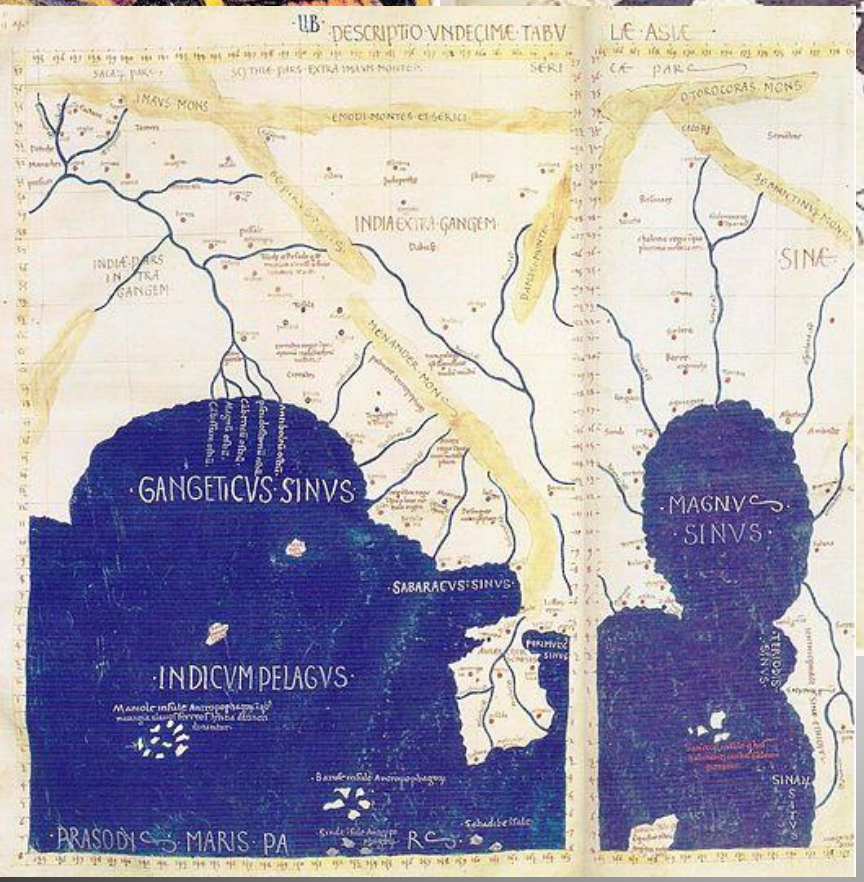
UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

