

CS225: Spatial Computing

Introduction to Spatial Computing

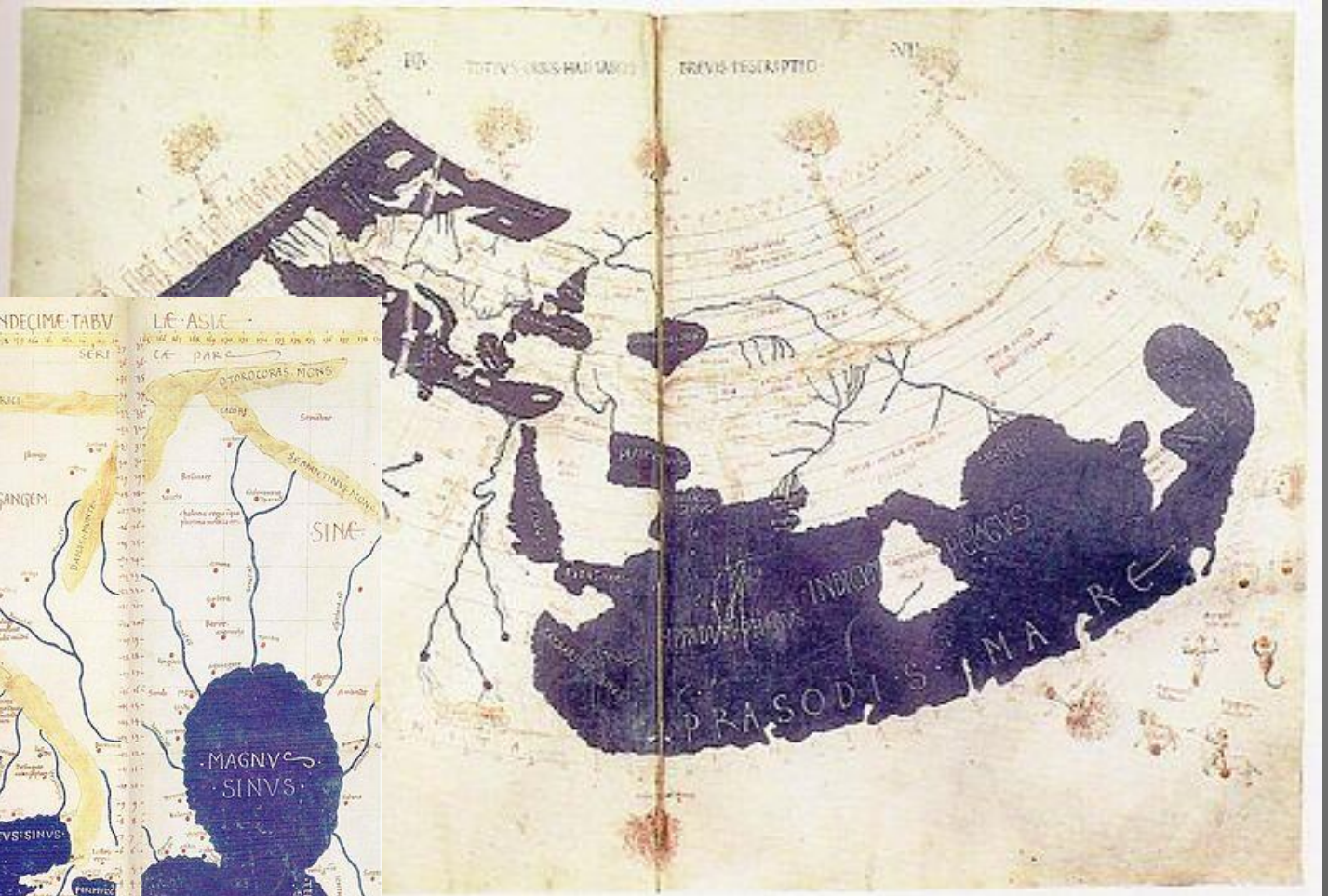
Amr Magdy

Computer Science and Engineering

www.cs.ucr.edu/~amr/

Once upon a
time...



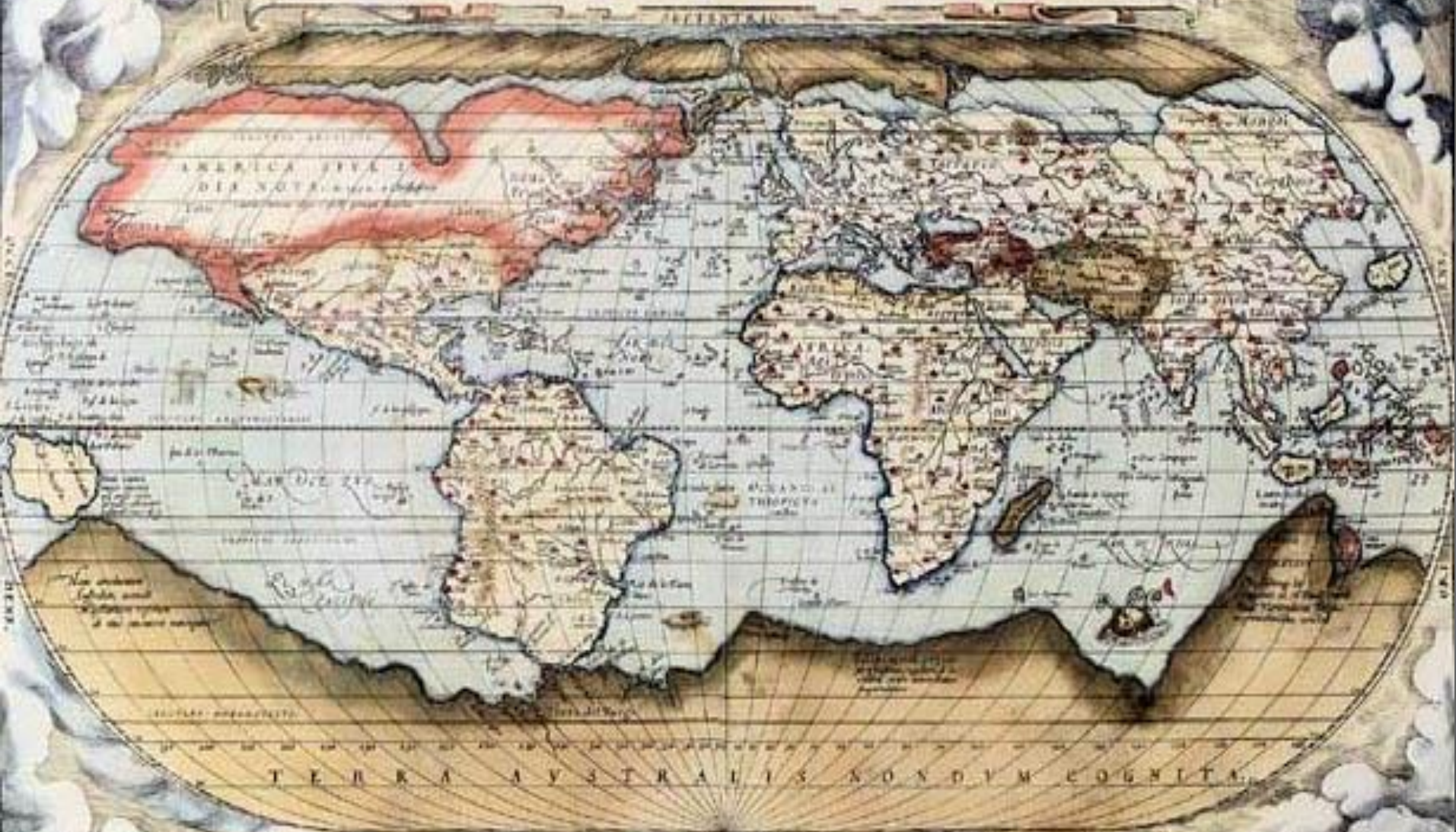


Al Idrisi (1099–1165)





TYPVS ORBIS TERRARVM



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

ARGONAVTICA.



ILLVSTRISSIMO
PRINCIPI CAROLO
COMITI ARENBERGIO
BARONI SEPTIMONTI
DOMINO MIRVARTIL
EQVITI AVRES VELL-
LERIS. ETC.

Ex. 1. *Exercises in Arithmetic*

Syrtes. See also
Syrtes de l'ouest.

Helpers des

REFERENCES

PARS.

THIRAC
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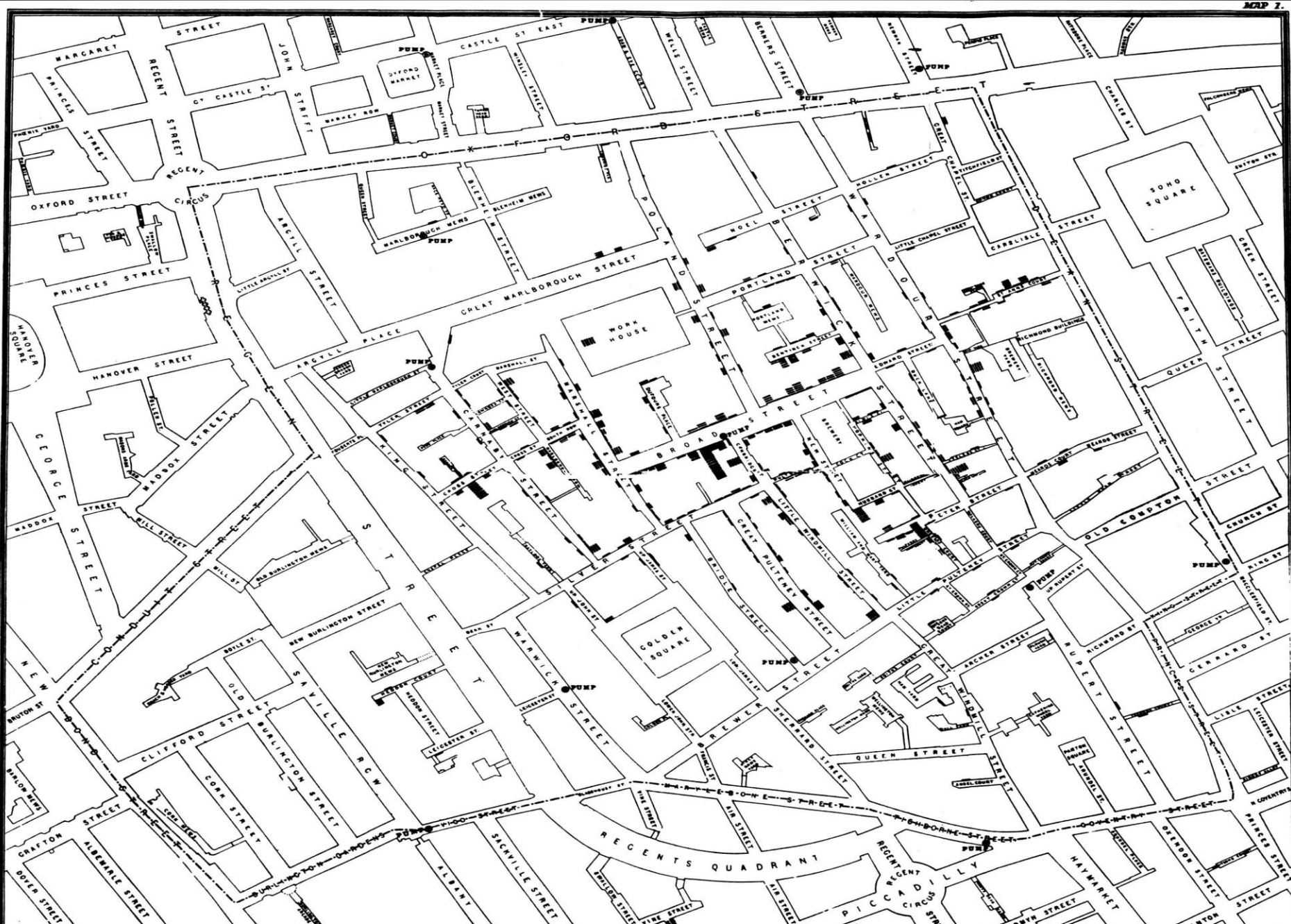
Act. 11

1874

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Cholera cases in the London epidemic of 1854



