

# **CS260-002: Spatial Data Modeling and Analysis**

## **Introduction to Spatial Computing**

Amr Magdy

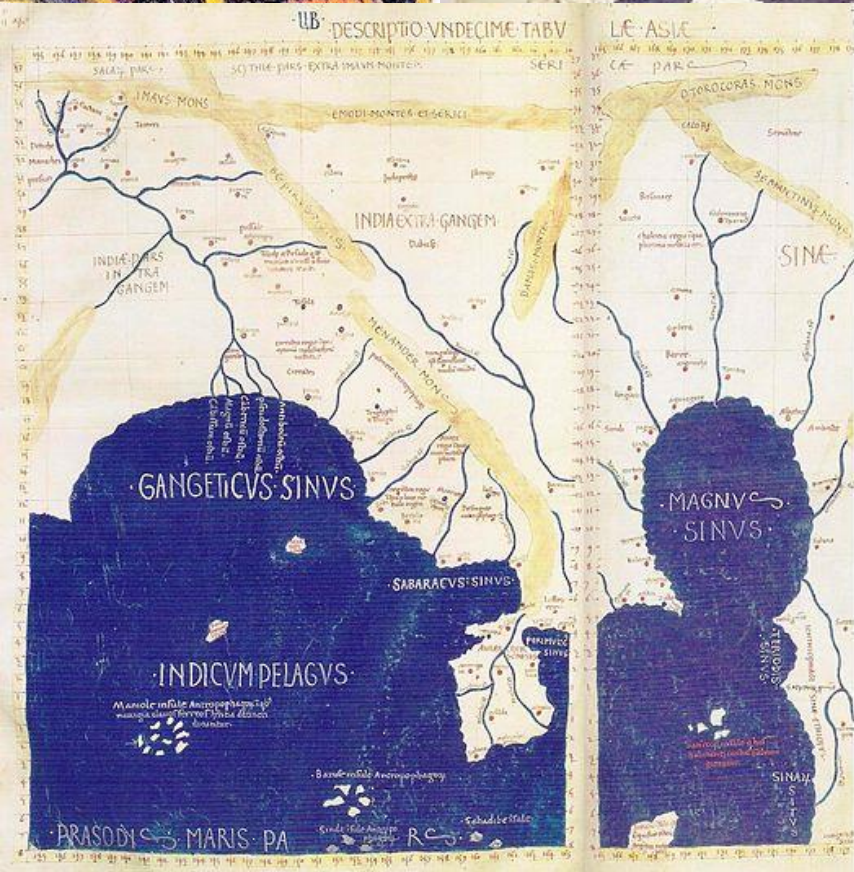
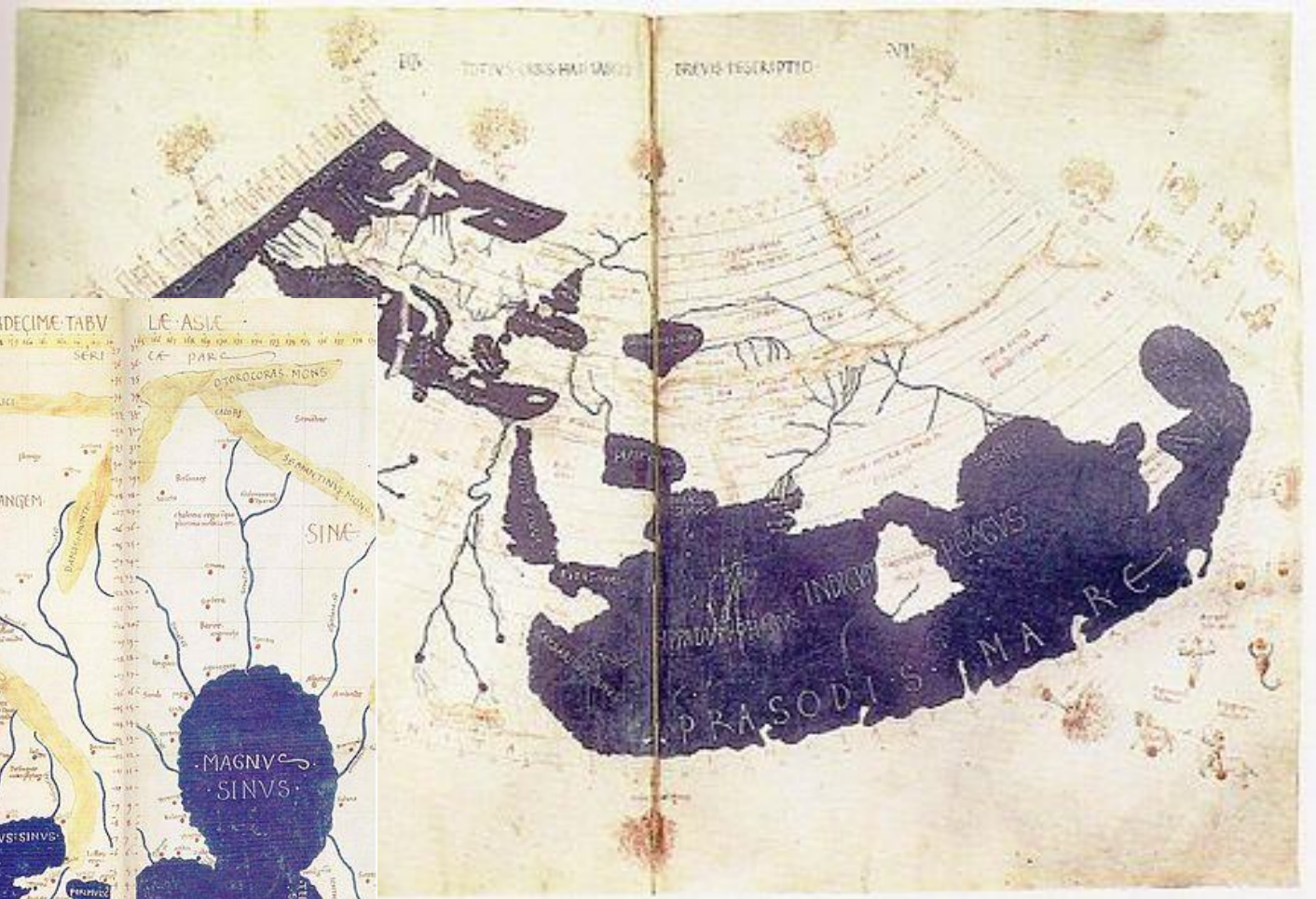
Computer Science and Engineering

[www.cs.ucr.edu/~amr/](http://www.cs.ucr.edu/~amr/)

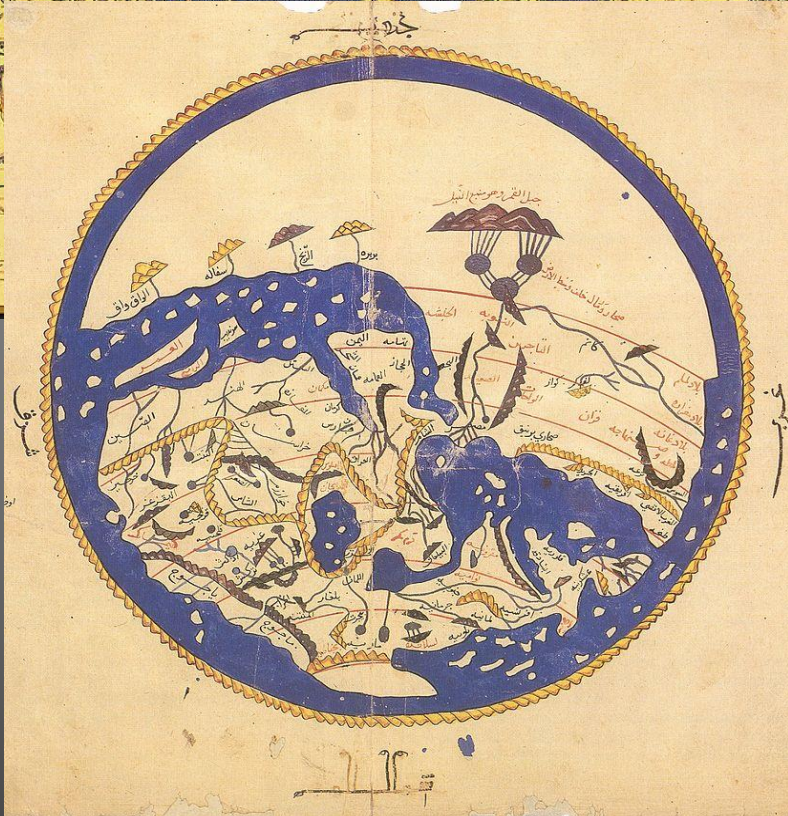
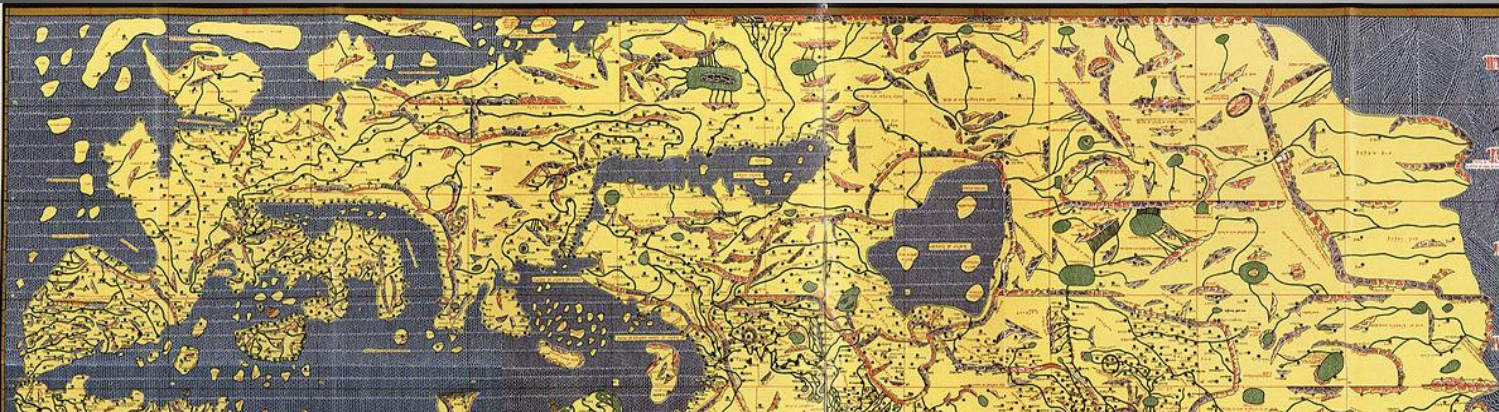
Once upon a  
time...