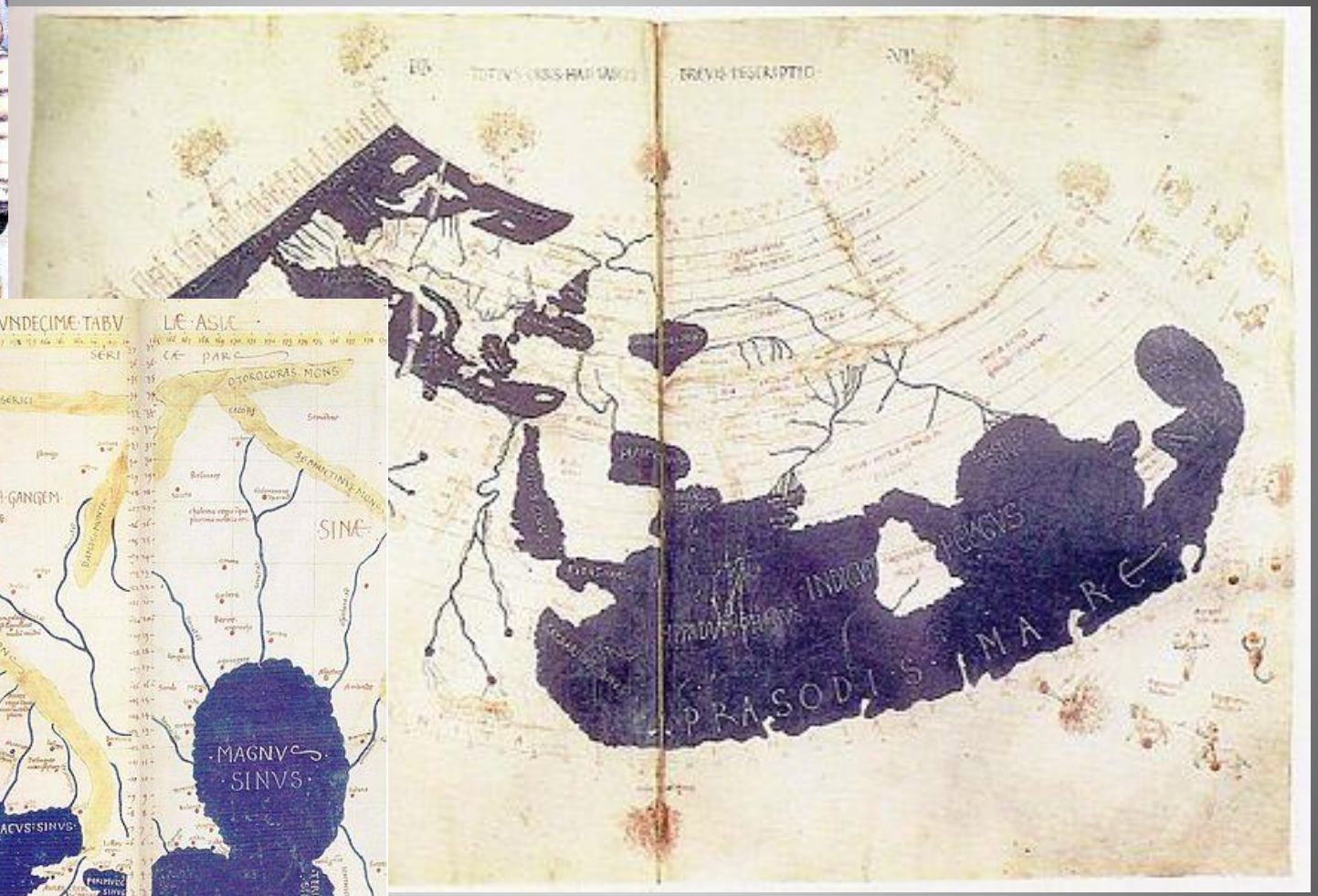
The Era of Big Spatial Data

Ahmed Eldawy
Computer Science and Engineering

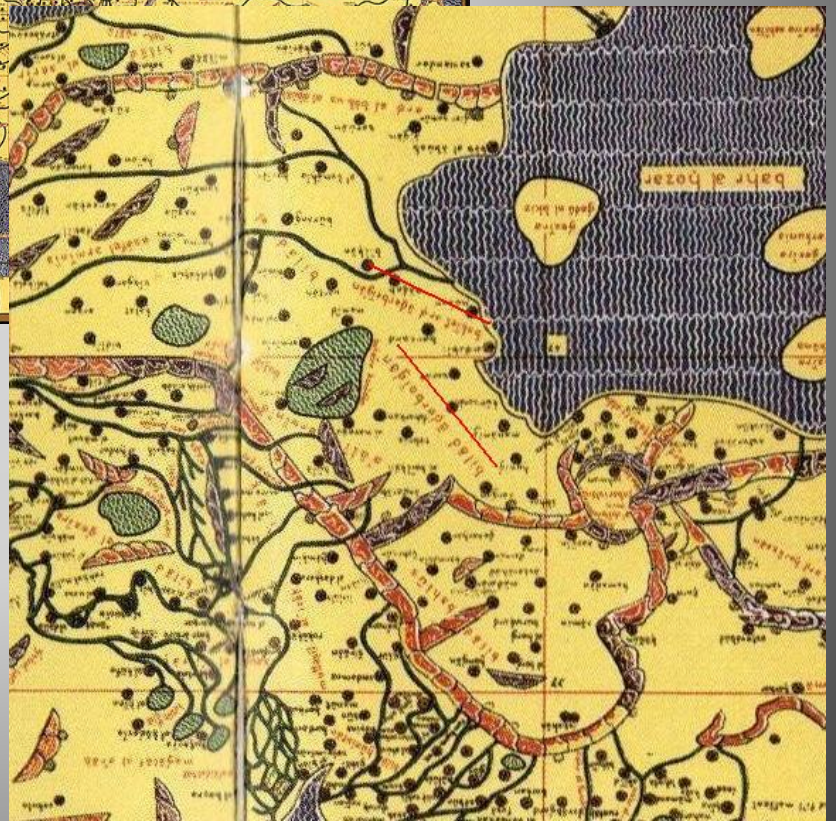

Once upon a
time...