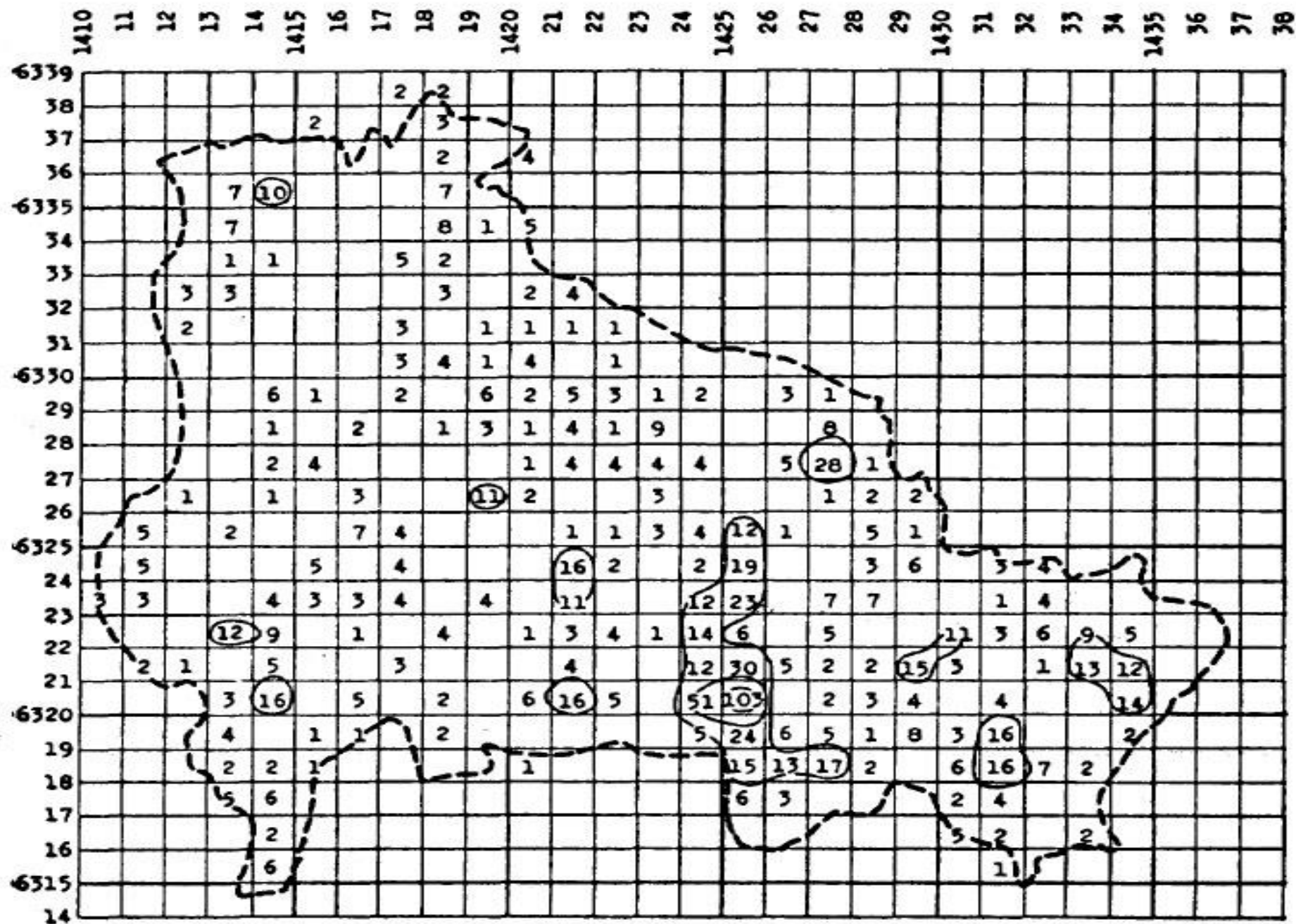


FIGURE 3—Children under 15 years of age in 1940.

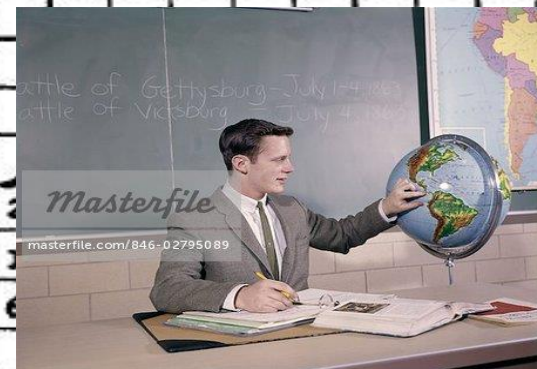
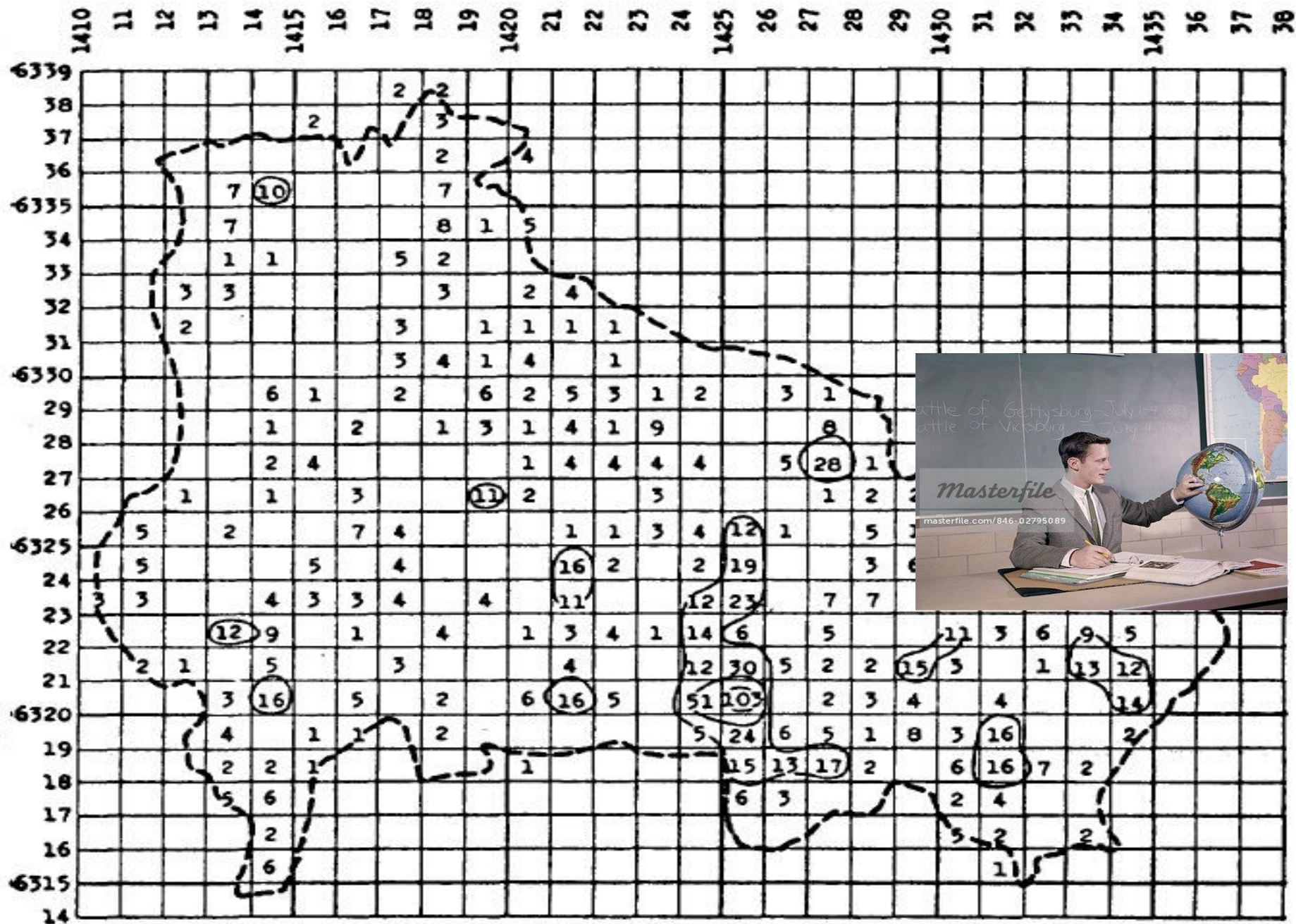
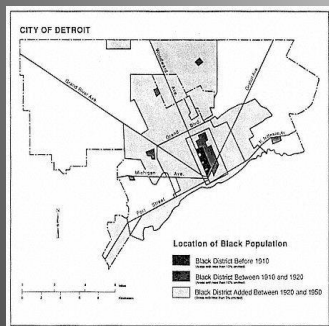
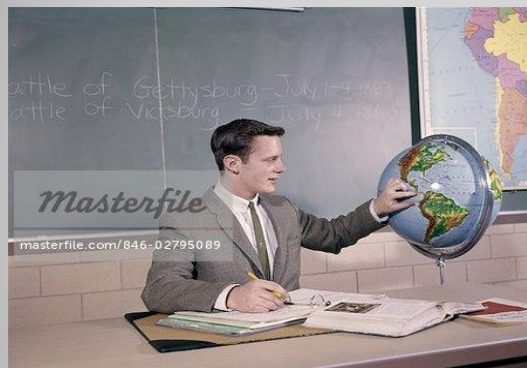
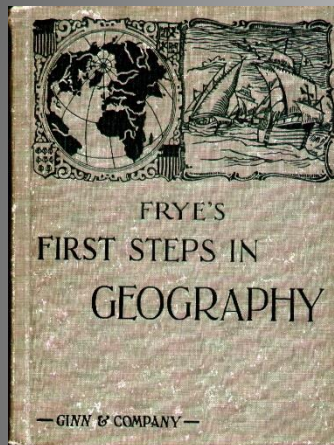


FIGURE 3—Children under 15 years of age in 1940.





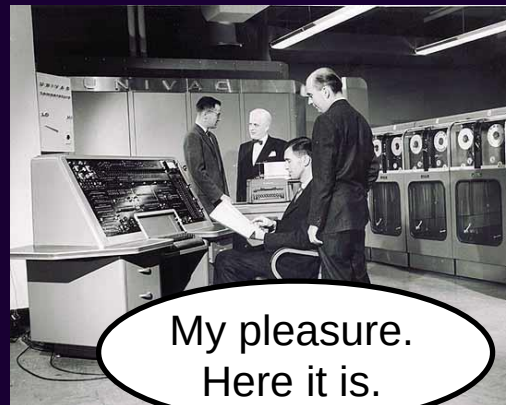
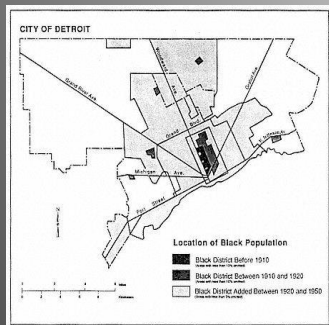
Cool **computer** technology..!!
Can I use it in my application



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

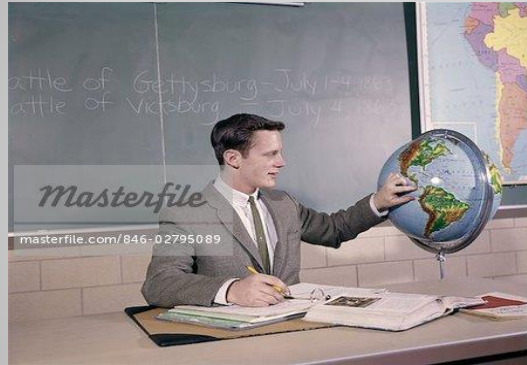


Oh..!! But, it is not
made for me. Can't
make use of it **as is**



My pleasure.
Here it is.

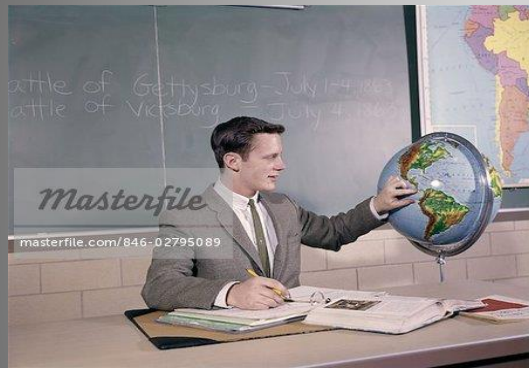


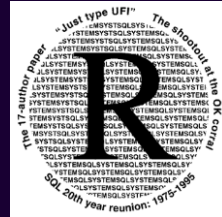
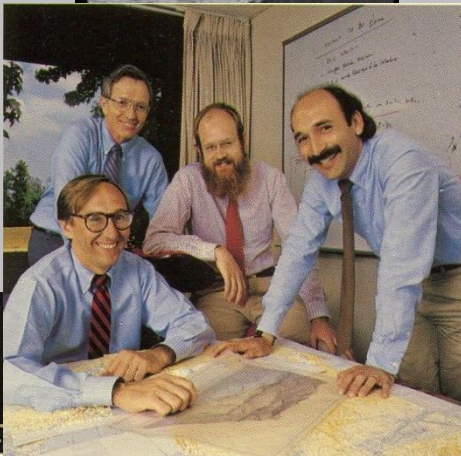


Kindly let me
understand your
needs

1969

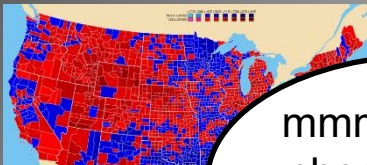
Kindly let me
get the
technology you
have



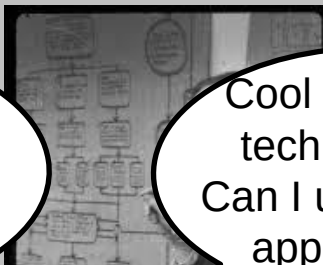


SQL

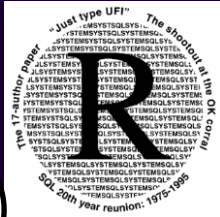




mmm...Let me check with my good friends there.