# Claudius Ptolemy (AD 90 – AD 168)

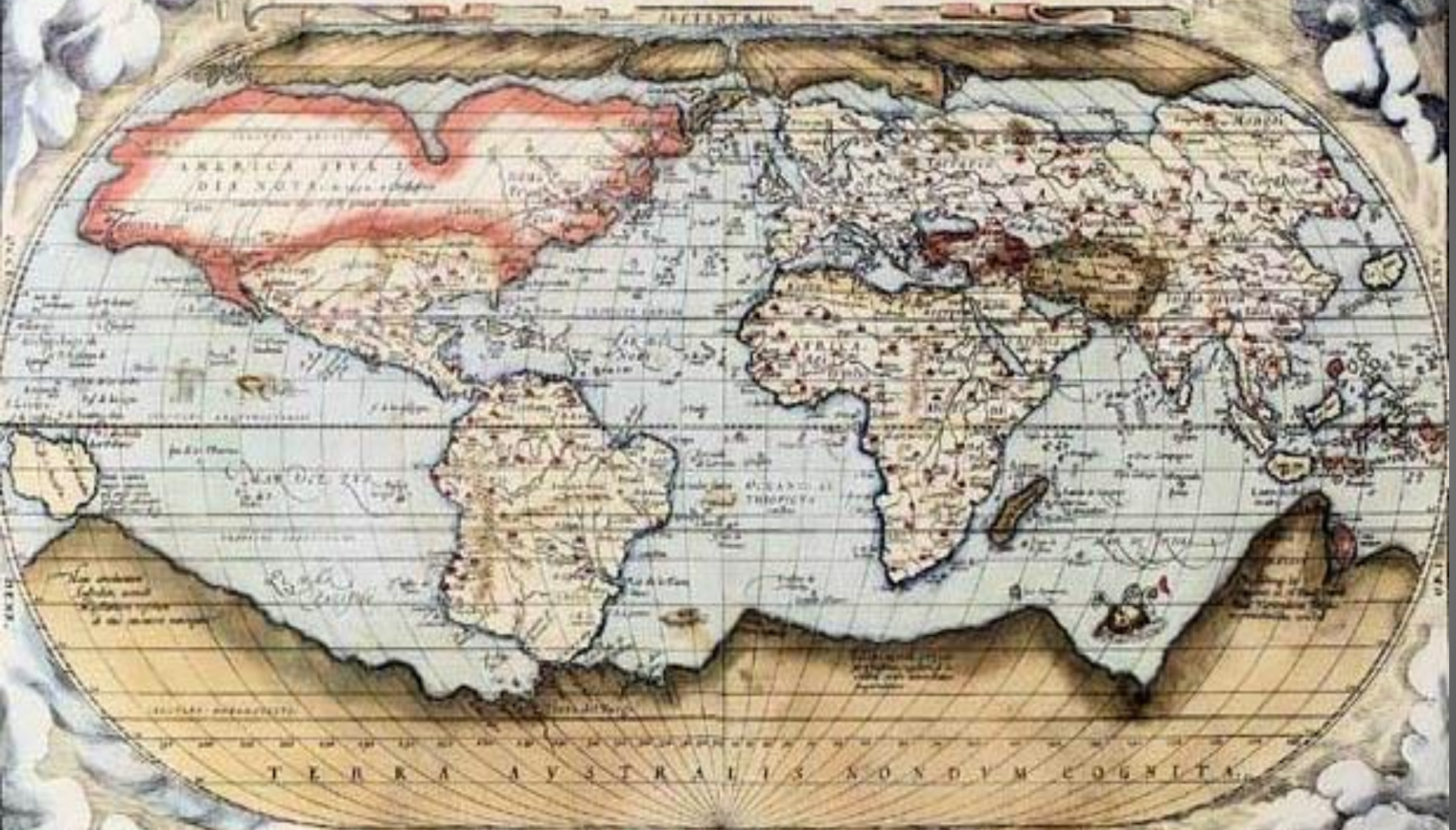


# Al Idrisi (1099–1165)





TYPVS ORBIS TERRARVM



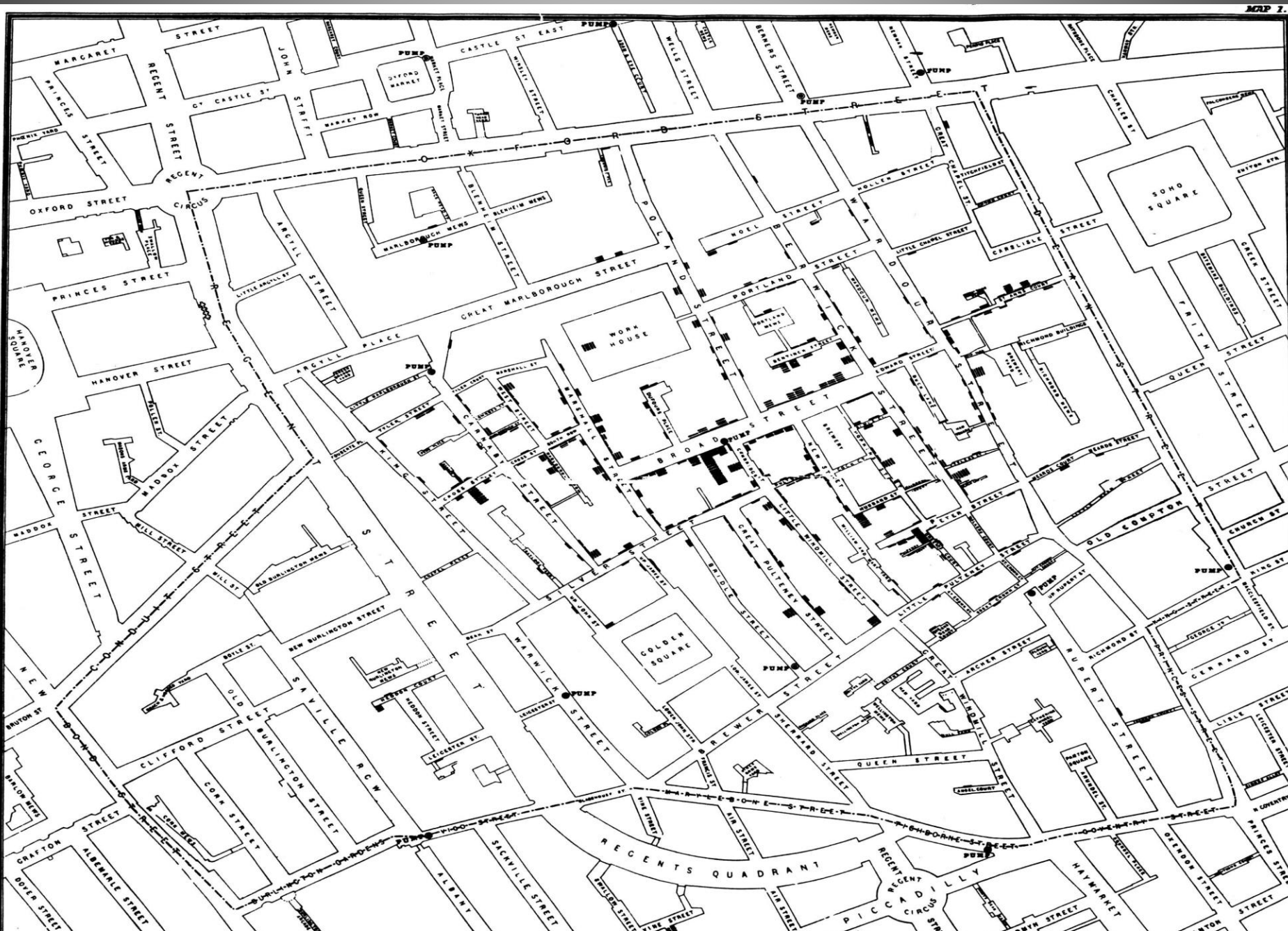
TERRA AUSTRALIS NONDUM COGNITA

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

# ARGONAVTICA.



# Cholera cases in the London epidemic of 1854





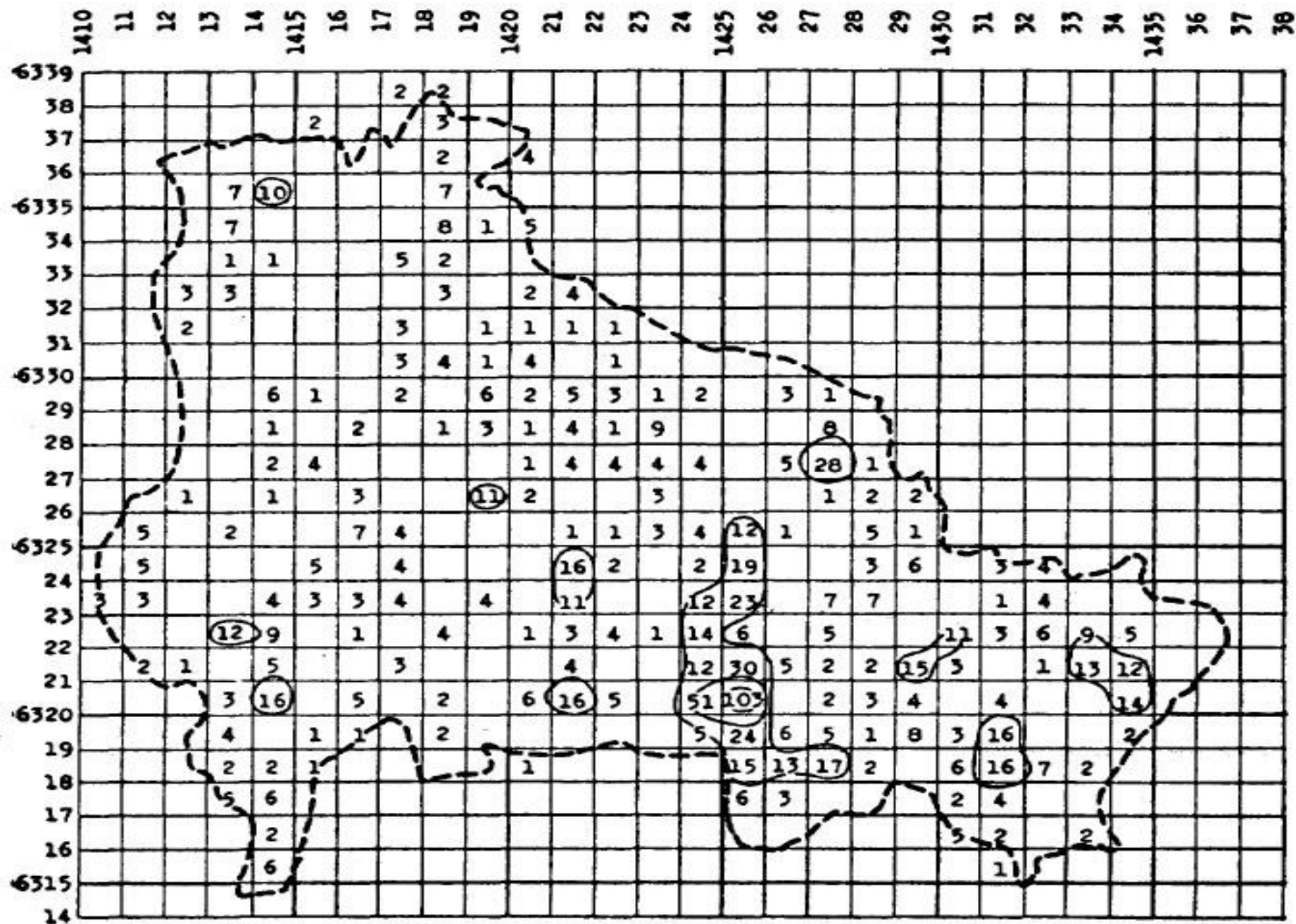


FIGURE 3—Children under 15 years of age in 1940.

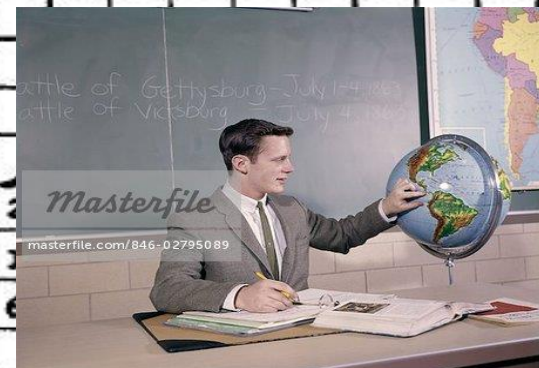
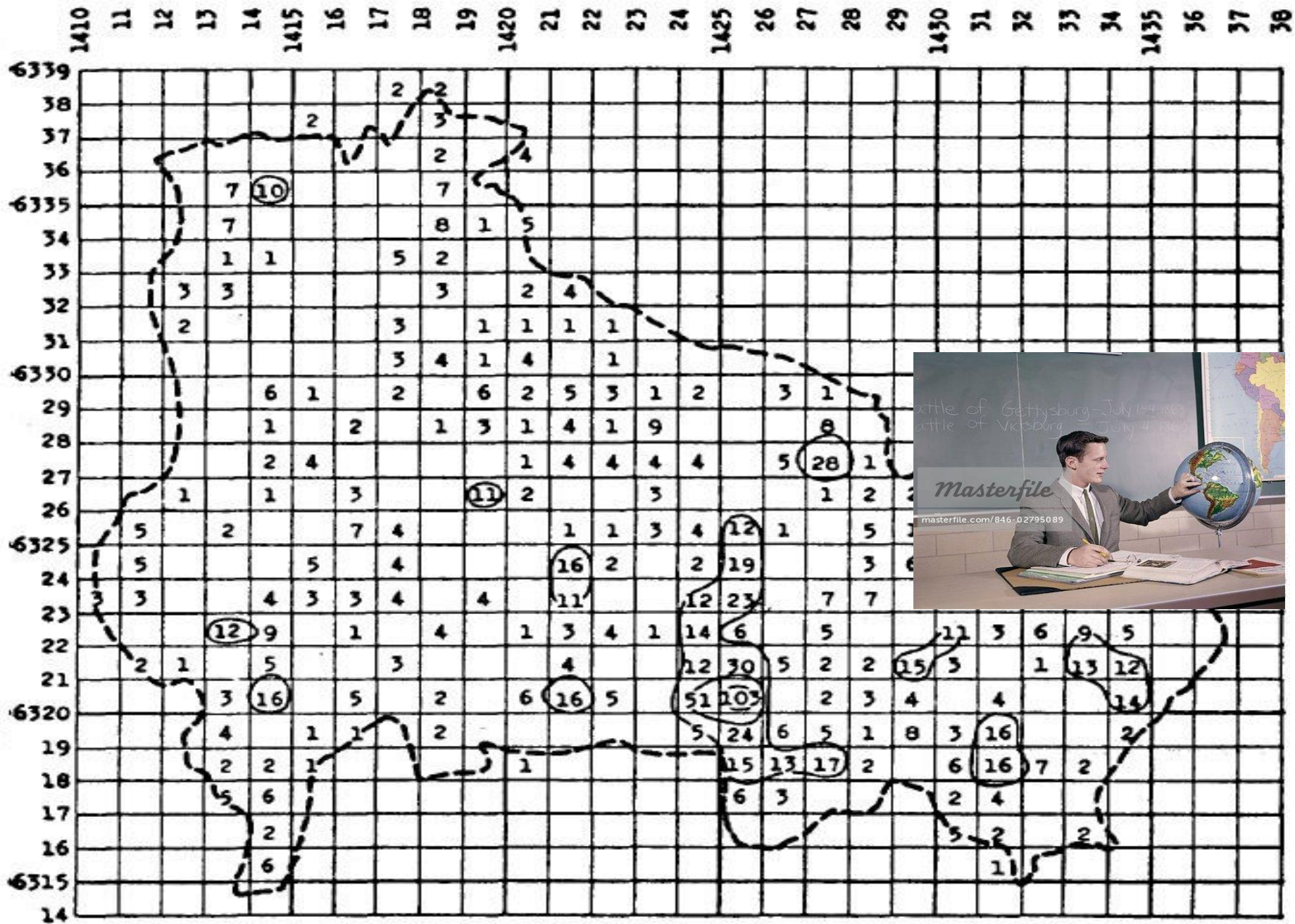
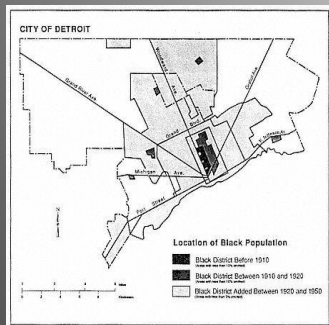
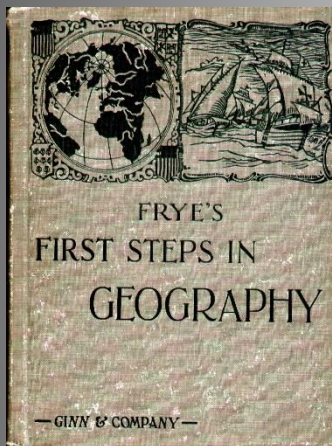
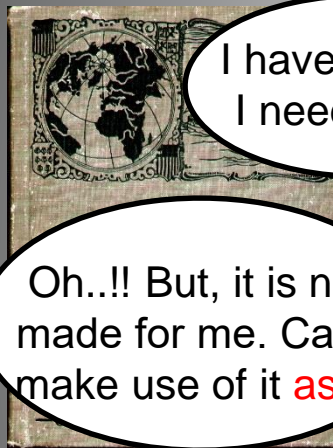


FIGURE 3—Children under 15 years of age in 1940.





