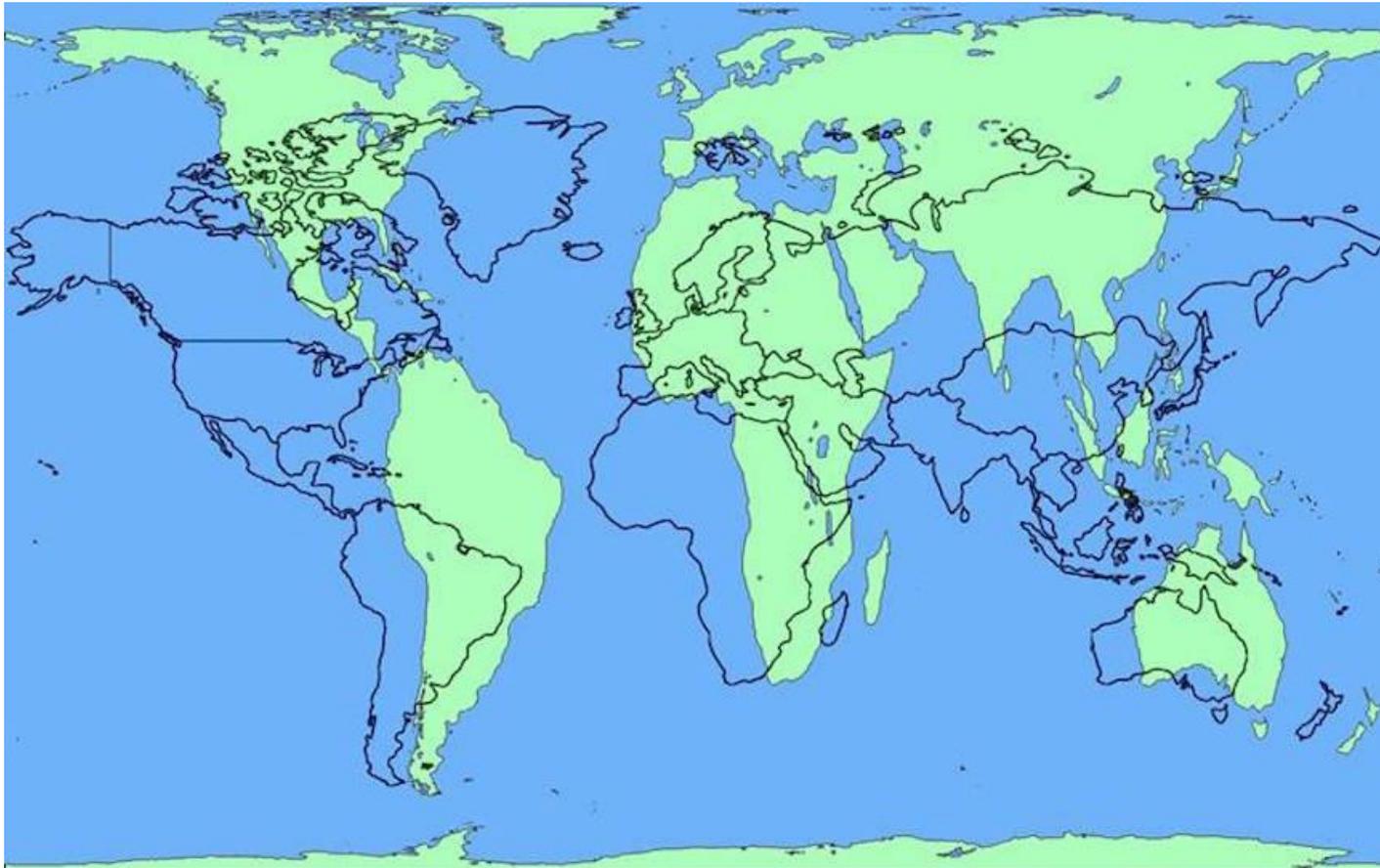
Map Orientation and Projections



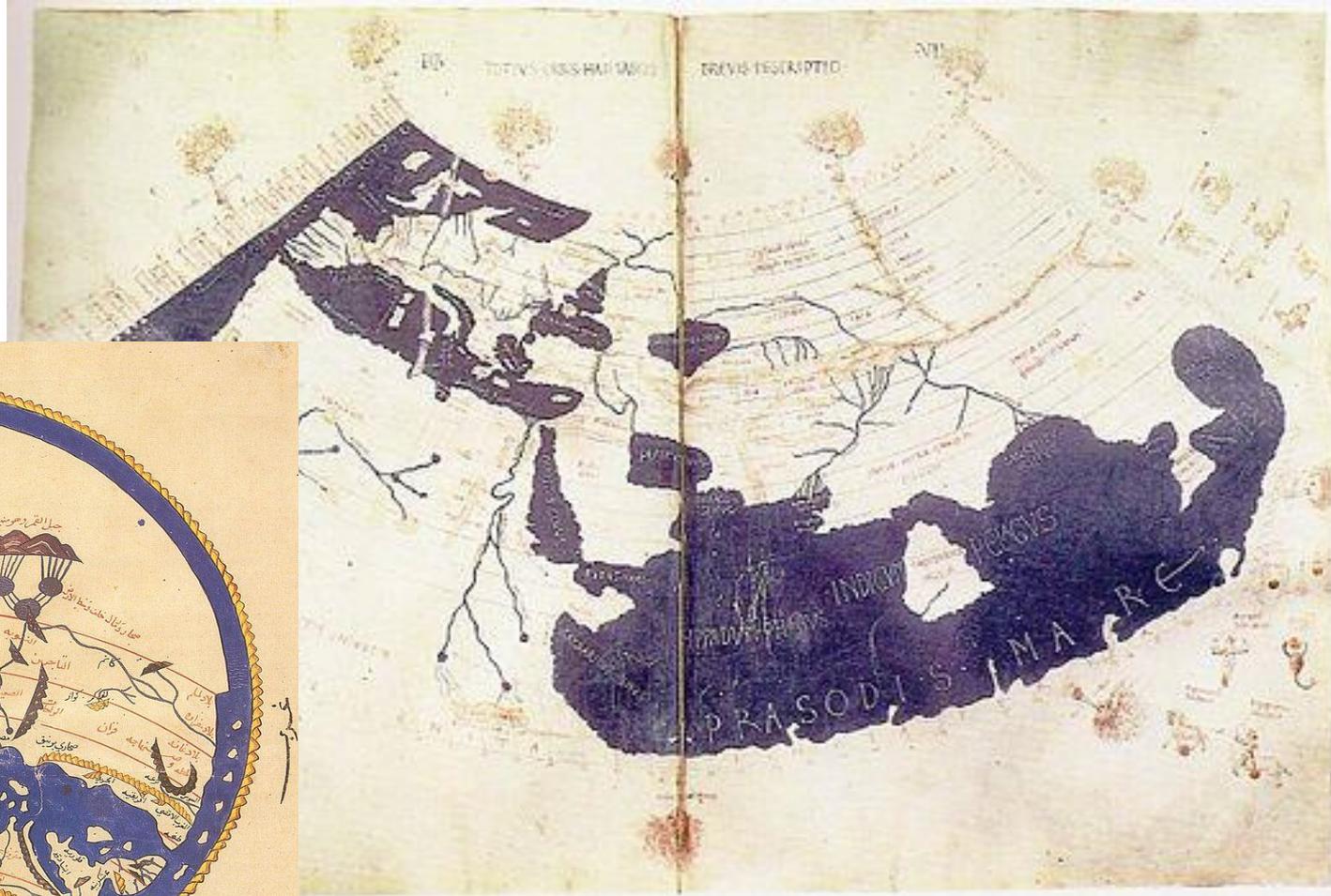
- › Mapping a 3D globe on a flat 2D plane
 - › <https://www.youtube.com/watch?v=kIID5FDi2JQ>

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Map Orientation and Projections



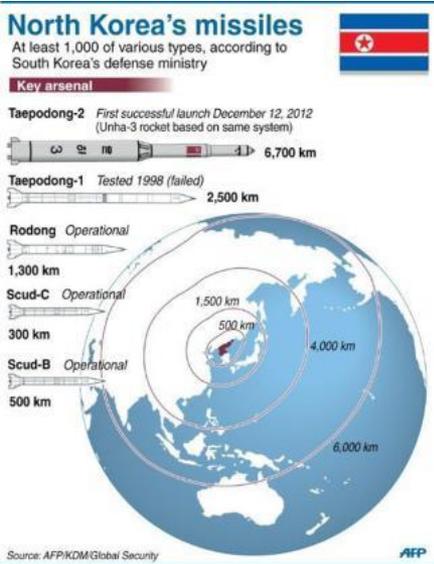
Map Orientation and Projections



Map Orientation and Projections



The Economist



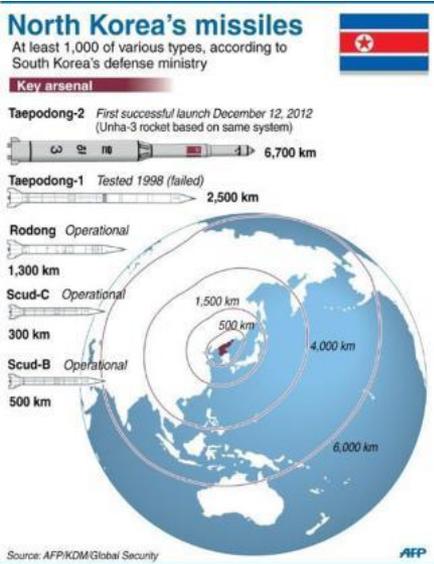
Map Orientation and Projections



The Economist

Correction

Original



Readings and Credits



› Readings

- › CACM Article: <https://cacm.acm.org/magazines/2016/1/195727-spatial-computing/fulltext>
- › CCC Workshop Report: https://cra.org/wp-content/uploads/sites/2/2015/05/Spatial_Computing_Report-2013.pdf
- › 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
 - › <http://www.vldb.org/pvldb/vol10/p1992-eldawy.pdf>
- › Prof. Shashi Shekhar book slides
 - › <http://www.spatial.cs.umn.edu/Book/slides/>
- › <http://www.edugrabs.com/components-of-dbms/>