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



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



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

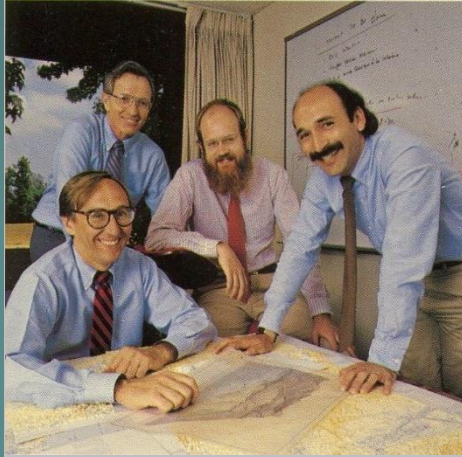
My pleasure.
Here it is.



Informix

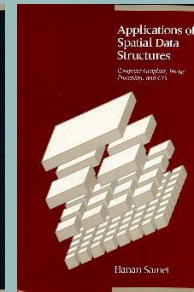
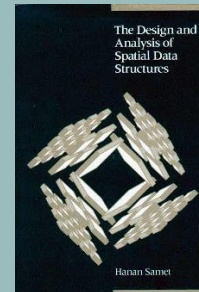
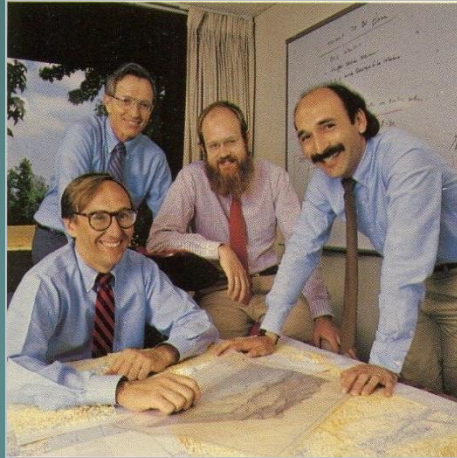
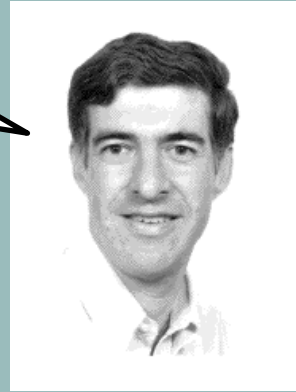
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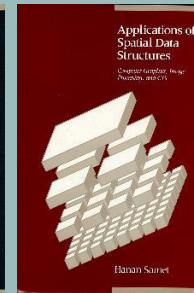
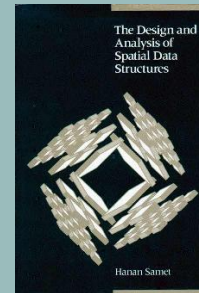
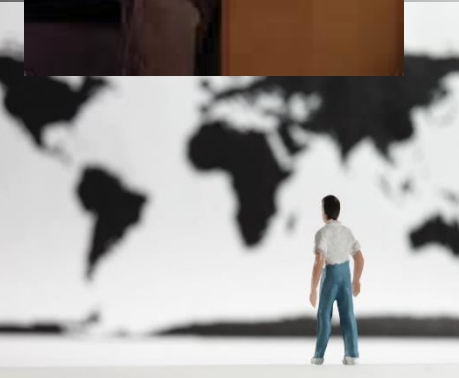


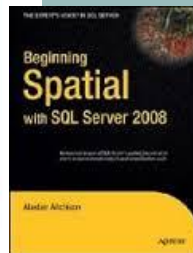
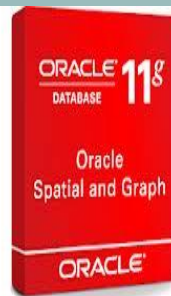
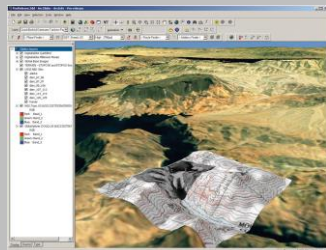
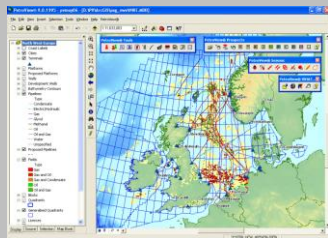
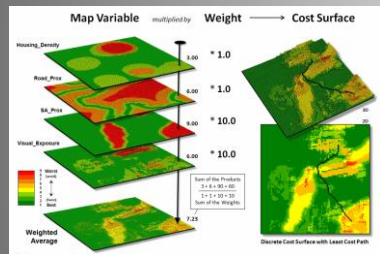


Kindly let me
understand your
needs

Kindly let me
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technology you
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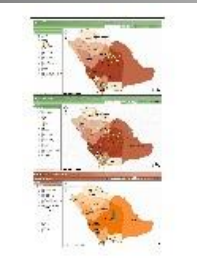
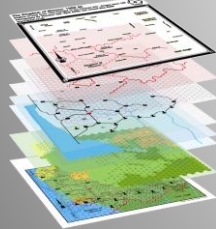
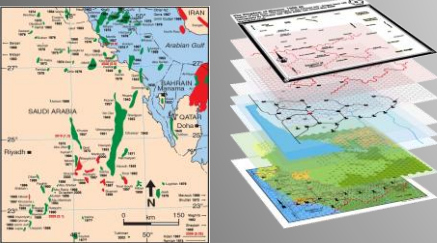
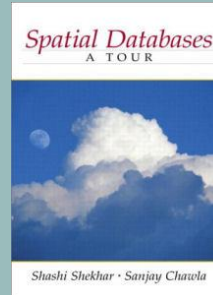
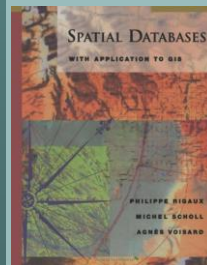
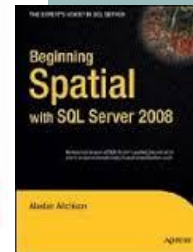
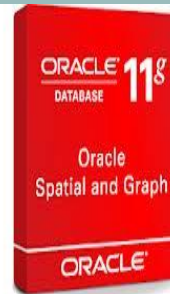
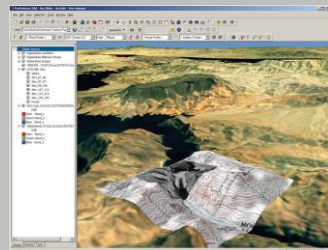
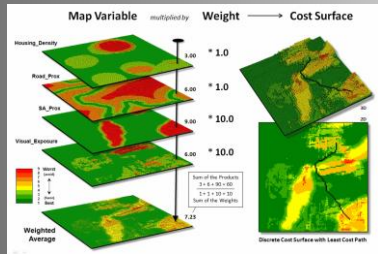


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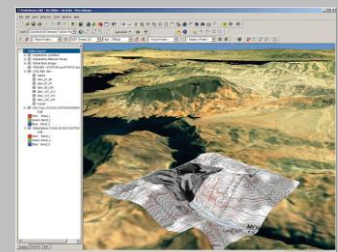
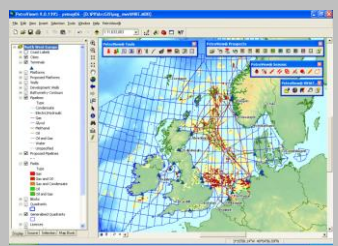
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hadoop

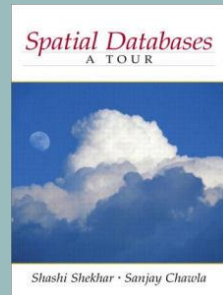
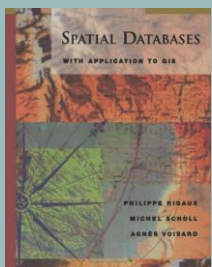
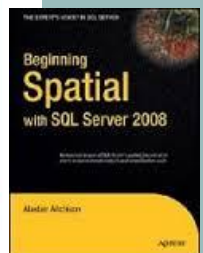
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IMPALA Spark



Arc
ESRI GIS



PostGIS
Geospatial Objects for PostgreSQL



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IBM DB2.

Microsoft SQL Server

PostgreSQL
the world's most advanced open source database

MySQL

SYBASE® | An SAP Company

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

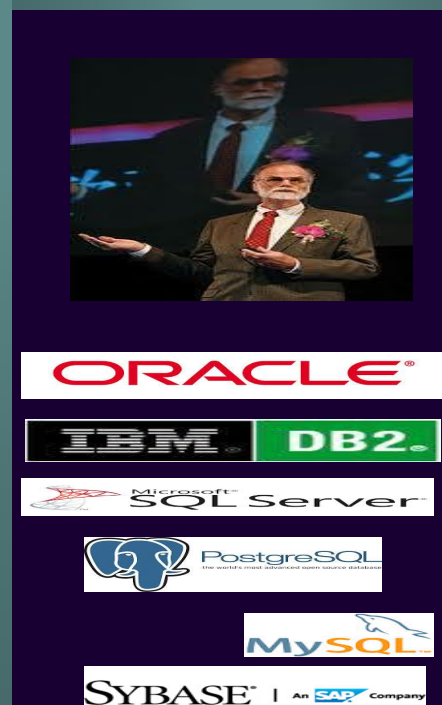
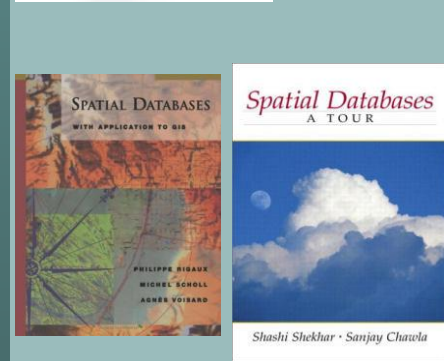
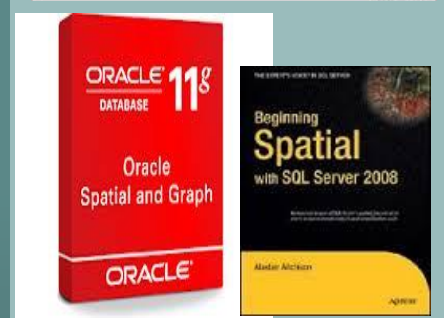
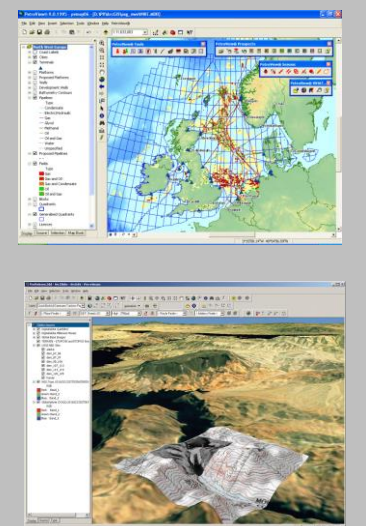
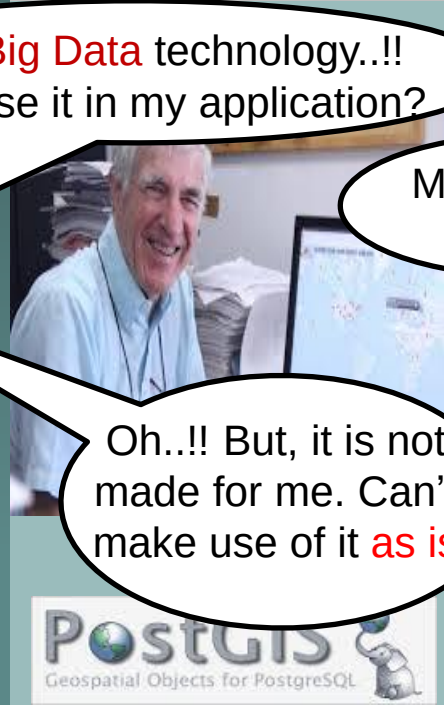
Cool **Big Data** technology..!!
Can I use it in my application?