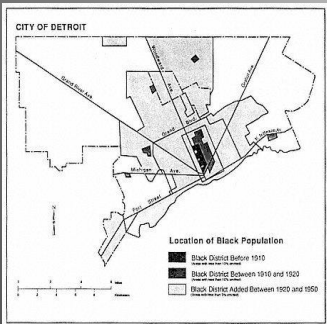
Cool **computer** technology..!!  
Can I use it in my application



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

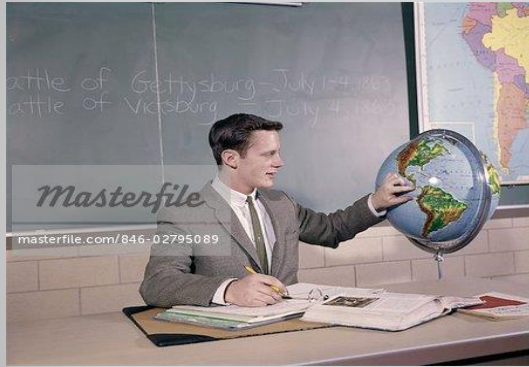


Oh..!! But, it is not made for me. Can't make use of it **as is**



My pleasure.  
Here it is.

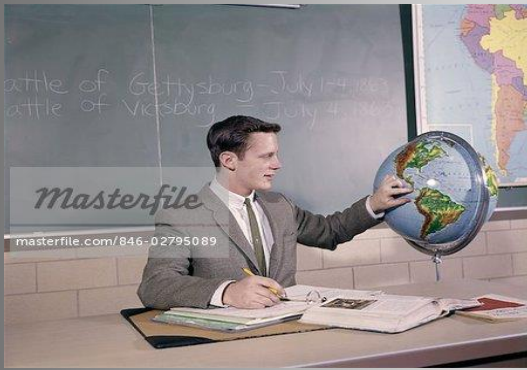




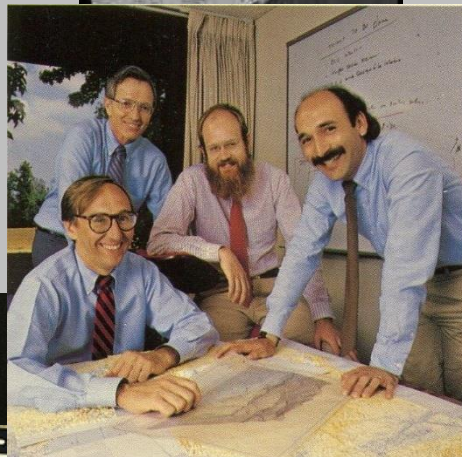
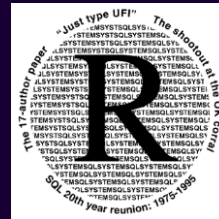
Kindly let me understand your needs

1969

Kindly let me get the technology you have



**ESRI**



# DATABASE MANAGEMENT SYSTEMS



Informix

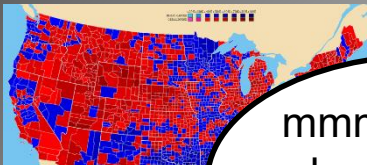
SQL



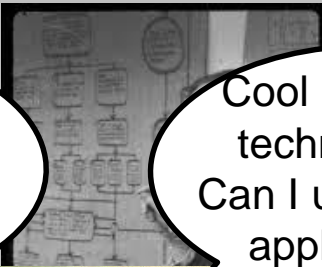
AIRLINE BOOKING



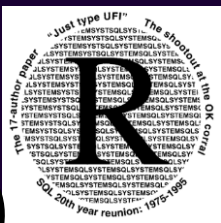
Banking



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



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

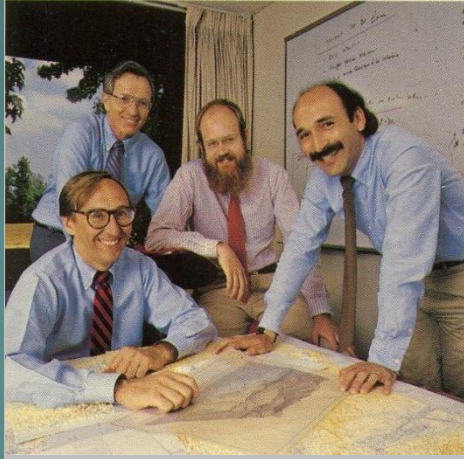


Informix

SQL

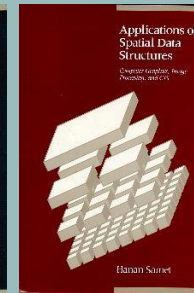
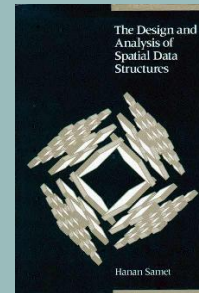
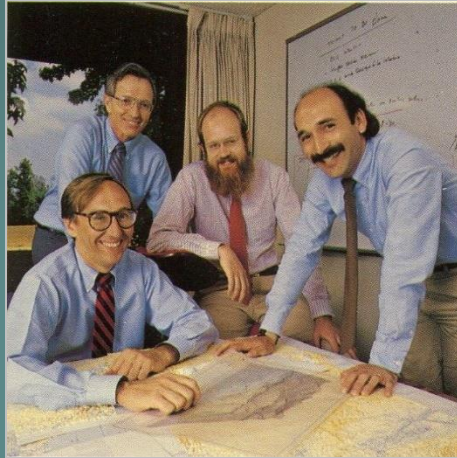
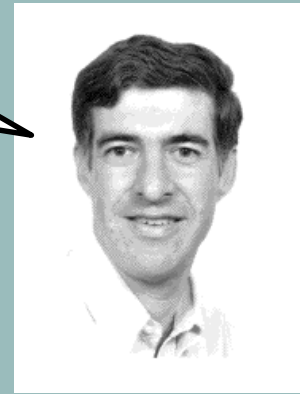


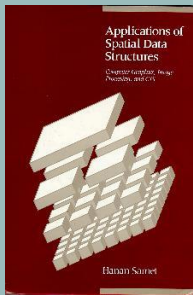
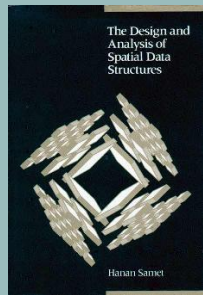


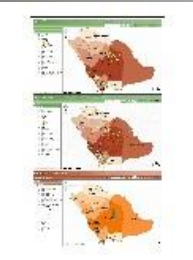
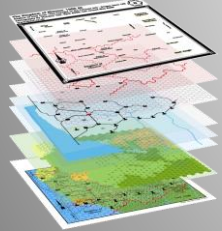
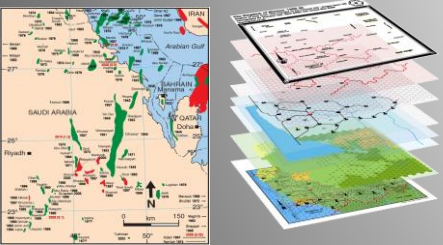
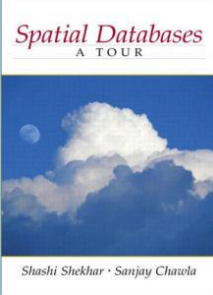
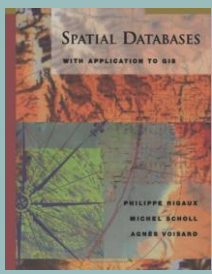
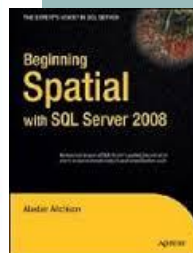
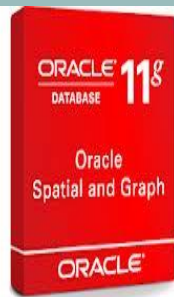
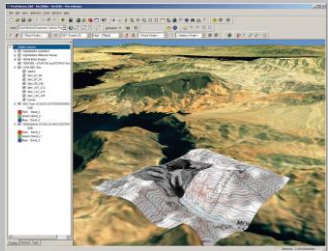
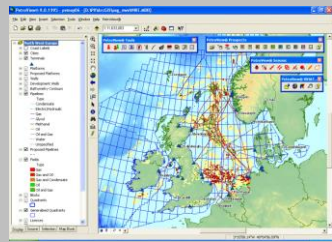
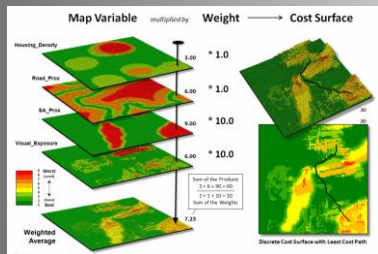


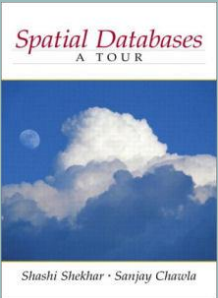
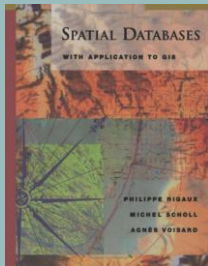
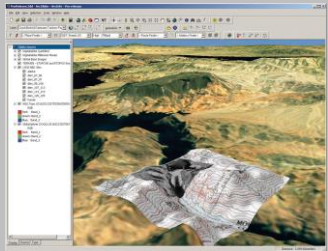
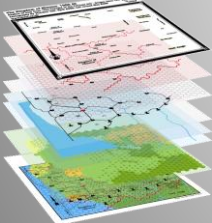
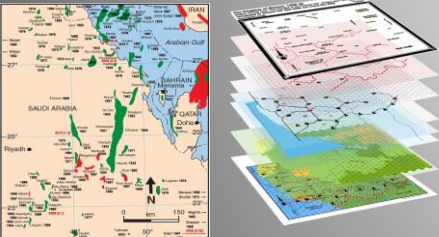
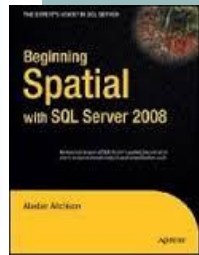
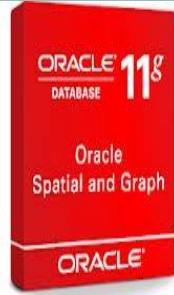
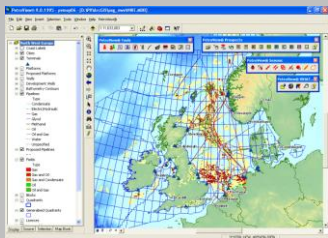
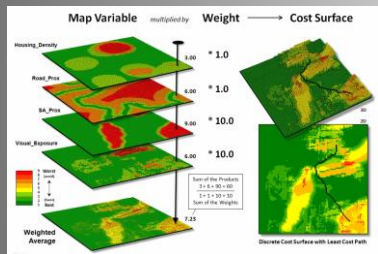
Kindly let me understand your needs

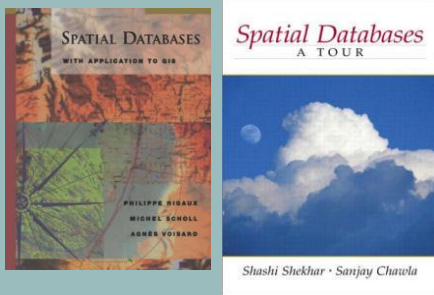
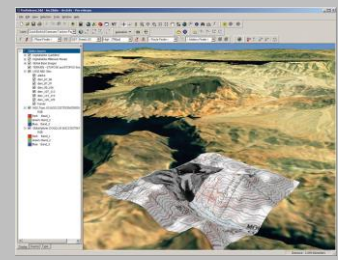
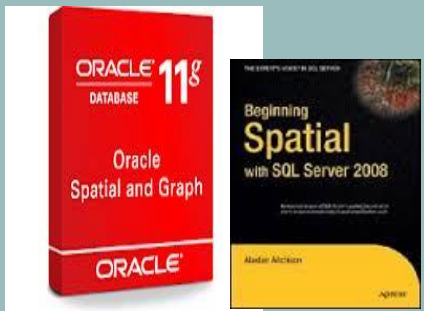
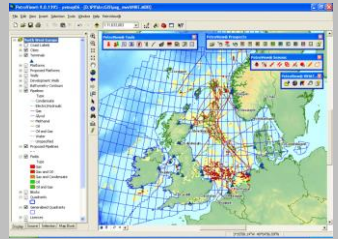
Kindly let me get the technology you have











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

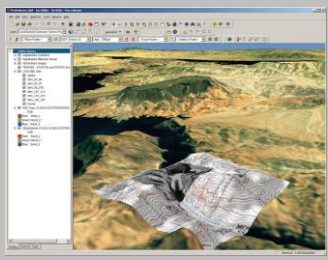
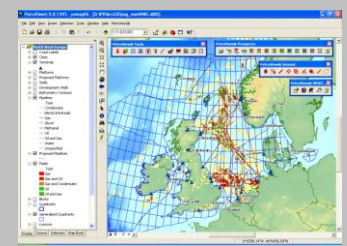
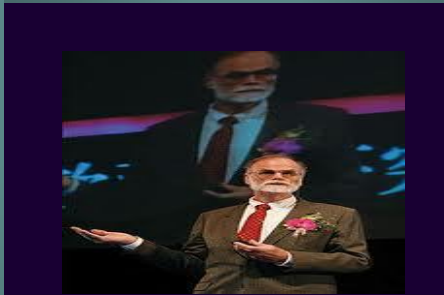
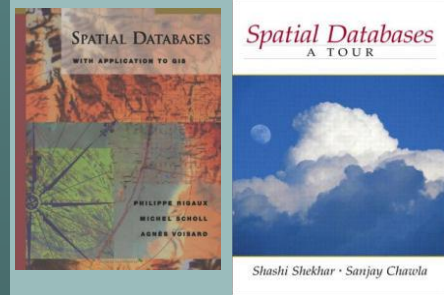
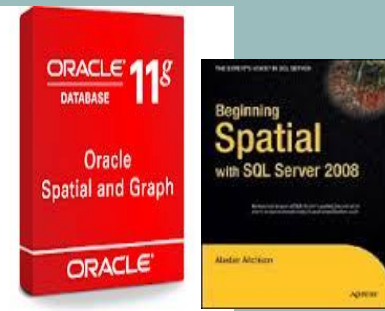
Cool **Big Data** technology..!!  
Can I use it in my application?