Claudius Ptolemy (AD 90 – AD 168)

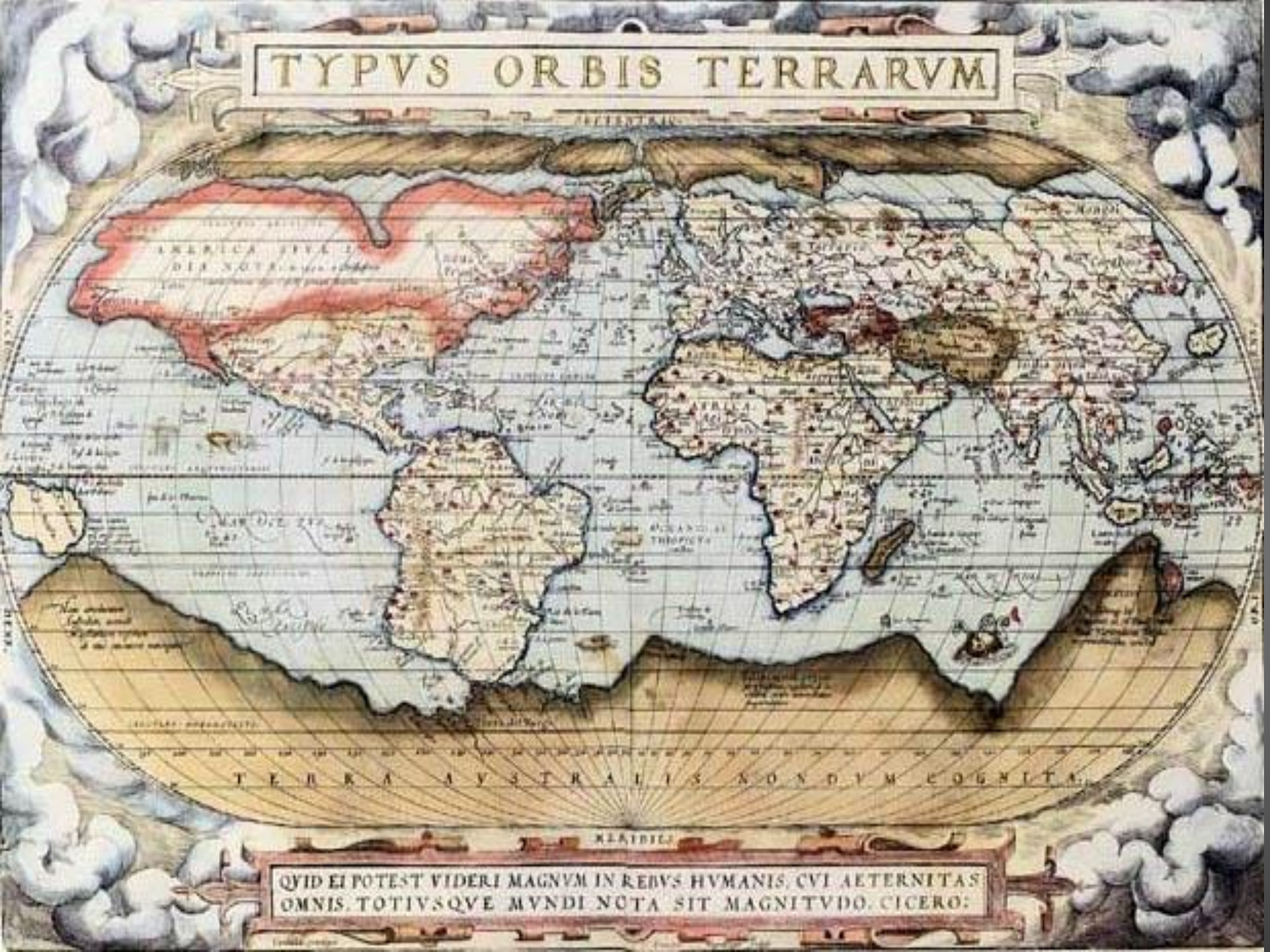




Al Idrisi (1099–1165)