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**





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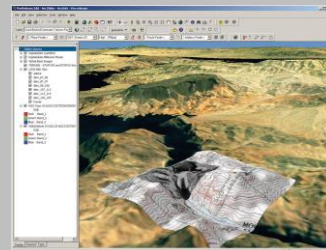
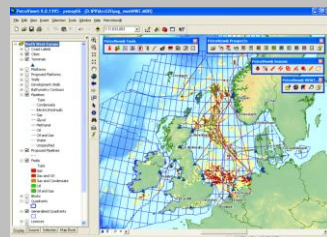
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amazon web services™ EC2

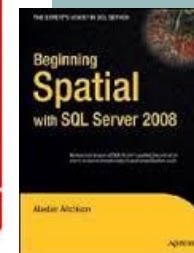
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IMPALA Spark



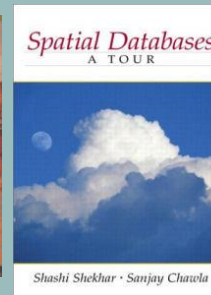
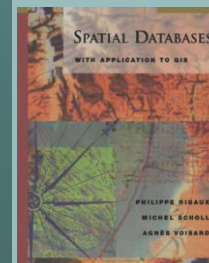
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Geospatial Objects for PostgreSQL



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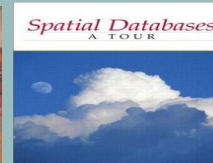
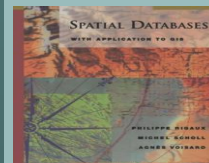
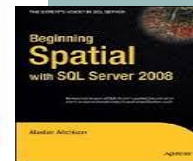
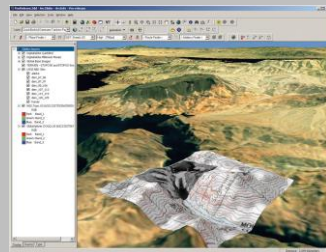
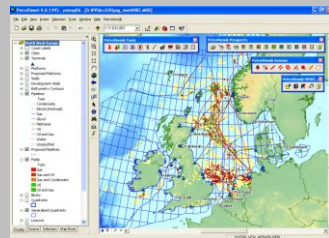
PostgreSQL
the world's most advanced open source database

MySQL

SYBASE® | An SAP Company

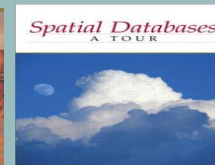
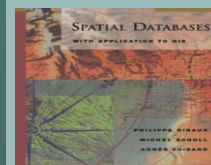
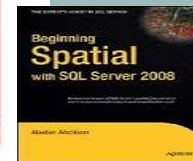
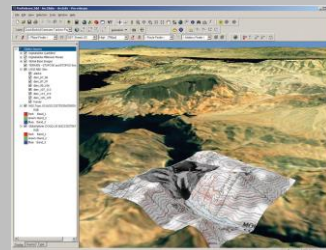
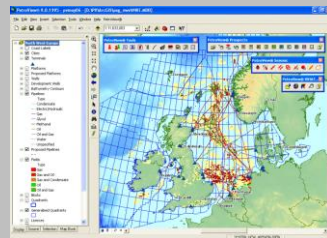


Kindly let me understand your needs





The Era of Big Spatial Data



The Era of Big Spatial Data

Recent products are there....



What is Spatial Computing?



What is Spatial Computing?



- › 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 around me?
 - ▶ restaurants, hotels, gas stations, ATMs...etc
 - ▶ 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
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(McKinsey Global Institute, 2011 report on Big Data)

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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)

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- › The governments
- › The public

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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)

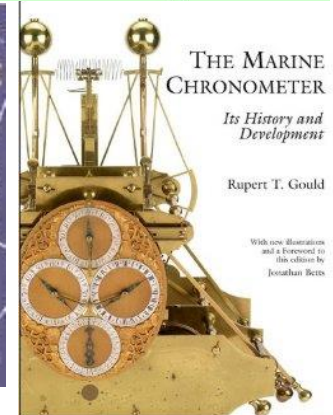
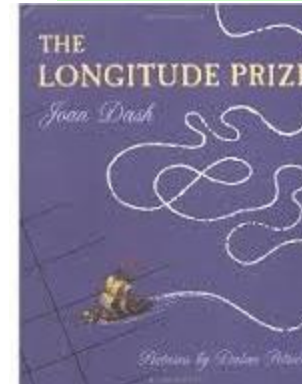
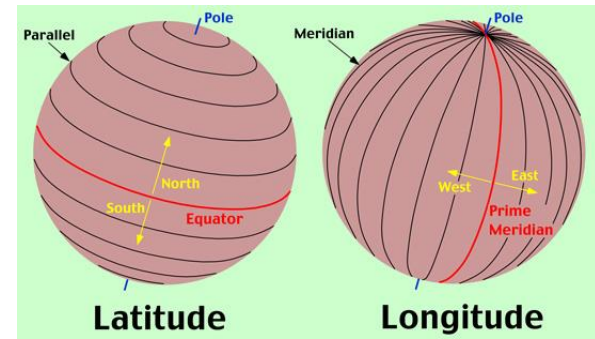
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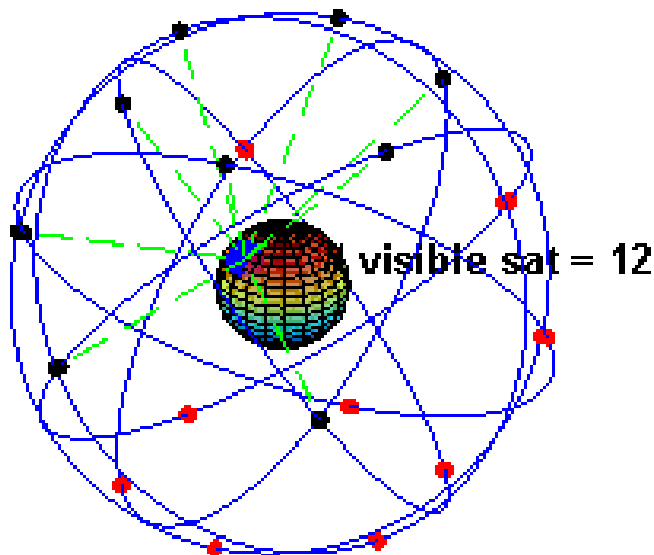
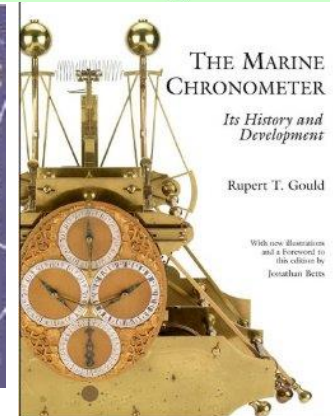
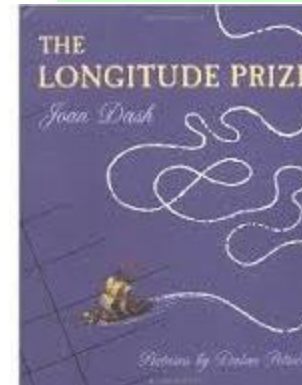
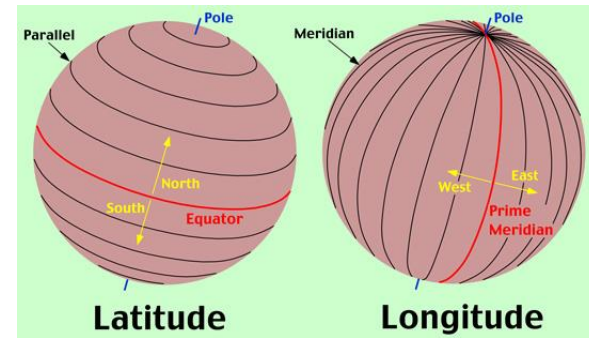
Global Positioning Systems (GPS)

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



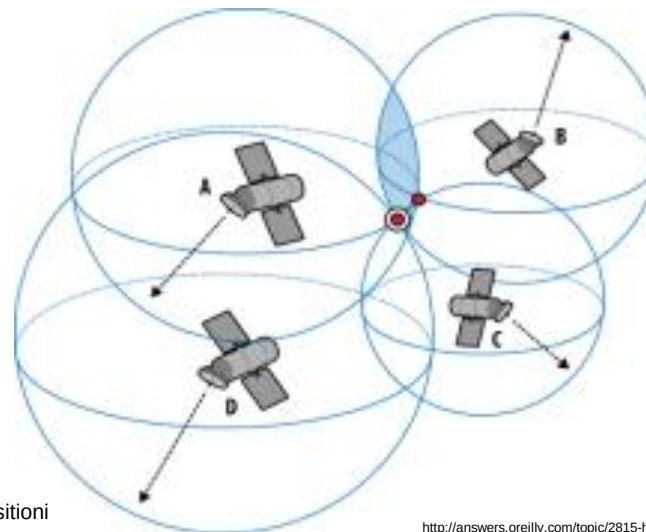
Global Positioning Systems (GPS)

- 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

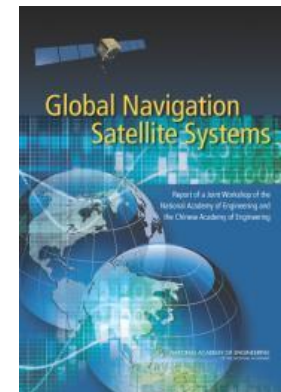


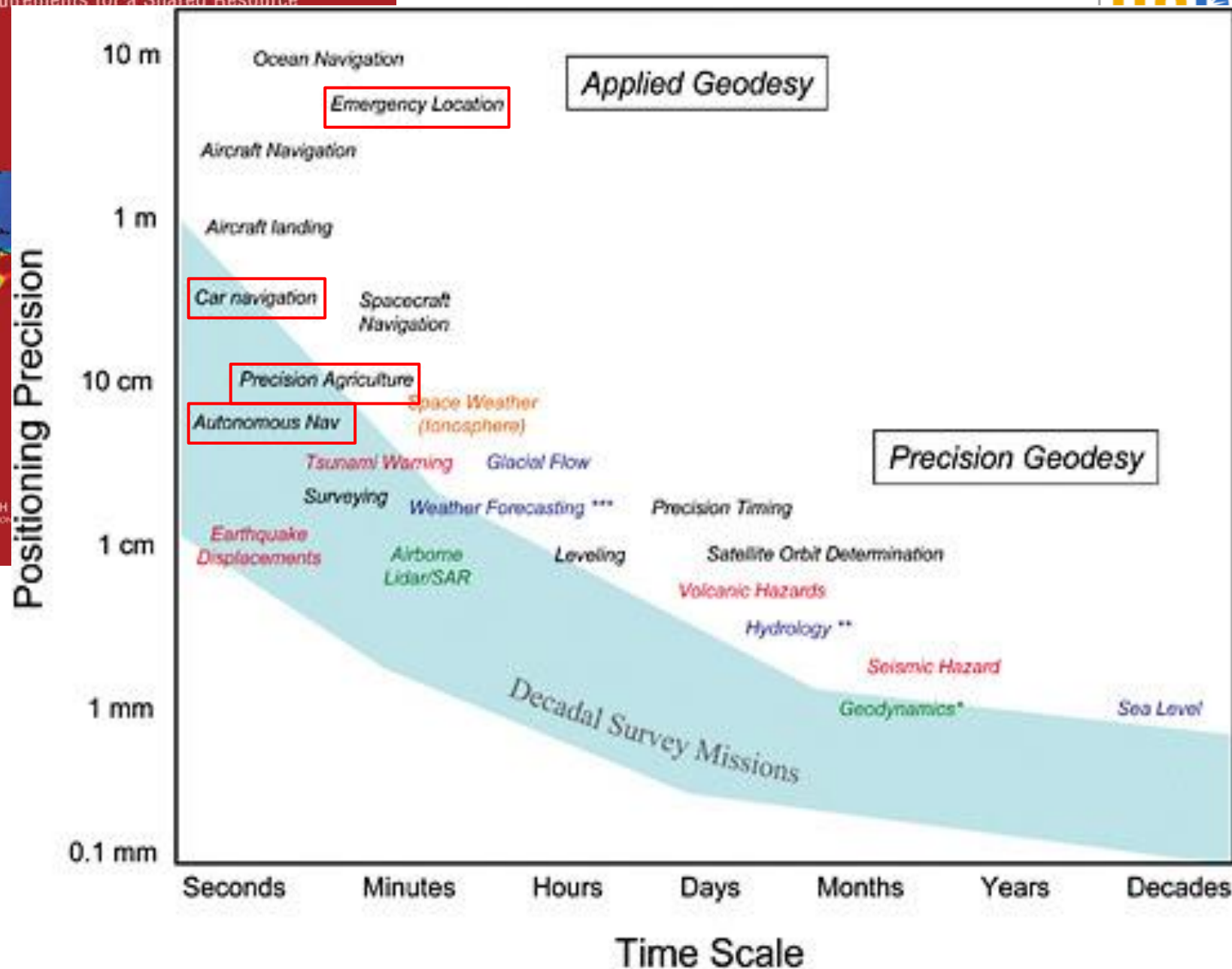
http://en.wikipedia.org/wiki/Global_Positioning_System

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



Future & Trends: Localization Indoors, Underground, & Underwater

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 - Blue Tooth, Wi-Fi, ...