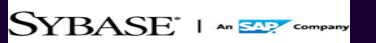
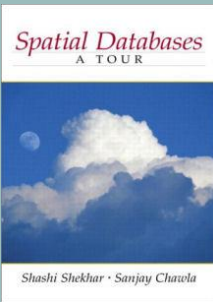
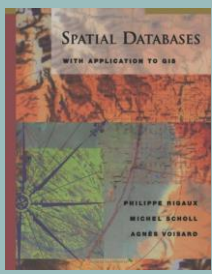
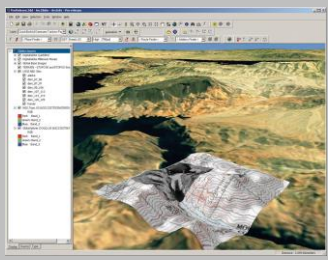
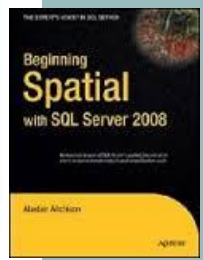
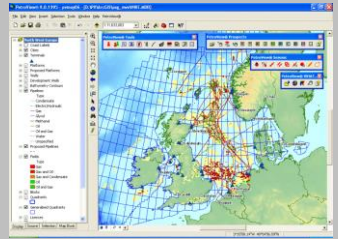
My pleasure.  
Here it is.

HELP..!! Again,  
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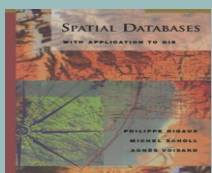
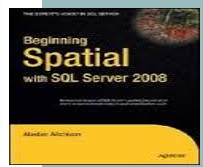
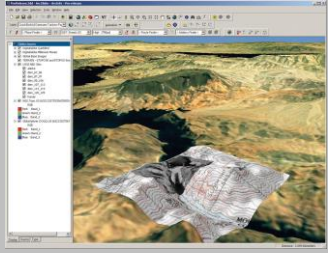
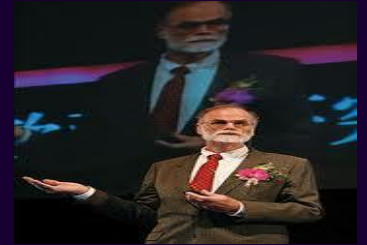
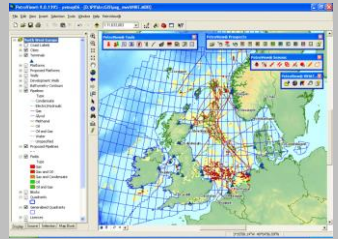
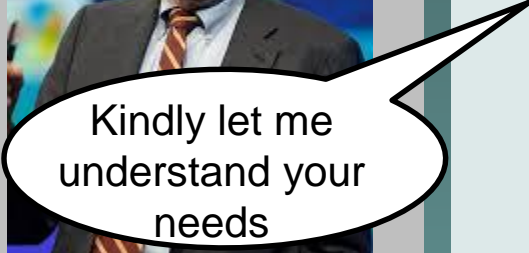
Sorry, seems like  
the DBMS  
technology cannot  
scale more

Oh..!! But, it is not  
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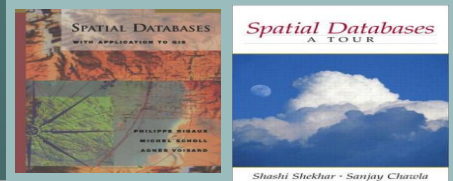
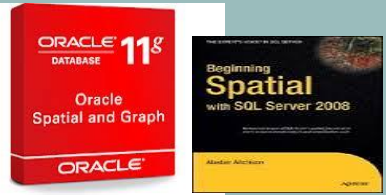
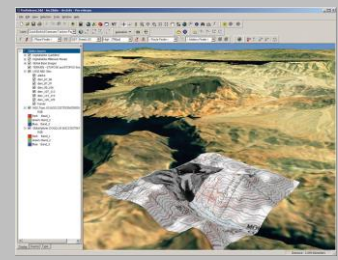
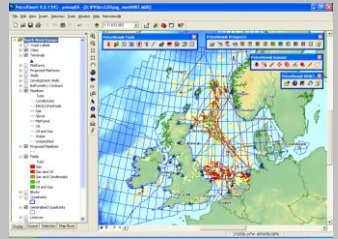








# The Era of Big Spatial Data



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Recent products are there....



**GeoSpark**

**rasdaman**  
raster data manager



**Hadoop-GIS**  
*Spatial Big Data Solutions*



**geomesa**

 **GeoTrellis**

The GeoTrellis logo features a stylized grid of colored squares (green, yellow, blue) to the left of the word "GeoTrellis" in a sans-serif font.

 **SpaceCurve**

The SpaceCurve logo features a stylized globe with curved lines representing latitude and longitude to the left of the word "SpaceCurve" in a sans-serif font.

 **SPHINX**

The SPHINX logo features a stylized sphinx head icon to the left of the word "SPHINX" in a bold, sans-serif font.

# 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 around me?
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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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**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)

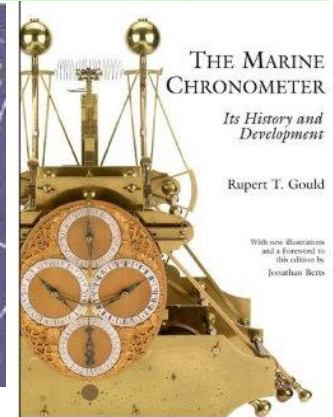
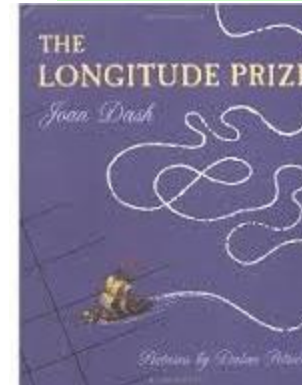
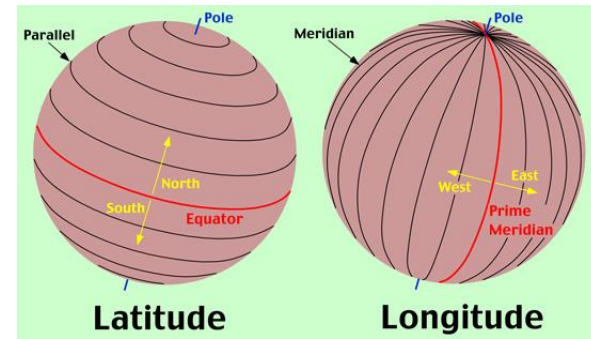
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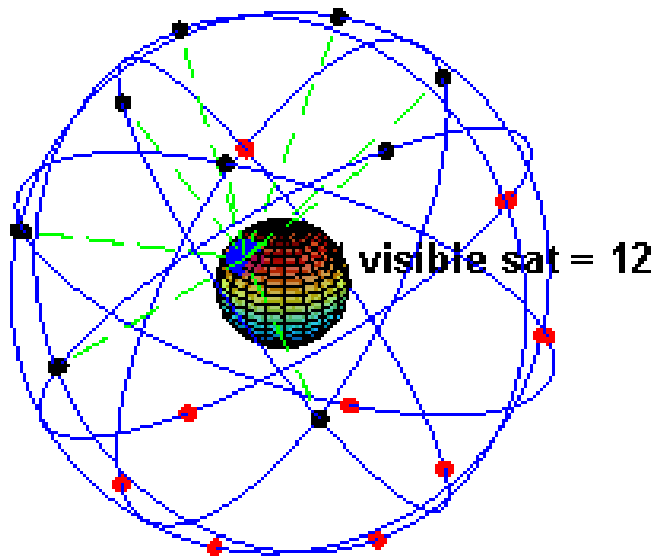
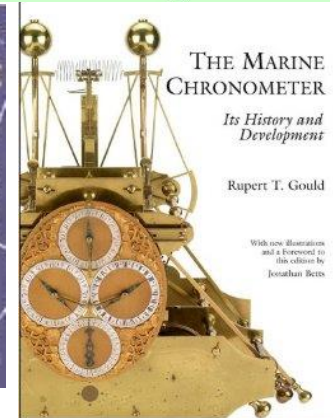
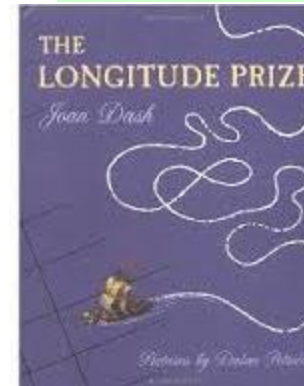
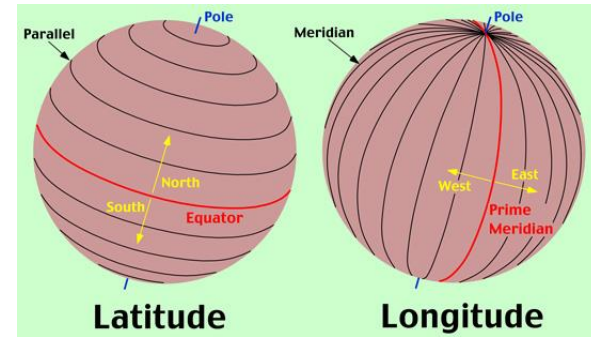
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  - › Latitude (compass, star positions) → ancient and medieval civilizations
  - › Longitude Prize (1714) → marine chronometer



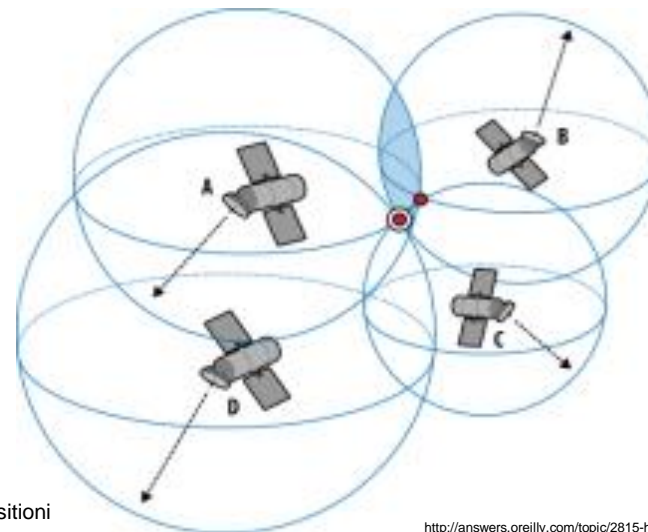
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- Global Navigation Satellite Systems
  - Infrastructure: satellites, ground stations, receivers, ...
  - Use: Positioning (sub-centimeter), Clock synchronization

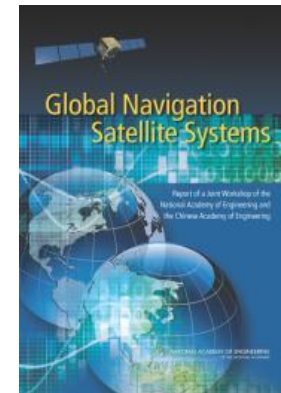


[http://en.wikipedia.org/wiki/Global\\_Positioning\\_System](http://en.wikipedia.org/wiki/Global_Positioning_System)