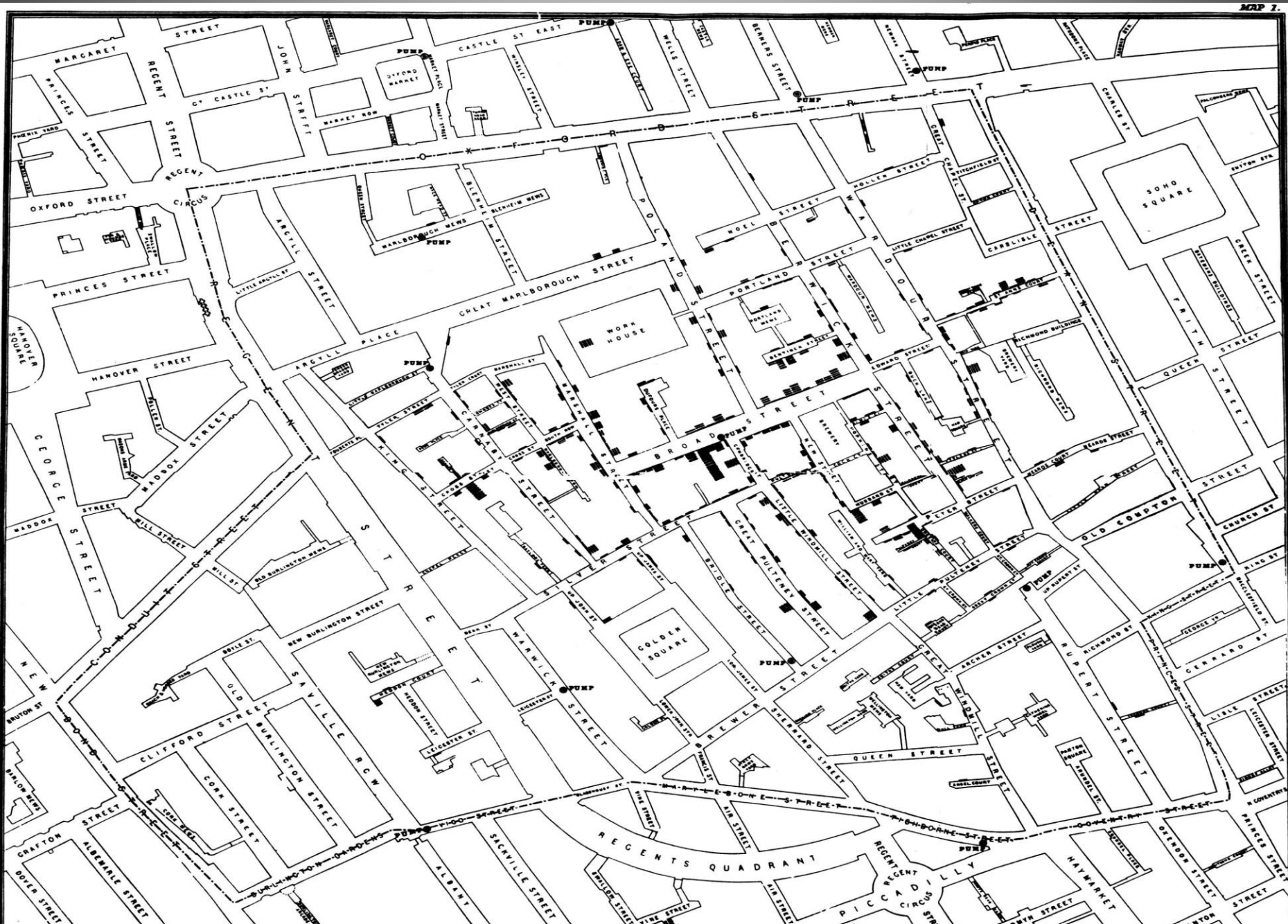



Mar Atlantico
EVROPA
AFRICA
INDIA
Brasil
Tropicus Cancri
Tropicus Capricorni
Mar do Sul
Equinocialis
Mar Pacifico
Mar Indico
Mar Meridional


TYPVS ORBIS TERRARVM
TERRA AVSTRALIS NONDVM COGNITA
QVID EI POTEST VIDERI MAGNVM IN REBVS HVMANIS, CVI AETERNITAS
OMNIS, TOTIVSQVE MVNDI NOTA SIT MAGNITVDO. CICERO:


ARGONAVTICA.
EVROPAE PARS.
ASIAE PARS.
LIBYAE PARS.
SAVROMATAE.
SCYTHAE.
GETAE
ARIMASPHAE.
MAEOTIS PALVS.
AXENVM Aequor, Iasone pollutum remige primum.
CAVCASEVM MARE.
CAPPADOCIA.
THRACIA.
CELTAE.
SARDOVM PELAGVS.
TYRRHENVM AQVOR.
IONIVM MARE.
LIBYSTICVM MARE.
PELOPIS REGIO.
Maeotim pelagus
THRACIA
PROPONTIS.
BITHYNIA.
ILLVSTRISSIMO PRINCIPI CAROLO COMITI ARENBERGIO, BARONI SEPTIMONTII, DOMINO MIRVARTII, EQVITI AVREI VELLERIS, ETC.