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Get In-Store
Notifications

© Walkbase, confidential

walkbase



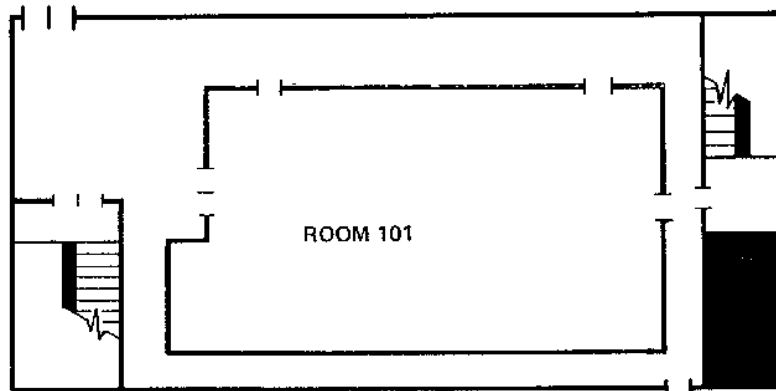
Future & Trends: Localization Indoors, Underground, & Underwater

<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 ?



EXIT #1



First Floor

EXIT #2



Get In-Store
Notifications

WiFi Localization



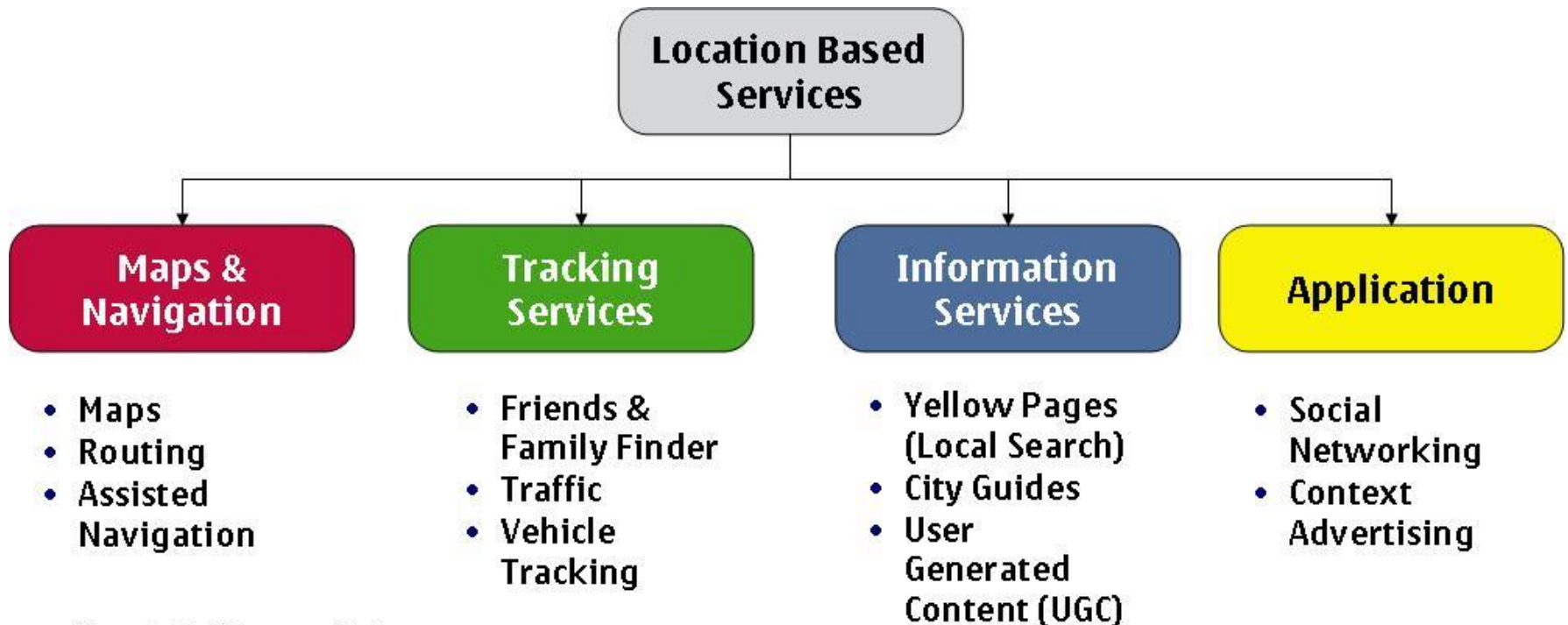
Major technologies and areas (past, present, & future)



- › 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)

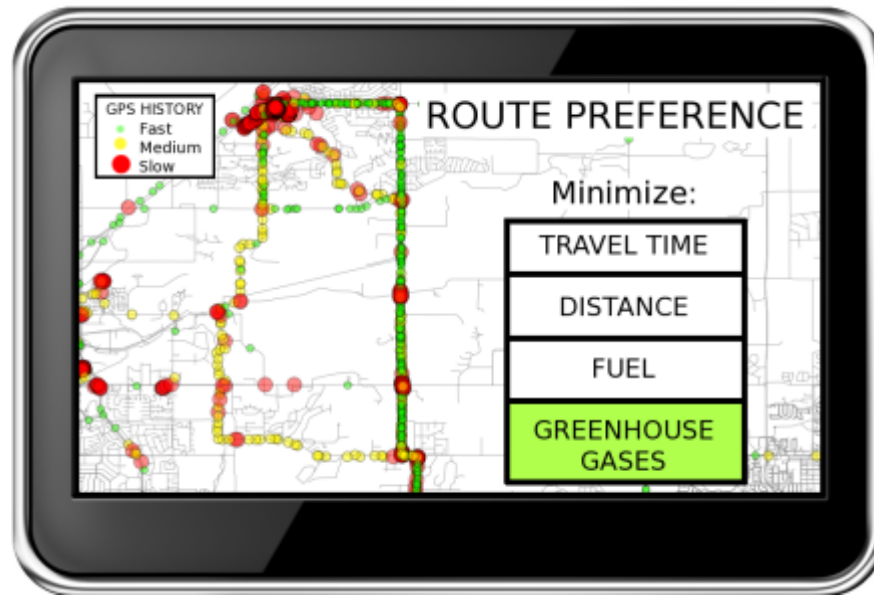
Location Based Services

- 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

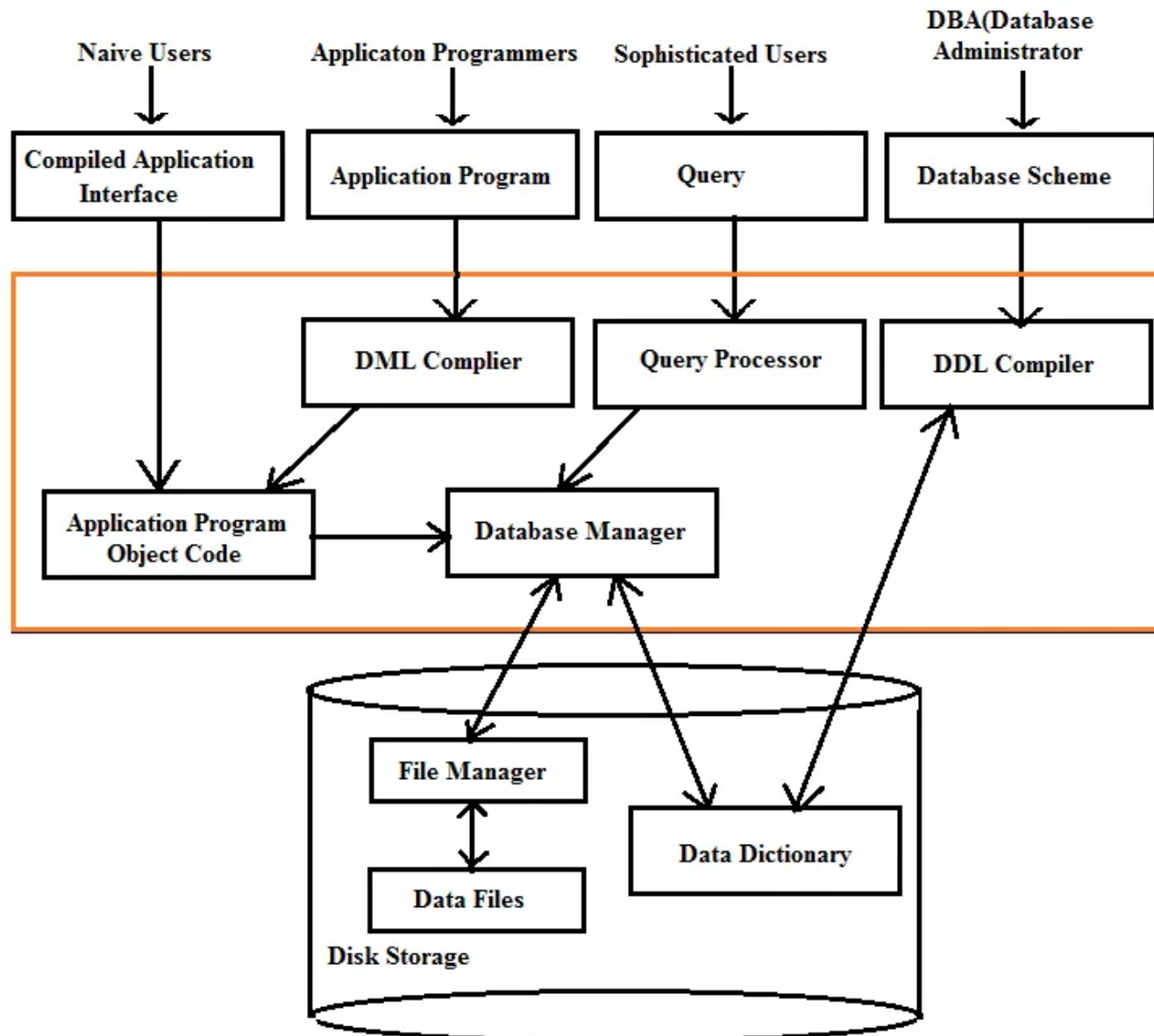


Major technologies and areas (past, present, & future)



- › 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)

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

Spatial Database Management Systems (SDBMS)



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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

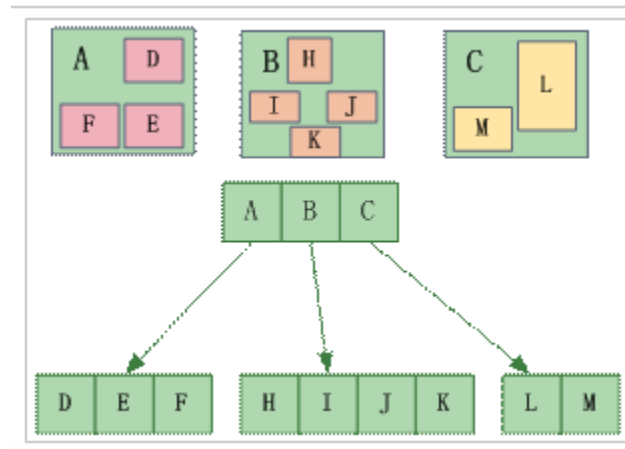
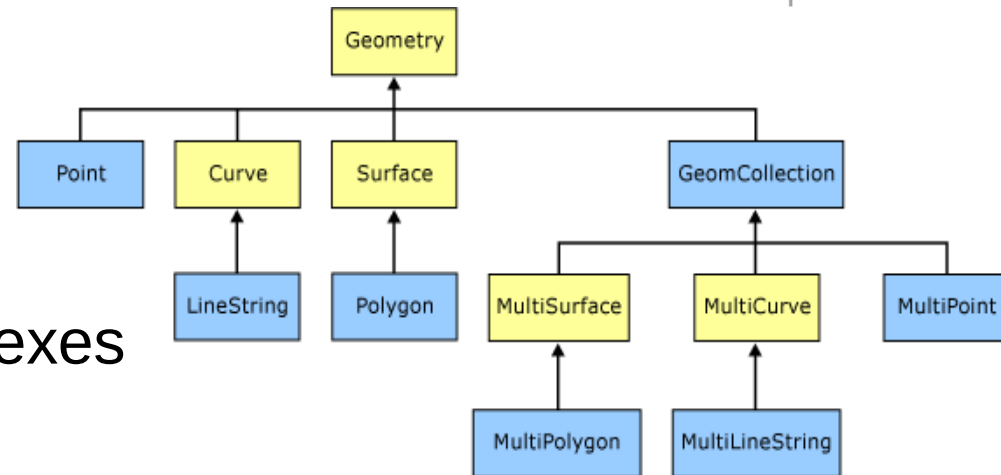


- › Non-spatial queries
 - › List the names of all bookstore with more than ten thousand titles
 - › List the names of ten customers, in terms of sales, in the year 2001

- › 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)