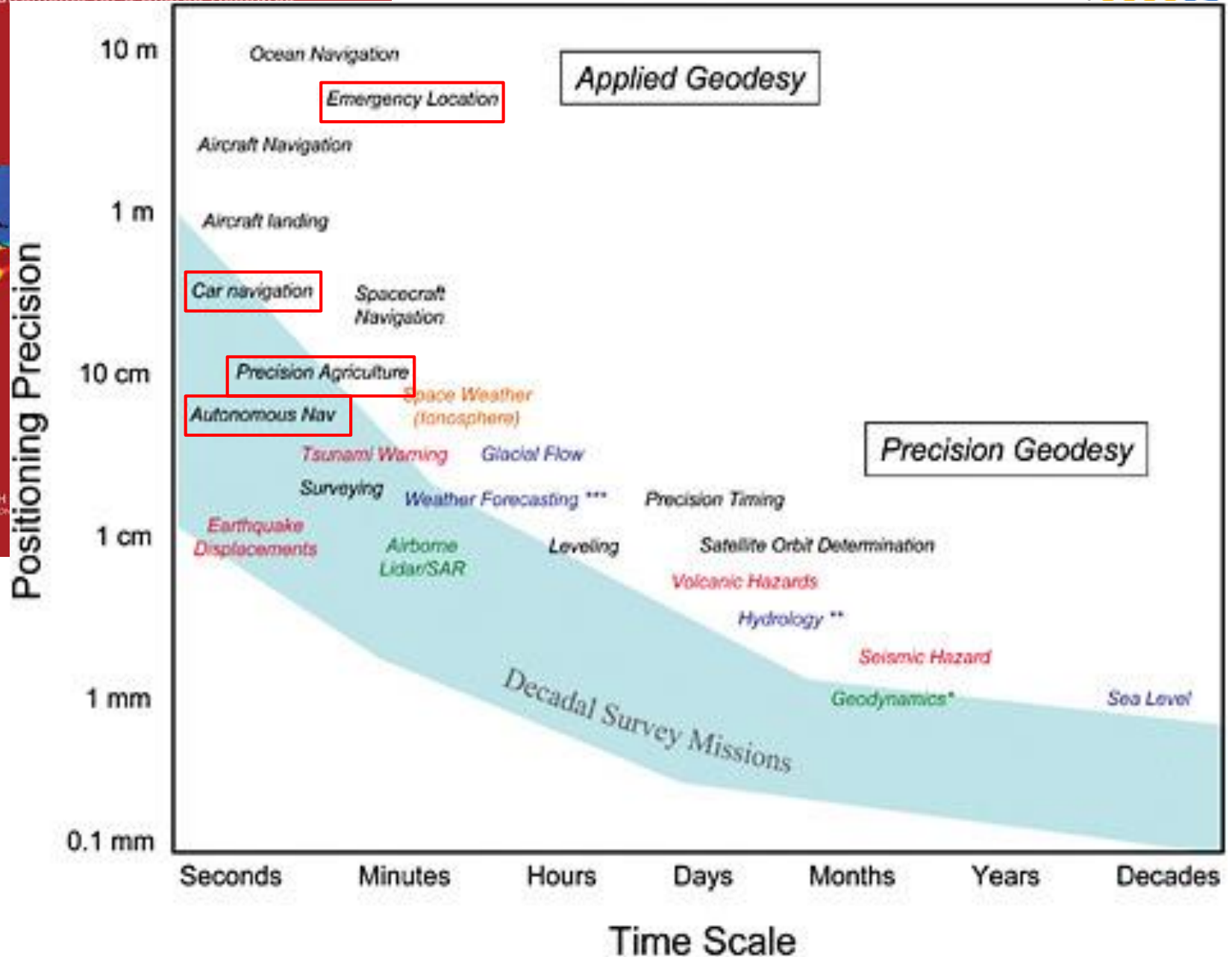
Trilateration



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



# Positioning Precision



# 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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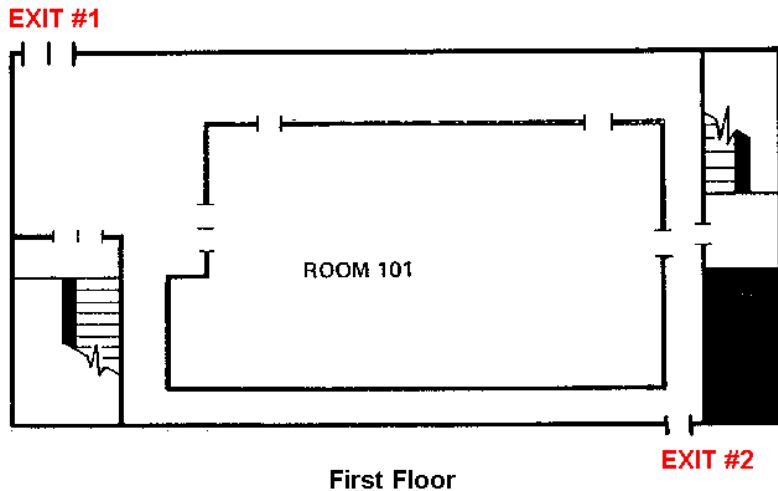
Get In-Store Notifications



# 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 ?



Get In-Store  
Notifications

WiFi Localization



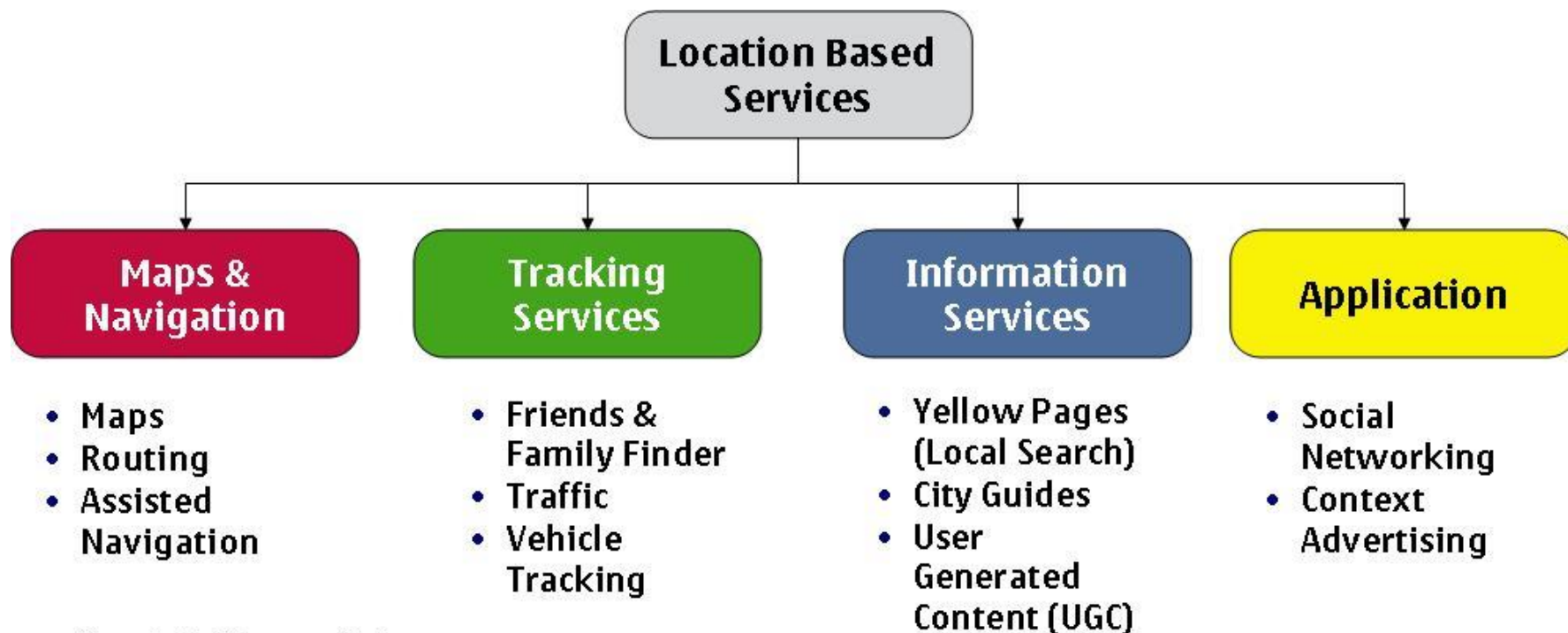
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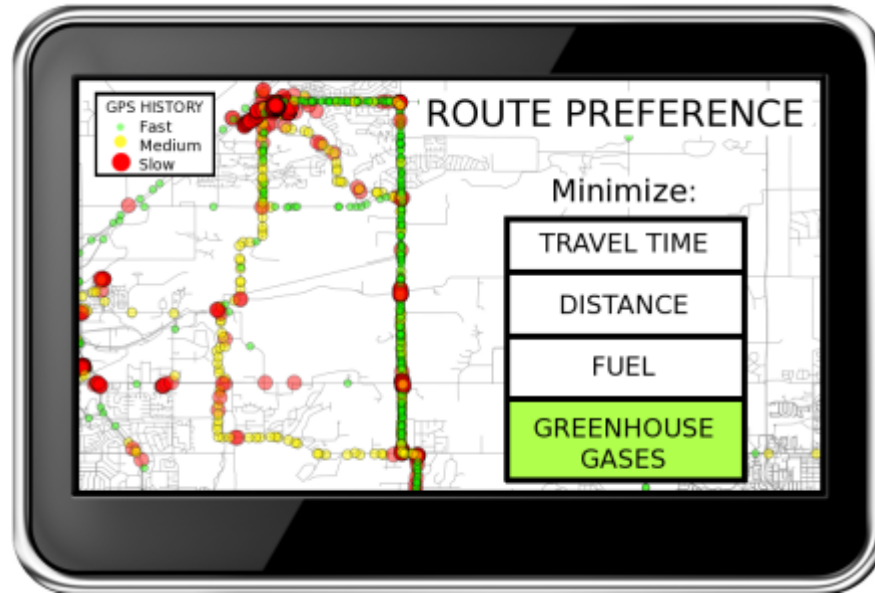
# Location Based Services

- › 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



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



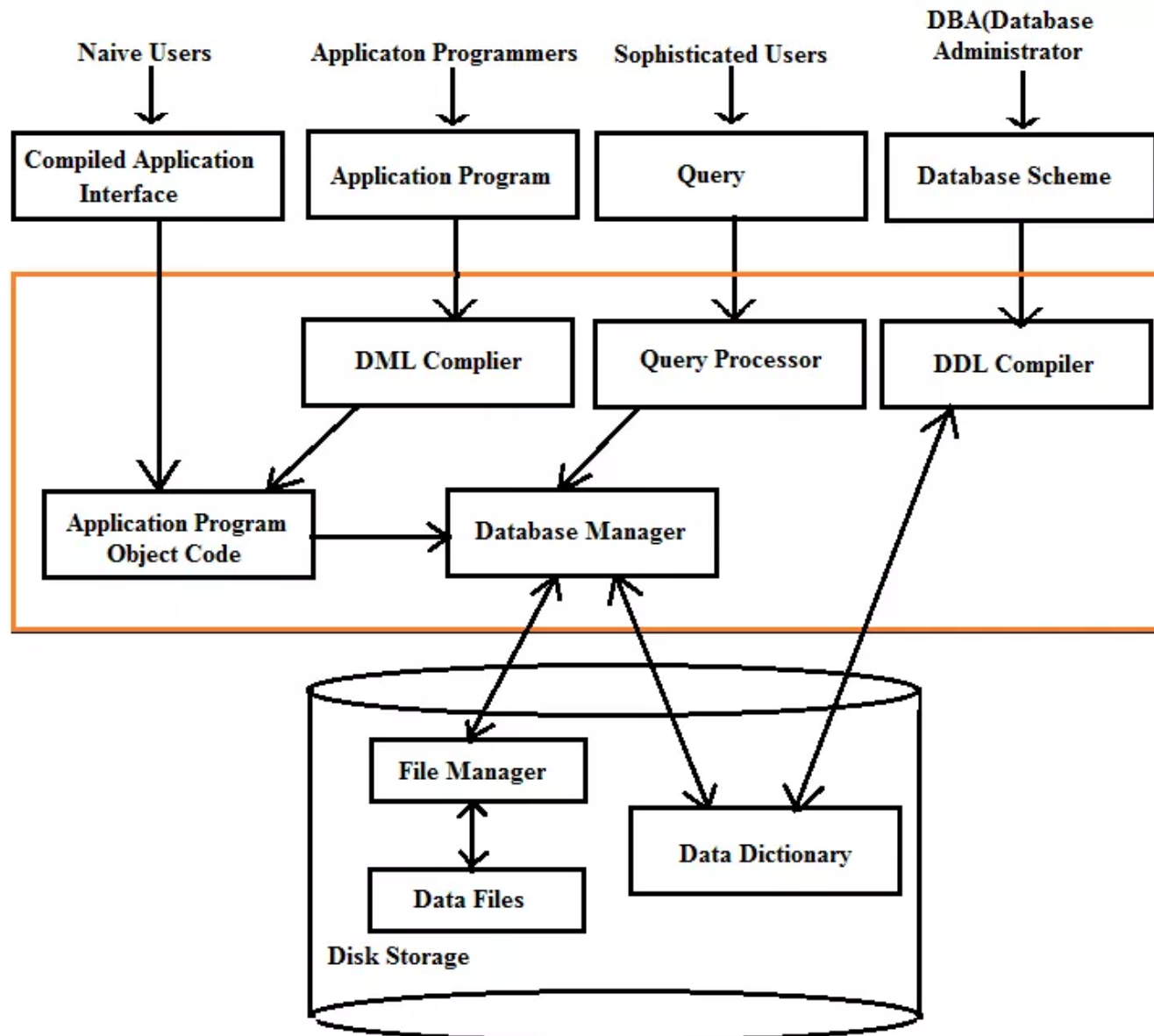
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# Database Management Systems (DBMSs)



# 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

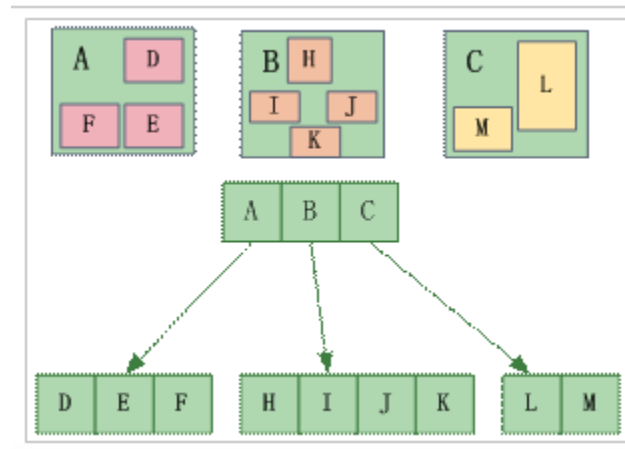
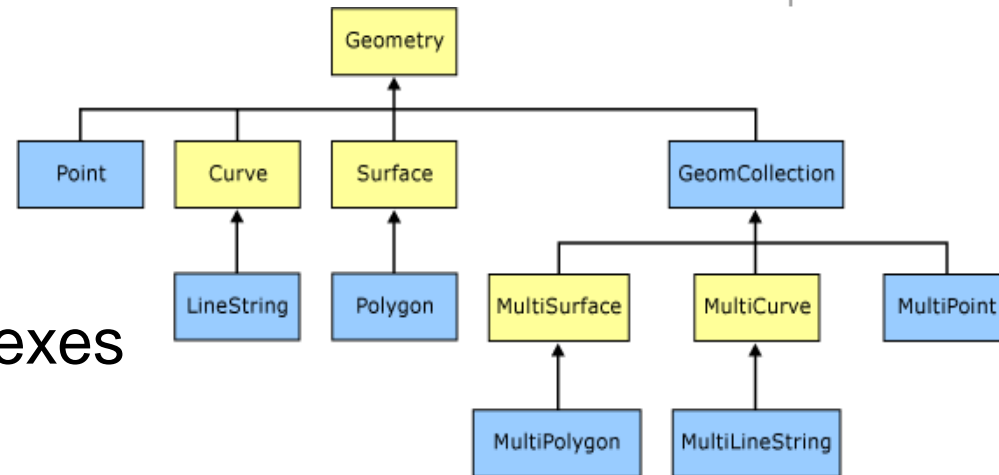
# SDBMS: Non-Spatial vs. Spatial Queries



- › 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,
```

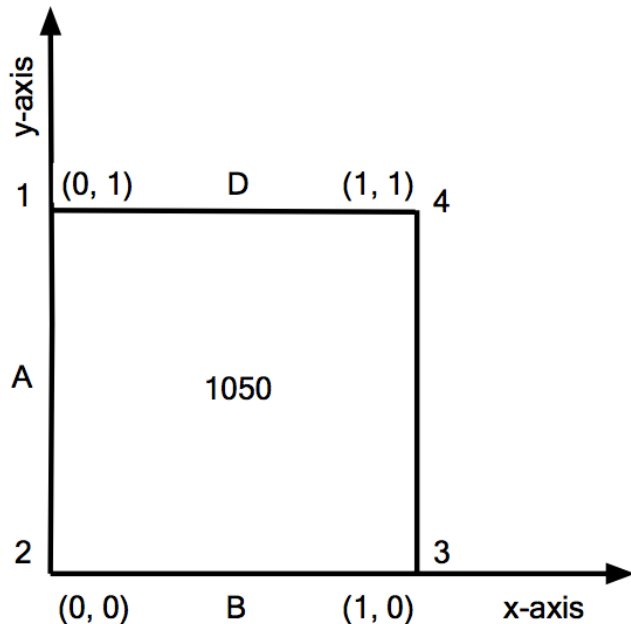
```
boundary      polygon );
```





# 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

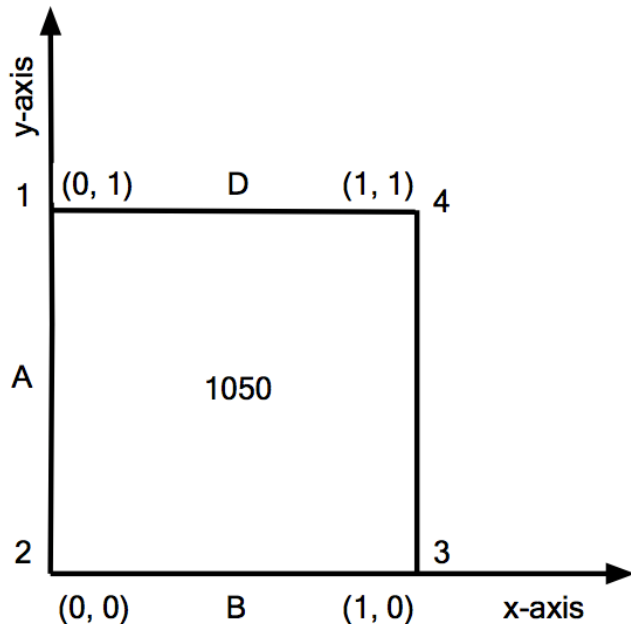


Census\_blocks

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

# Spatial beyond Databases



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

# Spatial beyond Databases

**Simba**



**GeoSpark**

**rasdaman**  
raster data manager



**Hadoop-GIS**  
*Spatial Big Data Solutions*



**geomesa**

 **GeoTrellis**

 **SpaceCurve**

 **SPHINX**

# 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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## 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

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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?
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# Challenges: Security vs. Utility

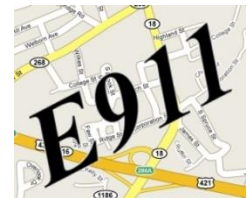


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  - › Public Safety
  - › Policy Makers
- › Agreements and disagreements
  - › Agreements: E911, emergency alerts
  - › Controversial: traffic monitoring



# 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

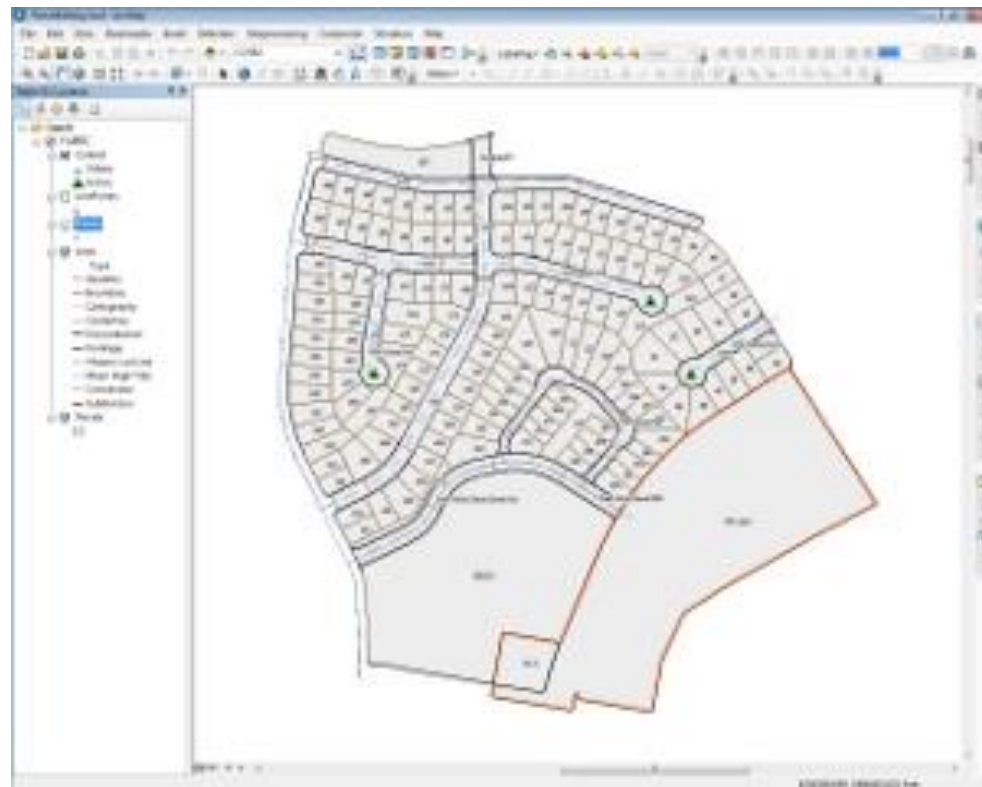
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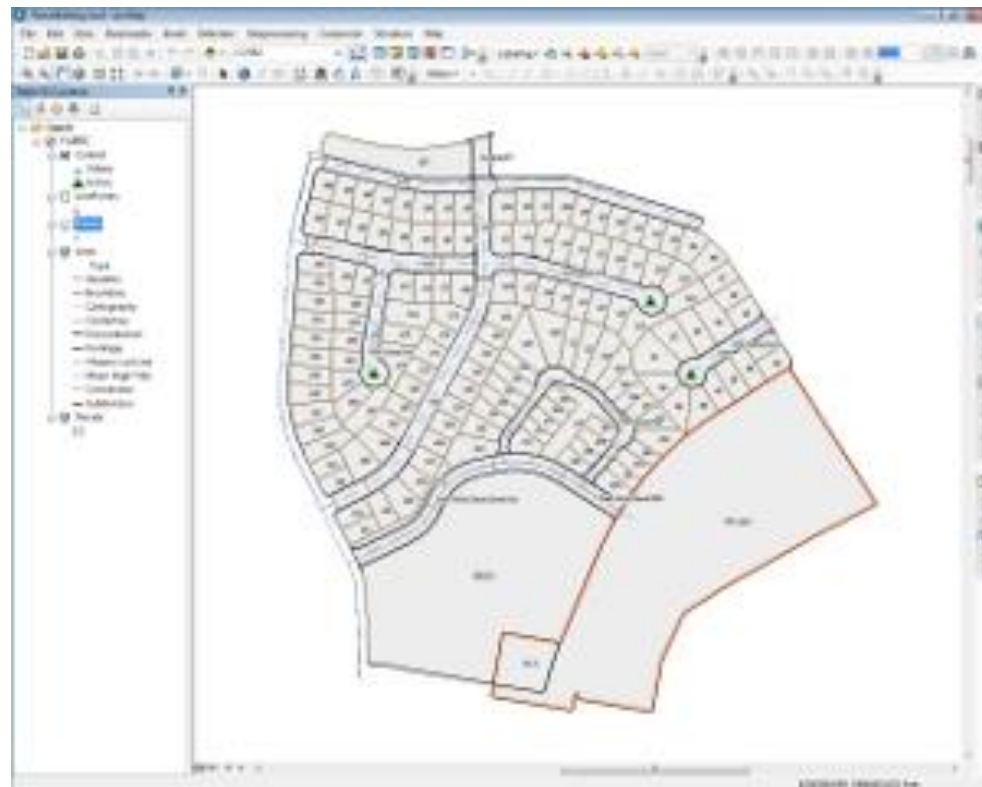
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  - ▶ Creating and using maps
  - ▶ Compiling geographic data
  - ▶ Analyzing mapped info
  - ▶ Sharing and discovering geographic information



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  - › Rich high-level analysis
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- › SDBMS used to store, index, and query spatial data efficiently