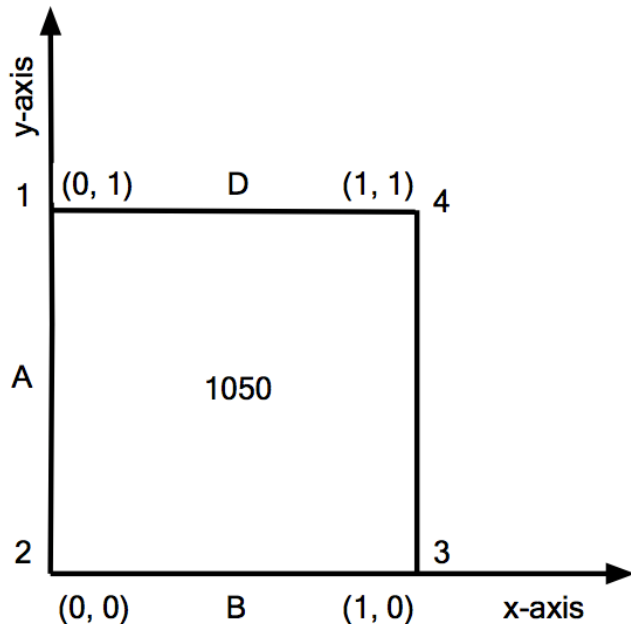
SDBMS Example

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 - ▶ County boundary (dashed white line)
 - ▶ Census block - name, area, population, boundary (dark line)
 - ▶ Water bodies (dark polygons)
 - ▶ Satellite Imagery (gray scale pixels)
- ▶ 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

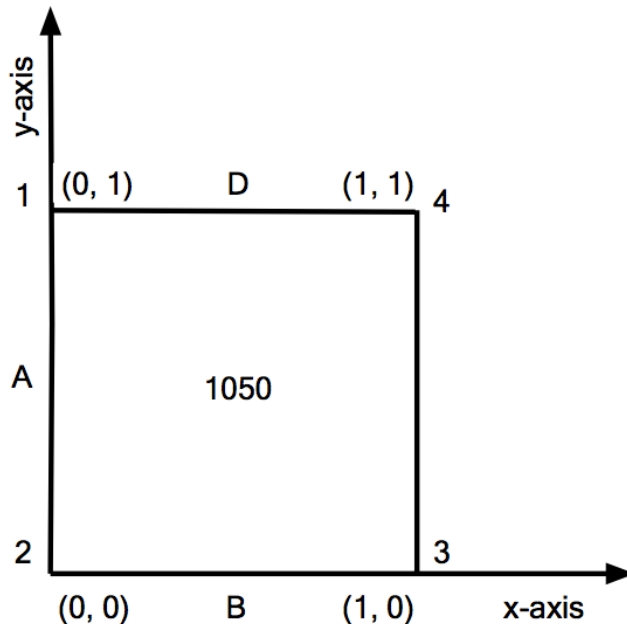


Census_blocks

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
1050	1	1839	Polyline ((0,0), (0,1), (1,1), (1,0))

Spatial beyond Databases

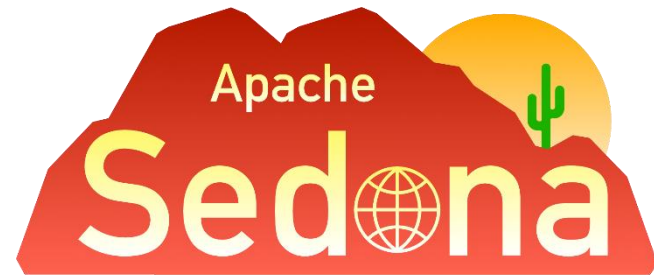


- › Distributed systems
 - › Hadoop, Spark, Impala, ...etc

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:
 - Who gets my data?
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- Involved groups:
 - Civil Society
 - Economic Entities
 - Public Safety
 - Policy Makers

Challenges: Security vs. Utility



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

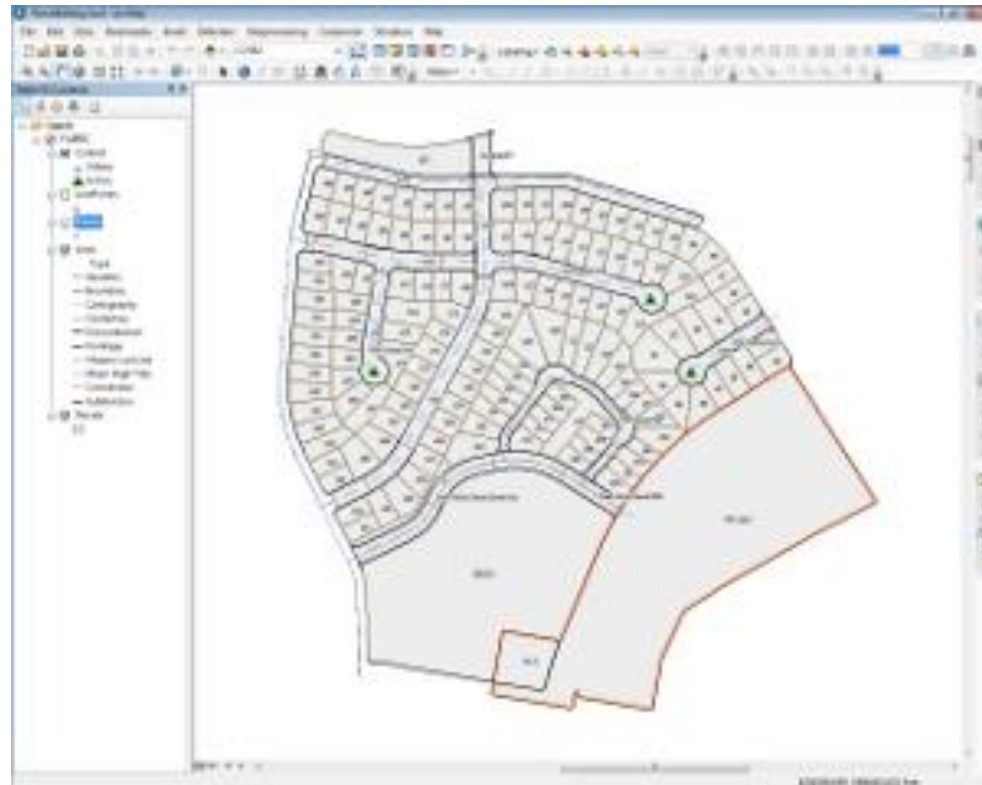
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Geographic Information Systems (GIS)

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

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 - Efficient and scalable fundamental querying and data management operations

How different GIS from SDBMS?

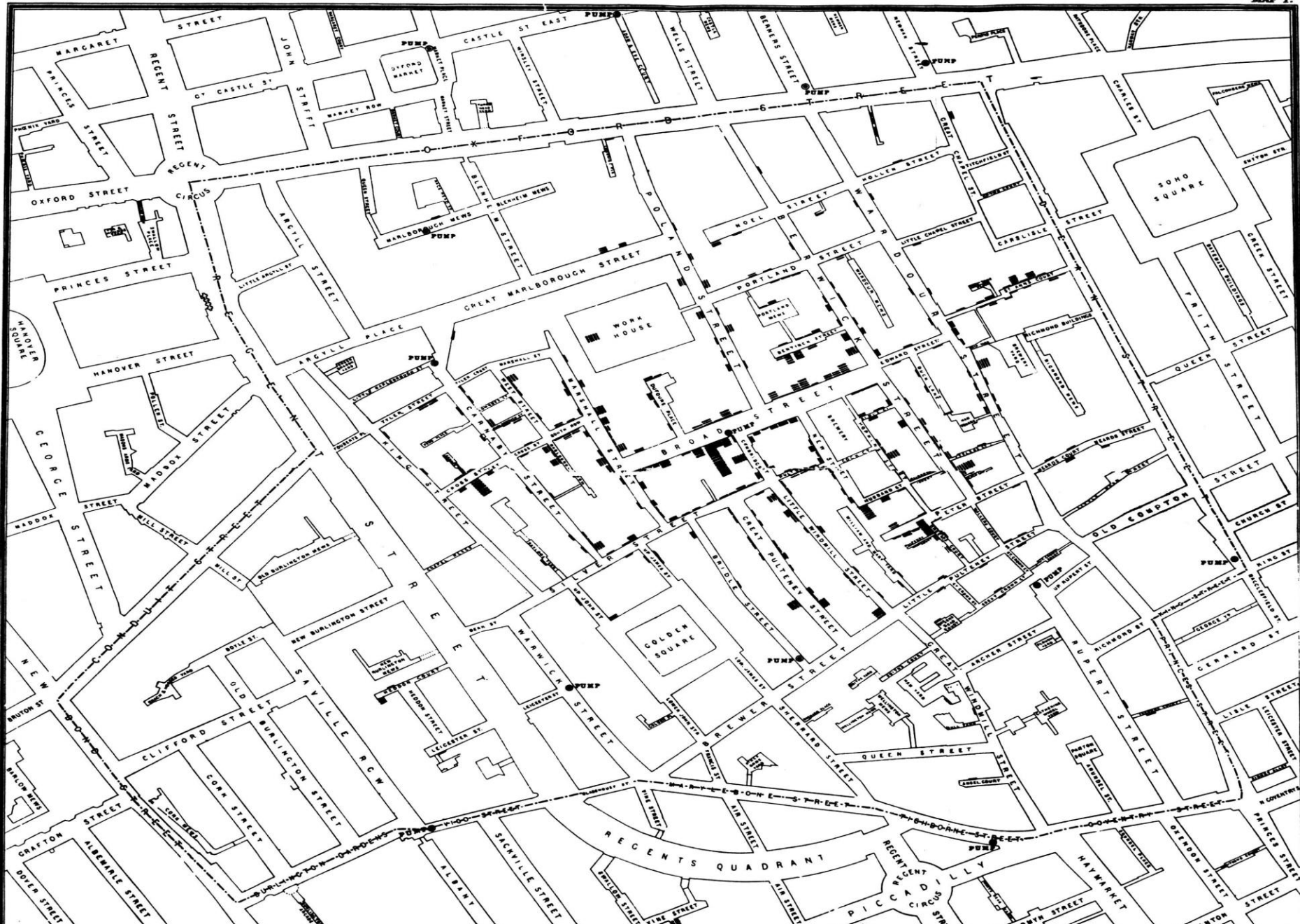
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 - Efficient and scalable fundamental querying and data management operations
- SDBMS can be used by applications other than GIS
 - Astronomy, location-based services, brain informatics, etc

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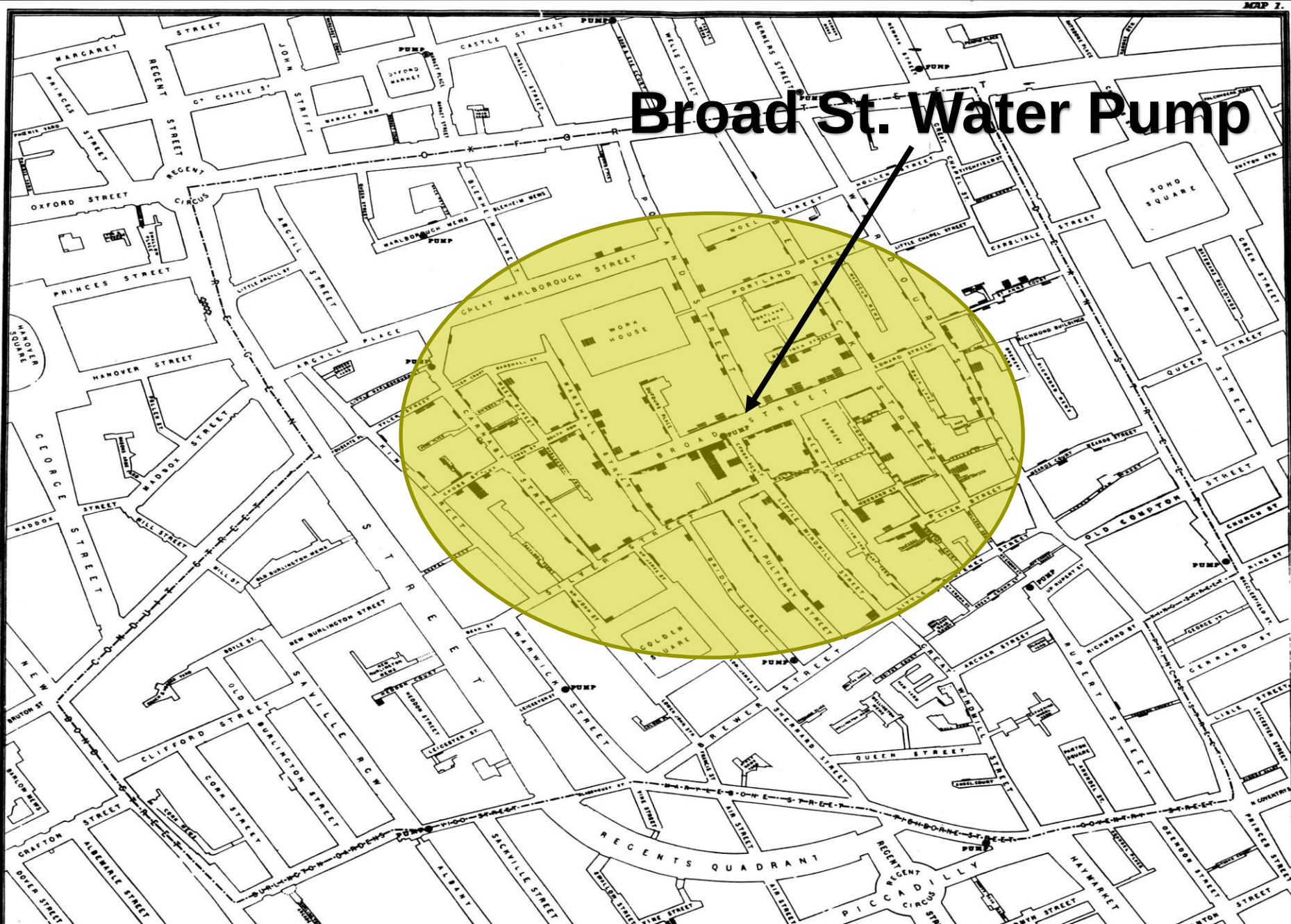
MAP 1.