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- › SDBMS can be used by applications other than GIS
  - › Astronomy, location-based services, brain informatics, etc

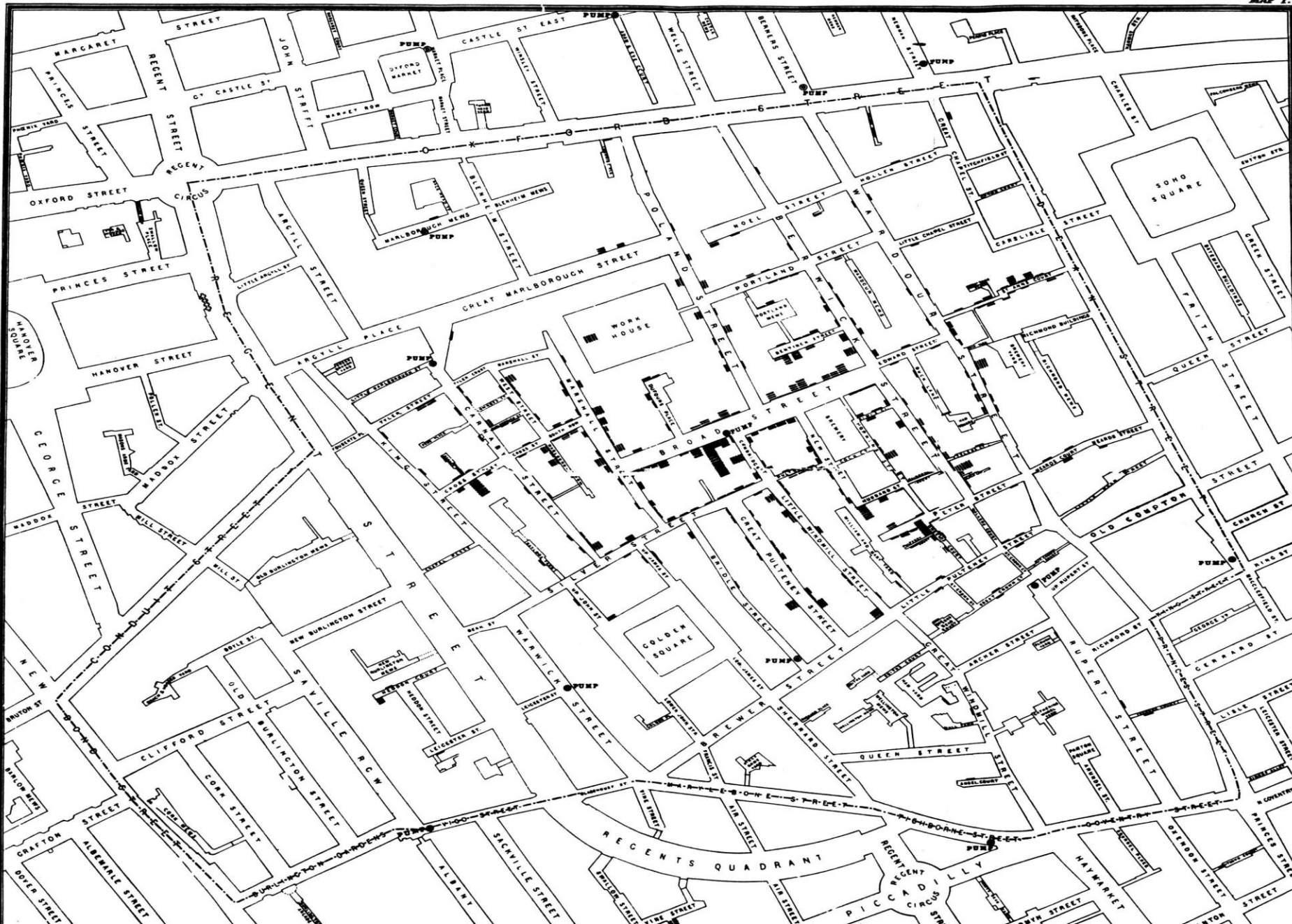
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# Cholera cases in the London epidemic of 1854

MAP 1.



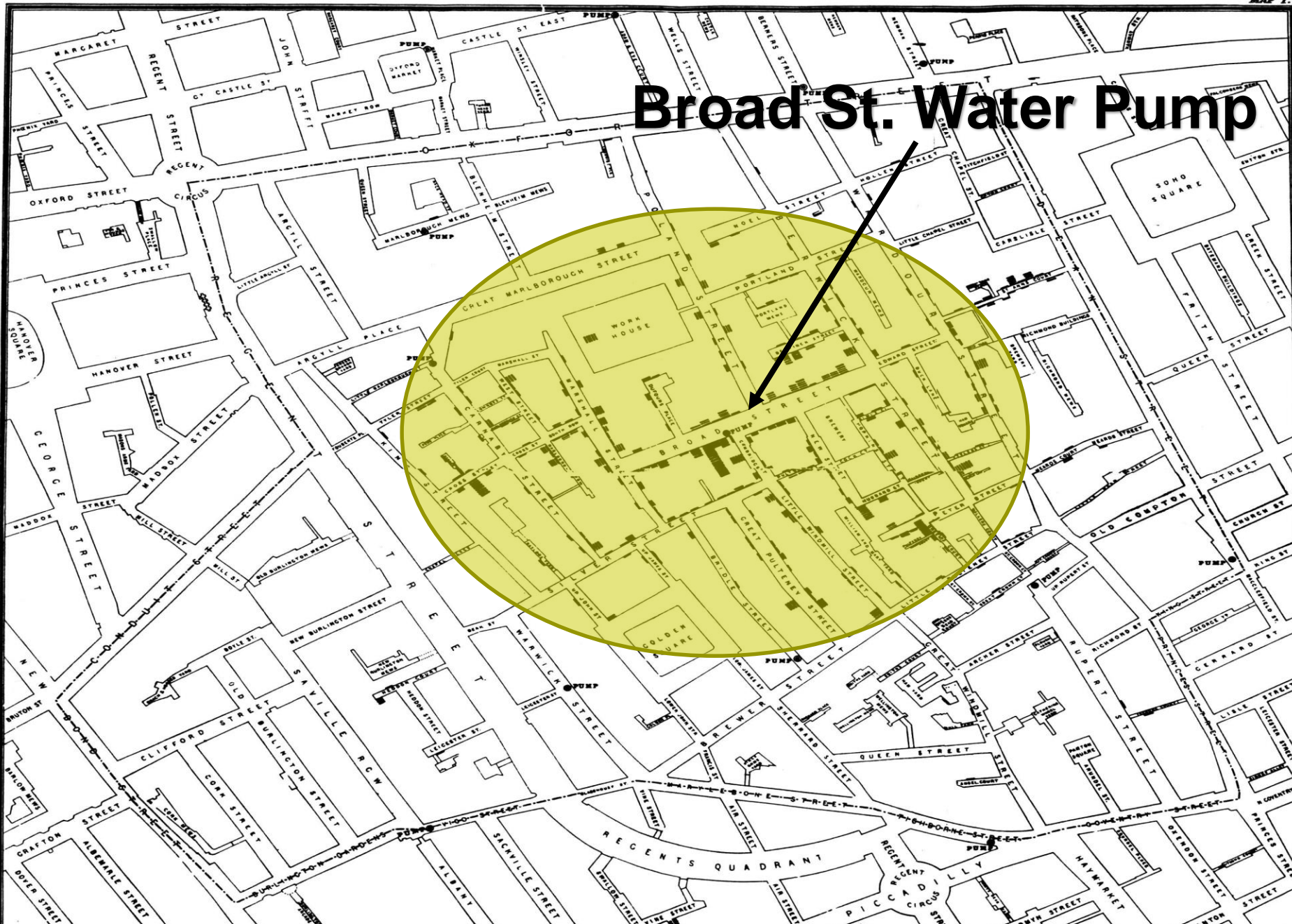
# Cholera cases in the London epidemic of 1854





# 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
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Source: New York Mayor's Office

By The New York Times

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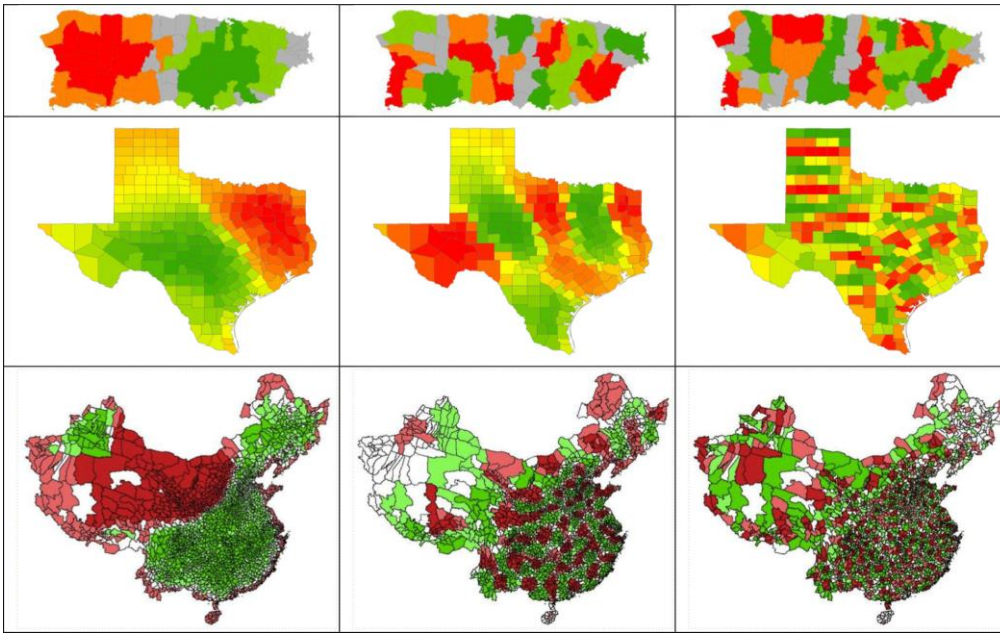
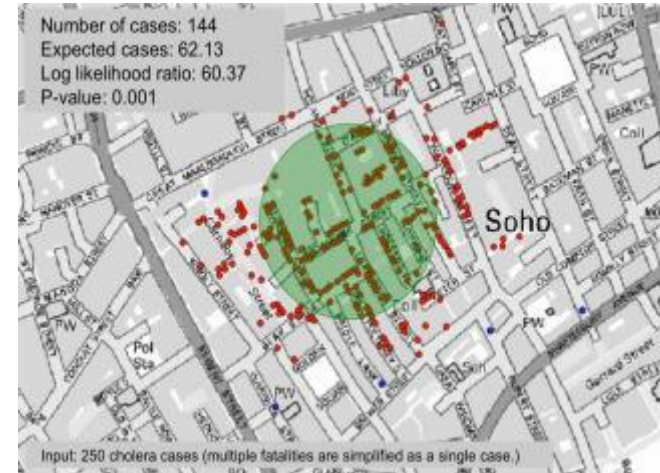
By The New York Times



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

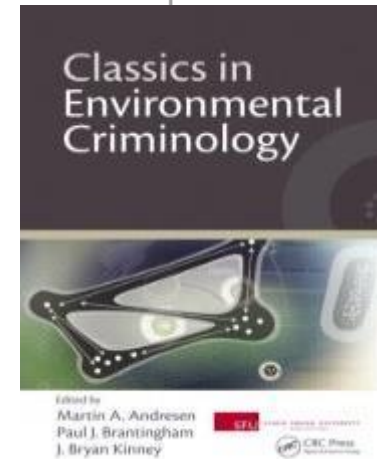
# Spatial Statistics

- › 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

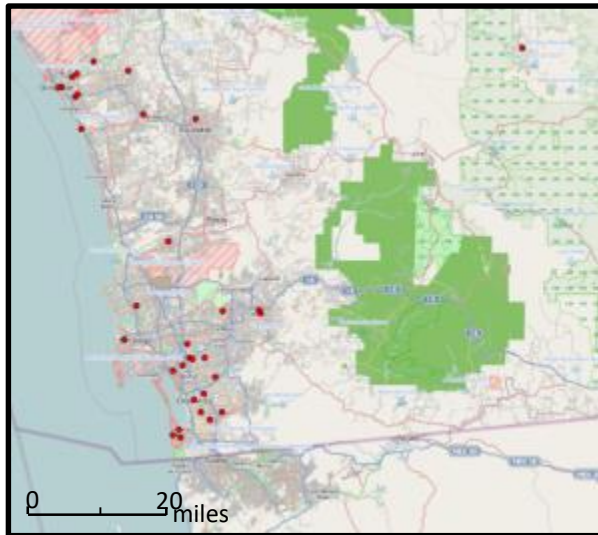


# Detecting Spatial Patterns

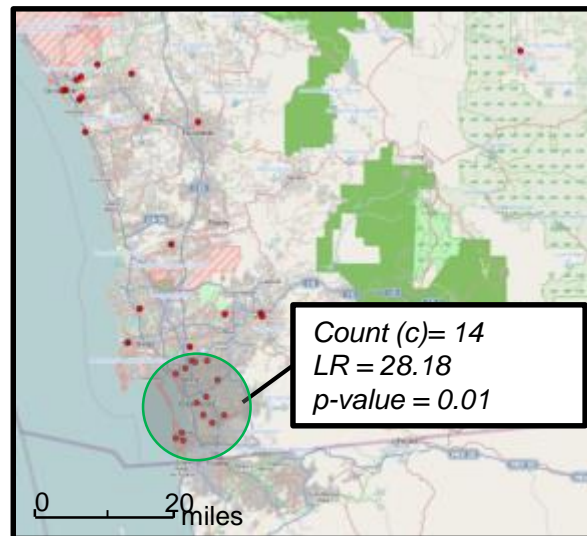
- › Arson crimes in San Diego in 2013
  - › Total 33 cases (red dots on the map)
  - › Activity Area is appr. 3000 sq. miles.
- › Arsonist caught in top green ring<sup>2</sup>



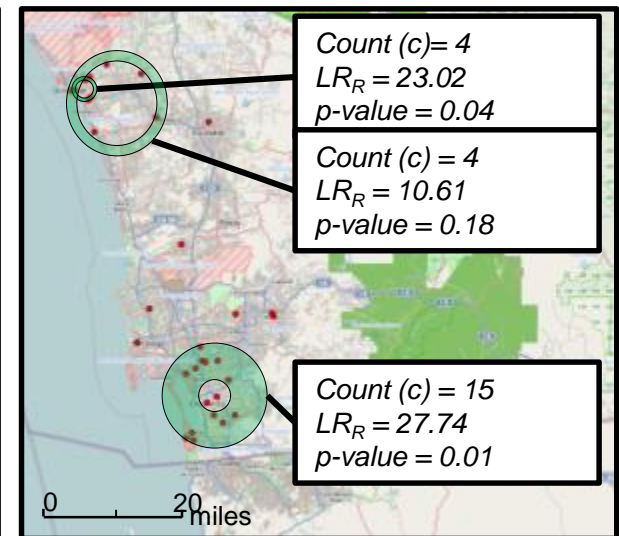
Input



SaTScan output



Significant Ring Detection

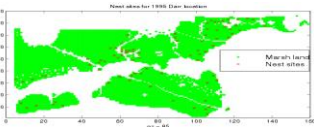


Green: Rings with LR >10 & p-value < 0.20

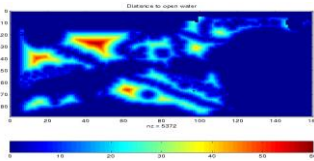
- (1) <http://www.sandiego.gov/police/services/statistics/index.shtml>
- (2) <http://www.nbcsandiego.com/news/local/Suspected-Arson-Grass-Fires-Oceanside-Mesa-Drive-Foussat-Road-218226321.html>
- (3) Ring-Shaped Hot-Spot Detection: A Summary of Results, IEEE Intl. Conf. on Data Mining, 2014.

## Location Prediction: nesting sites

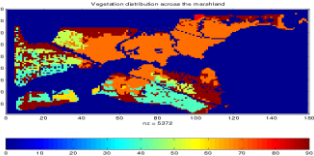
Nest locations



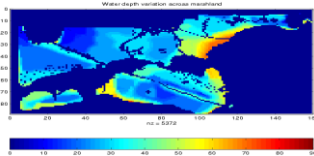
Distance to open water



Vegetation durability



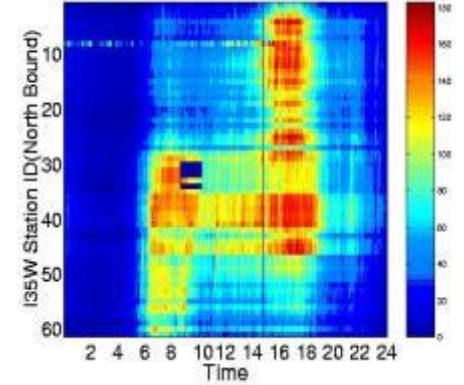
Water depth



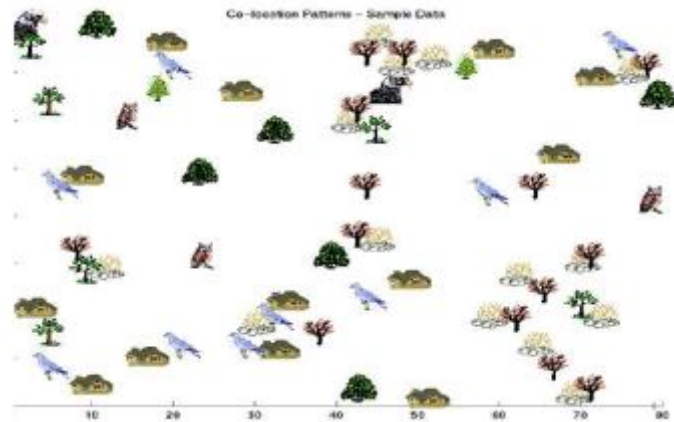
## Spatial outliers: sensor (#9) on I-35



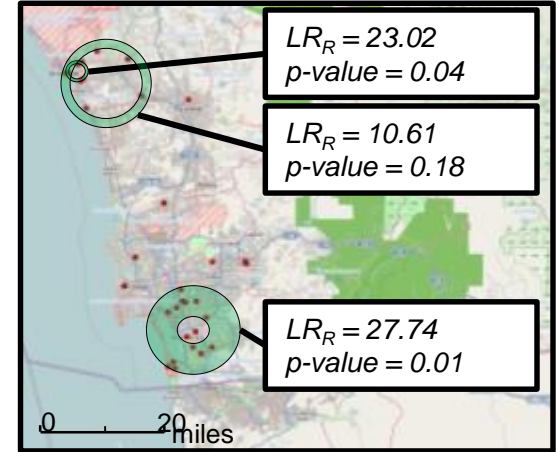
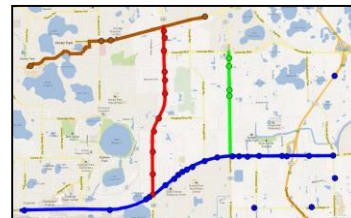
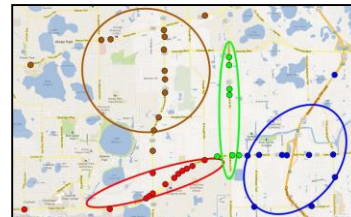
Average Traffic Volume (Time v.s. Station)



## Co-location Patterns



## Spatial Concept Aware Summarization



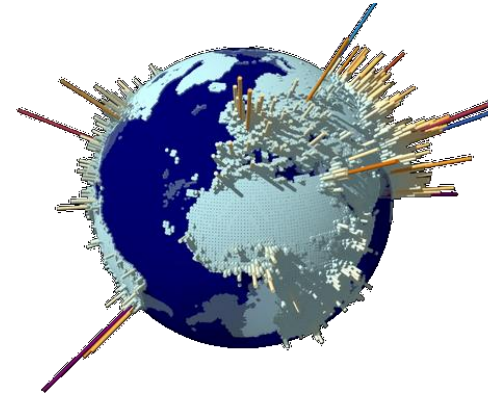
# Major technologies and areas (past, present, & future)



- › 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)**

# Virtual Globes and VGI (or CGI)

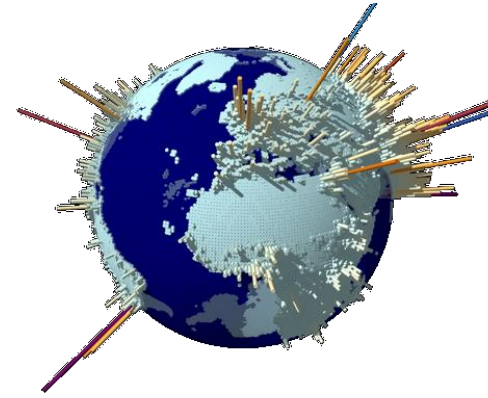
- › LBS accessibility
- › Visualization
- › Volunteering  
(or Crowdsourcing) geo  
information
- › Education





# Virtual Globes and VGI (or CGI)

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



# 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



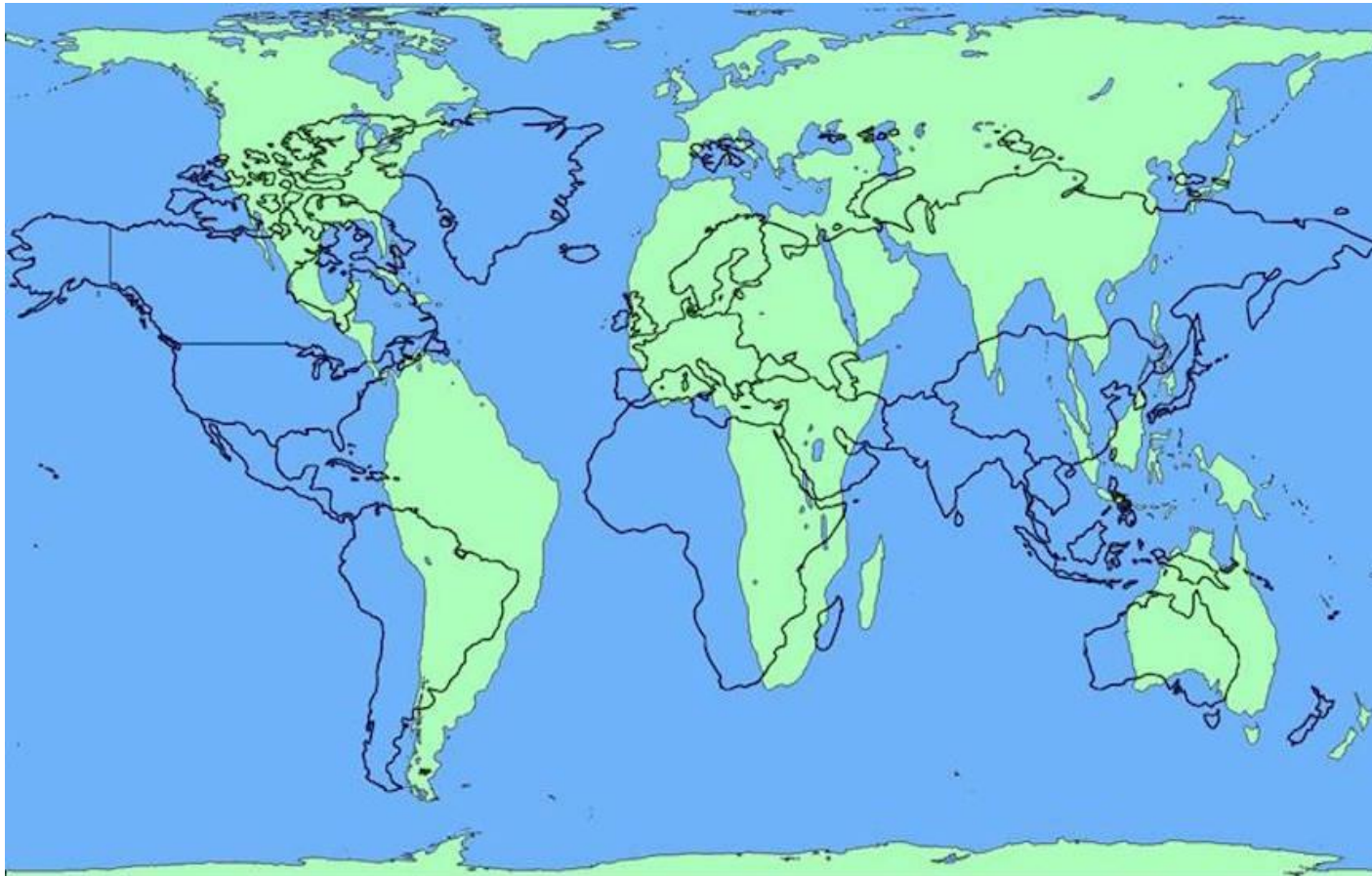
# Map Orientation and Projections



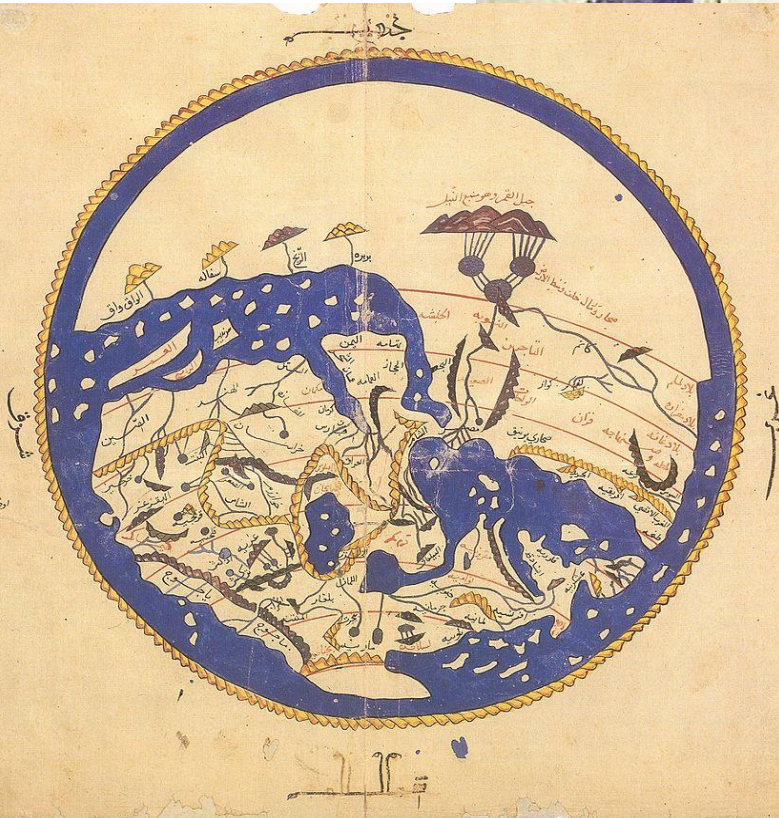
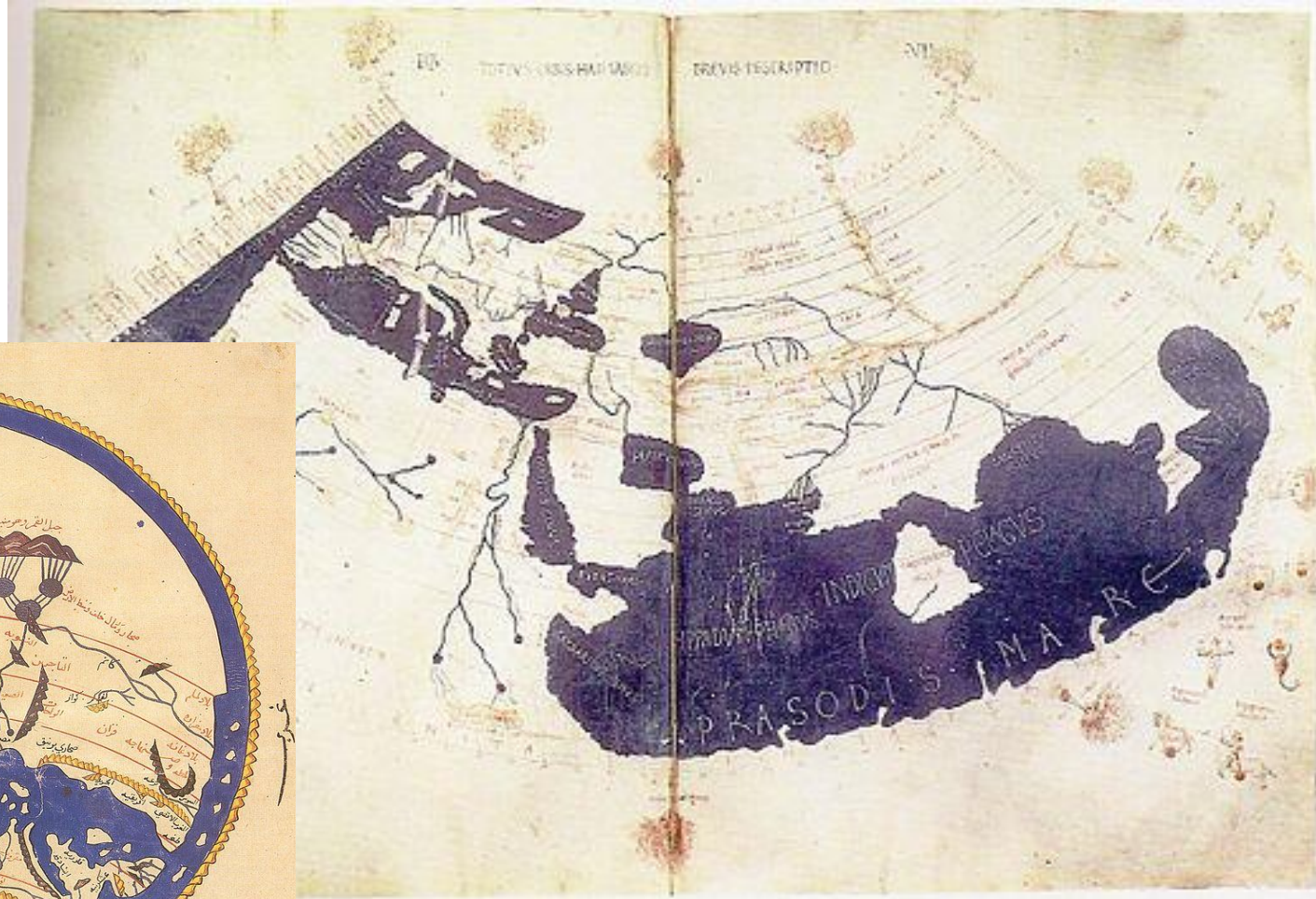
- › Mapping a 3D globe on a flat 2D plane
  - › <https://www.youtube.com/watch?v=kIID5FDi2JQ>

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# Map Orientation and Projections



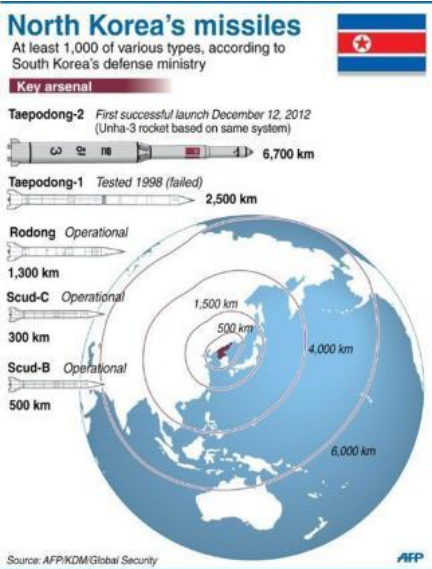
# Map Orientation and Projections



# Map Orientation and Projections



The Economist



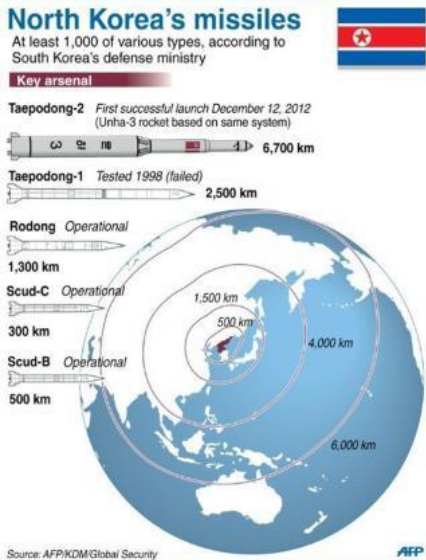
# Map Orientation and Projections



The Economist

Correction

Original



2,000 km



# 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](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](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/>