Cholera cases in the London epidemic of 1854



Cholera cases in the London epidemic of 1854



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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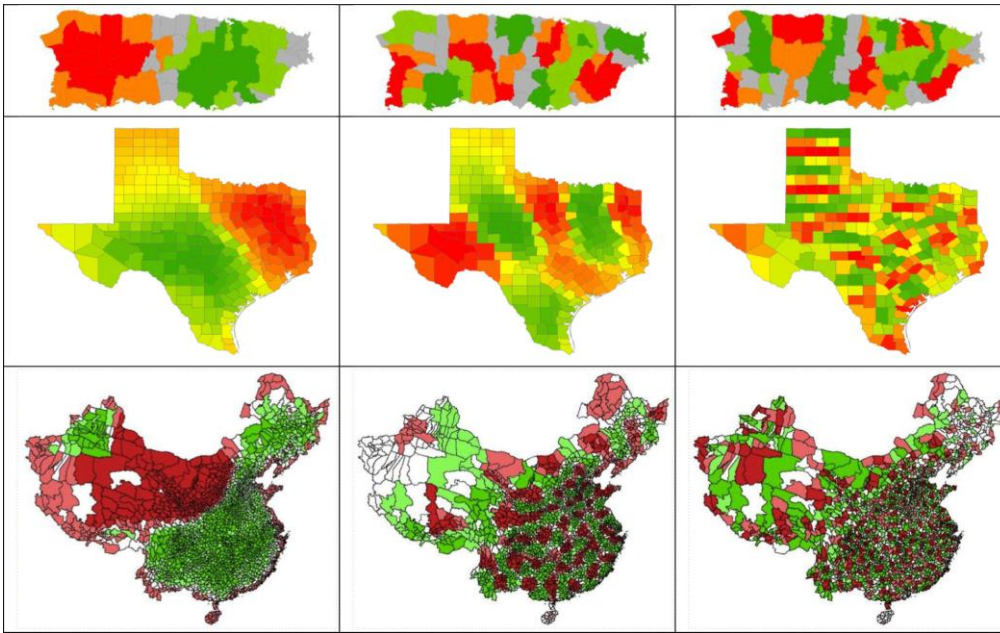
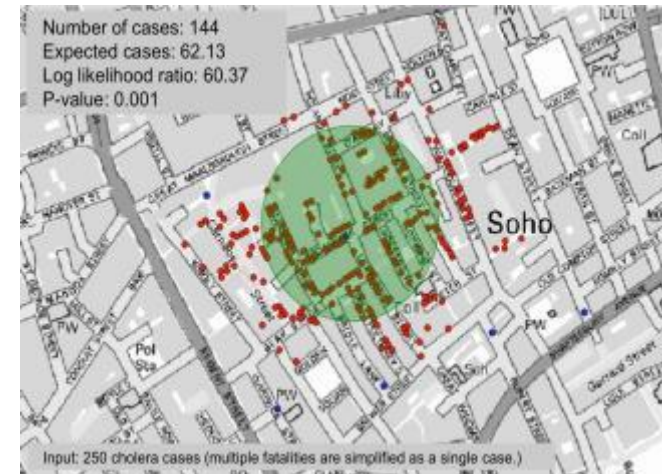
By The New York Times



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

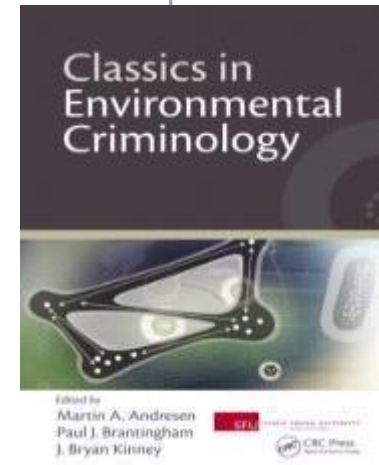
Spatial Statistics

- 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

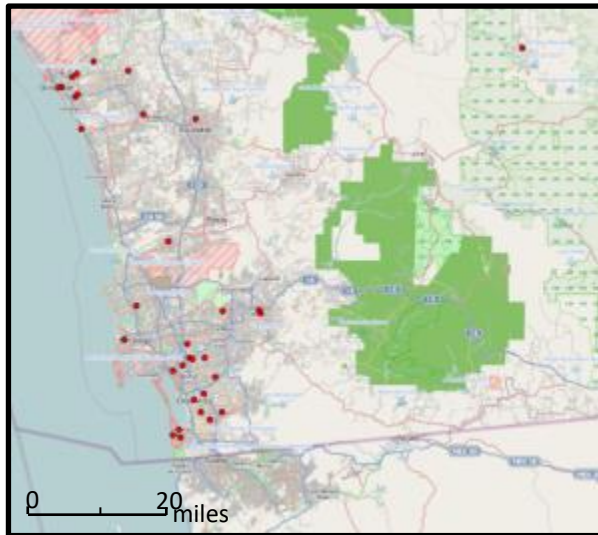


Detecting Spatial Patterns

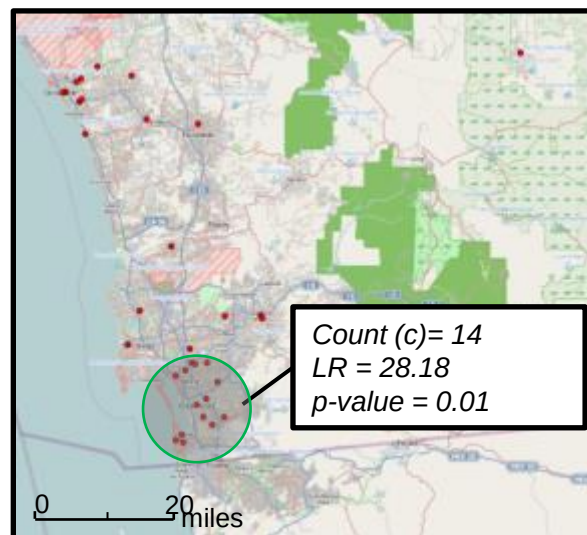
- Arson crimes in San Diego in 2013
 - Total 33 cases (red dots on the map)
 - Activity Area is appr. 3000 sq. miles.
- Arsonist caught in top green ring²



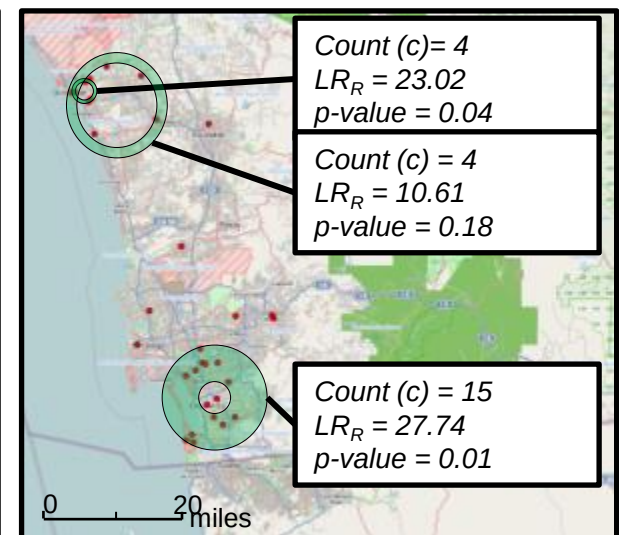
Input



SaTScan output



Significant Ring Detection

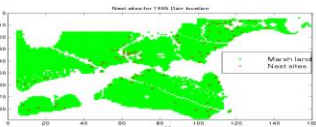


Green: Rings with $LR > 10$ & p-value < 0.20

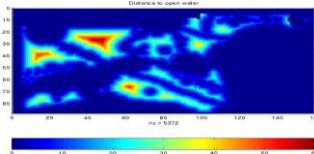
- <http://www.sandiego.gov/police/services/statistics/index.shtml>
- <http://www.nbcsandiego.com/news/local/Suspected-Arson-Grass-Fires-Oceanside-Mesa-Drive-Foussat-Road-218226321.html>
- Ring-Shaped Hot-Spot Detection: A Summary of Results, IEEE Intl. Conf. on Data Mining, 2014.

Location Prediction: nesting sites

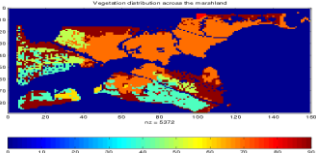
Nest locations



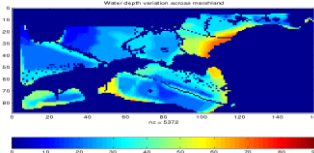
Distance to open water



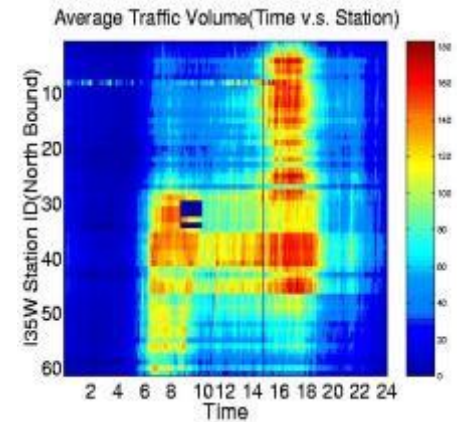
Vegetation durability



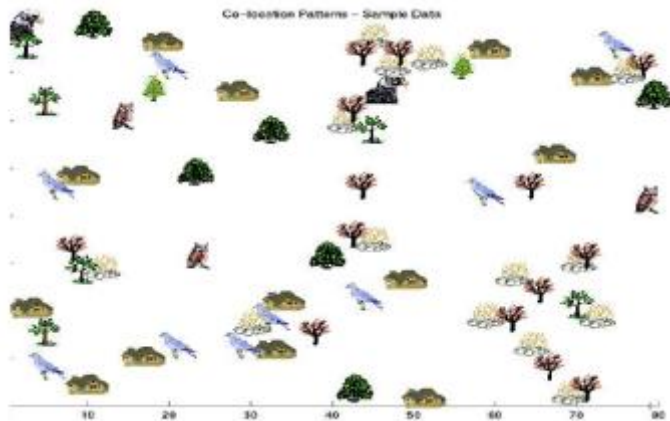
Water depth



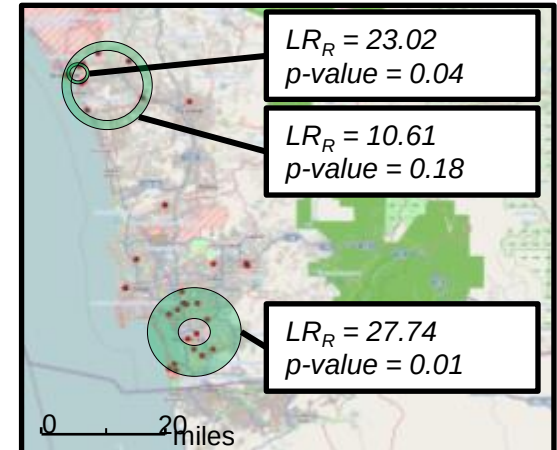
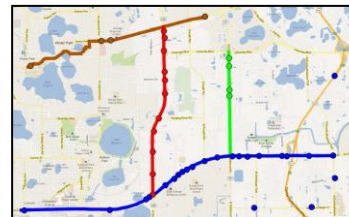
Spatial outliers: sensor (#9) on I-35



Co-location Patterns



Spatial Concept Aware Summarization



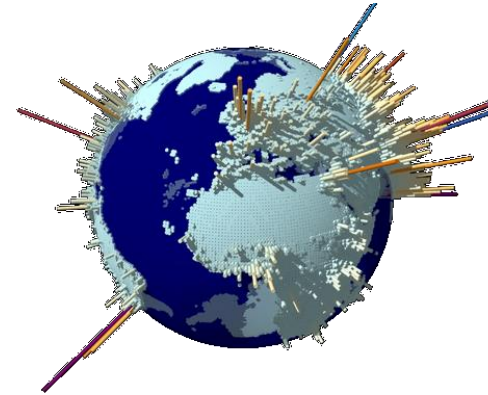
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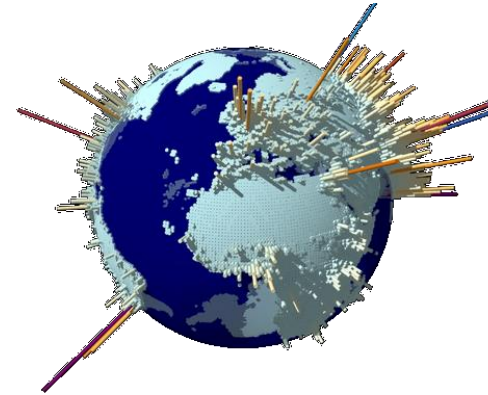
Virtual Globes and VGI (or CGI)

- › LBS accessibility
- › Visualization
- › Volunteering
(or Crowdsourcing) geo
information
- › Education



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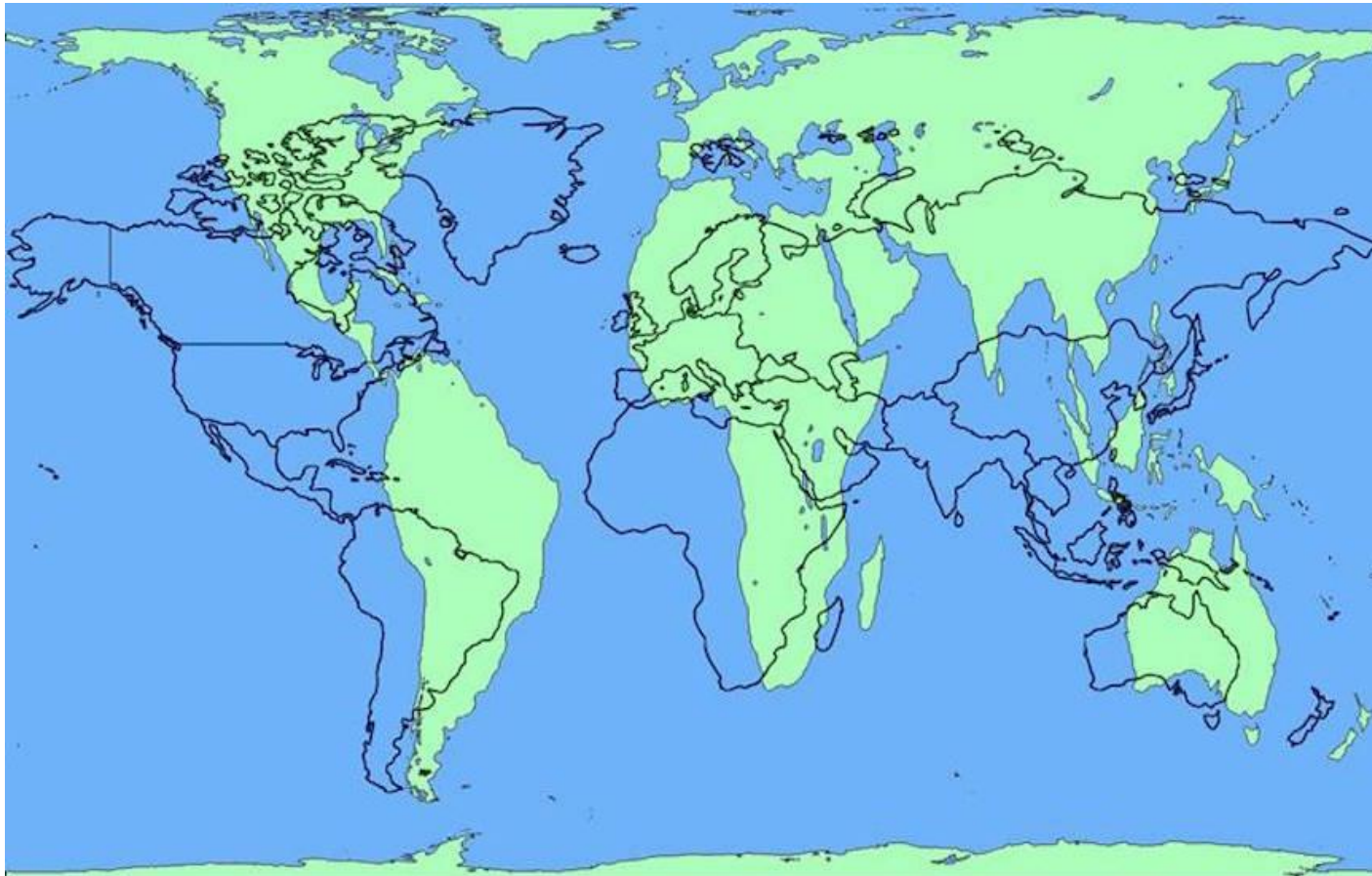


Map Orientation and Projections

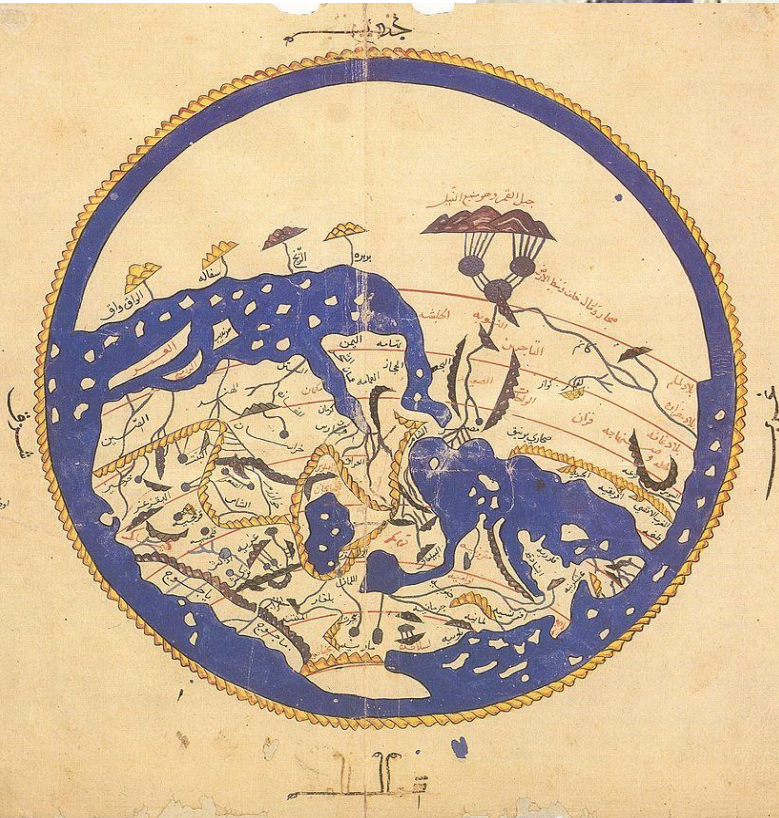
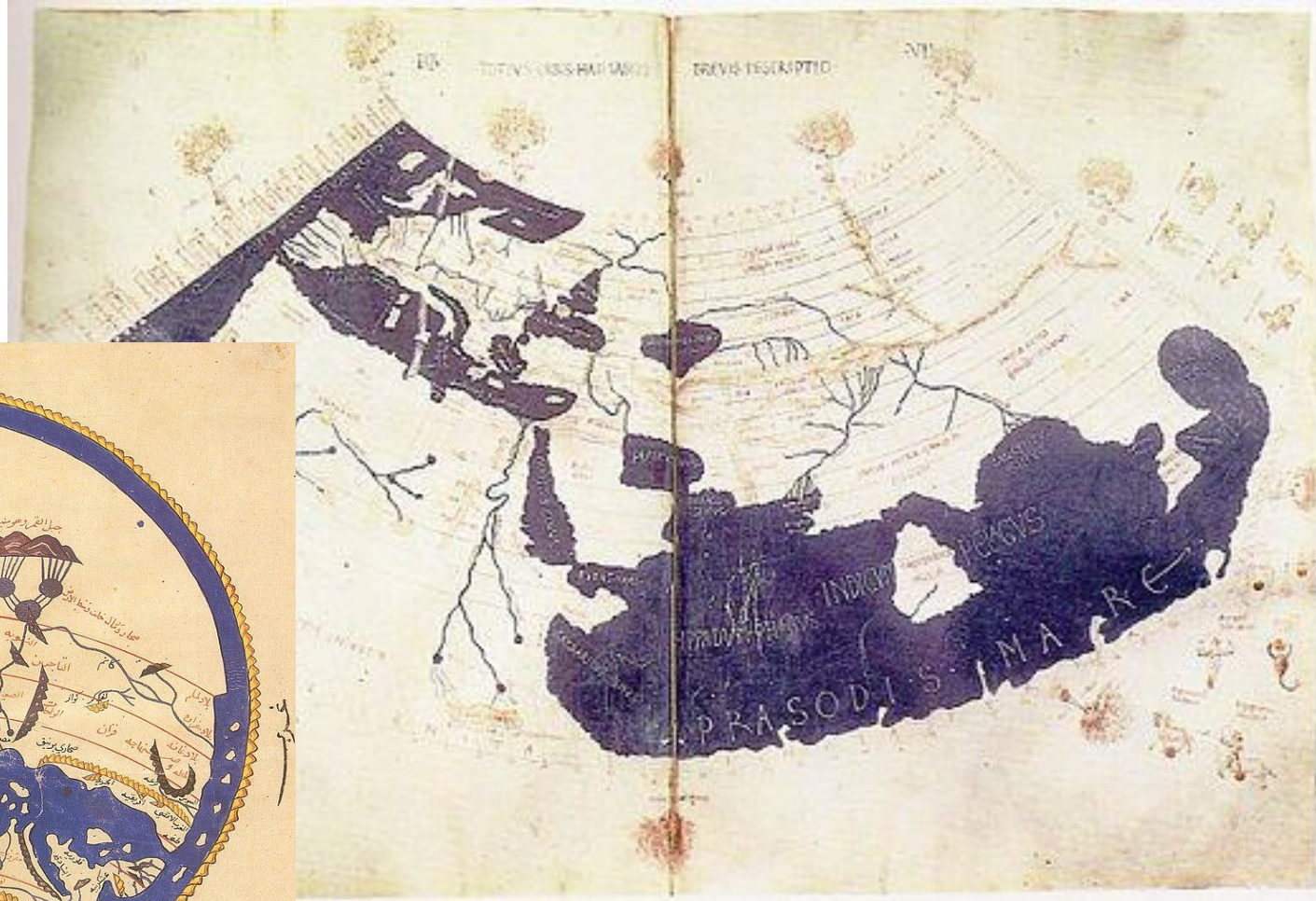
- › Mapping a 3D globe on a flat 2D plane
 - › <https://www.youtube.com/watch?v=kIID5FDi2JQ>

Map Orientation and Projections

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Map Orientation and Projections



Map Orientation and Projections



Map Orientation and Projections



The Economist

North Korea's missiles

At least 1,000 of various types, according to South Korea's defense ministry



Key arsenal

Taepodong-2 First successful launch December 12, 2012 (Unha-3 rocket based on same system)

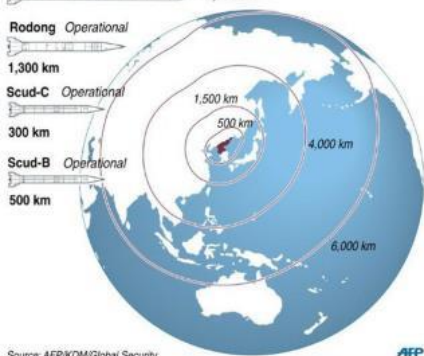
6,700 km

Taepodong-1 Tested 1998 (failed) 2,500 km

Rodong Operational 1,300 km

Scud-C Operational 300 km

Scud-B Operational 500 km



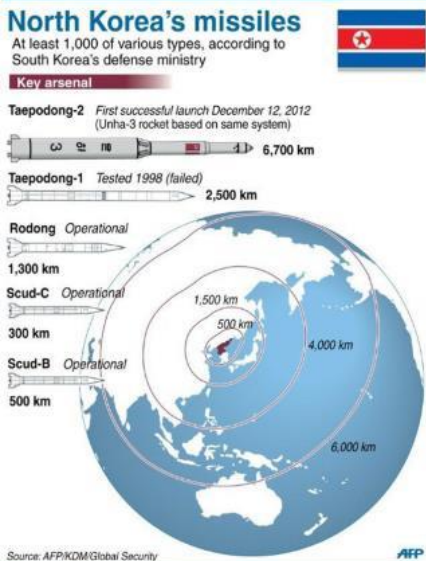
Map Orientation and Projections



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/>