Cholera cases in the London epidemic of 1854



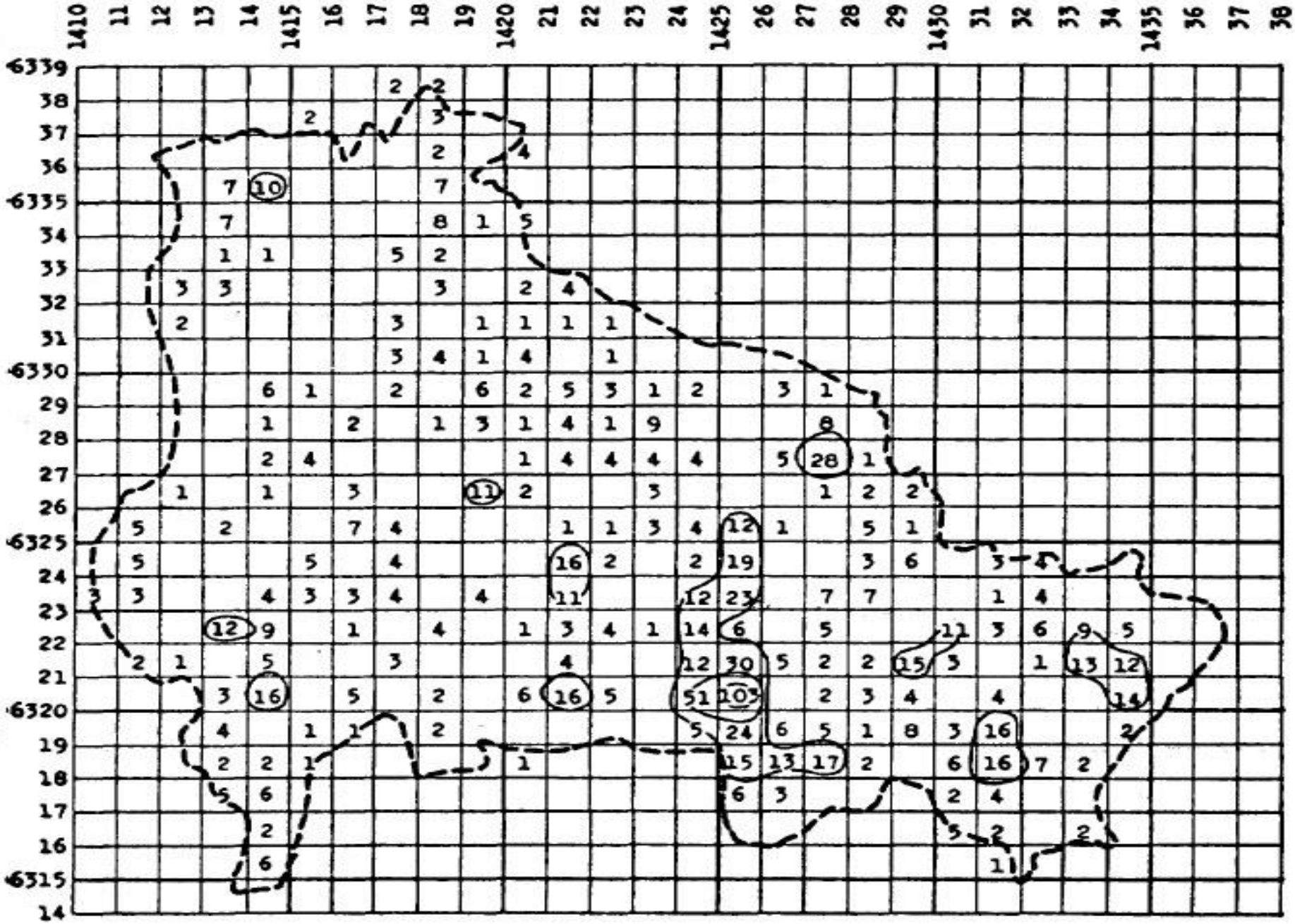


FIGURE 3—Children under 15 years of age in 1940.

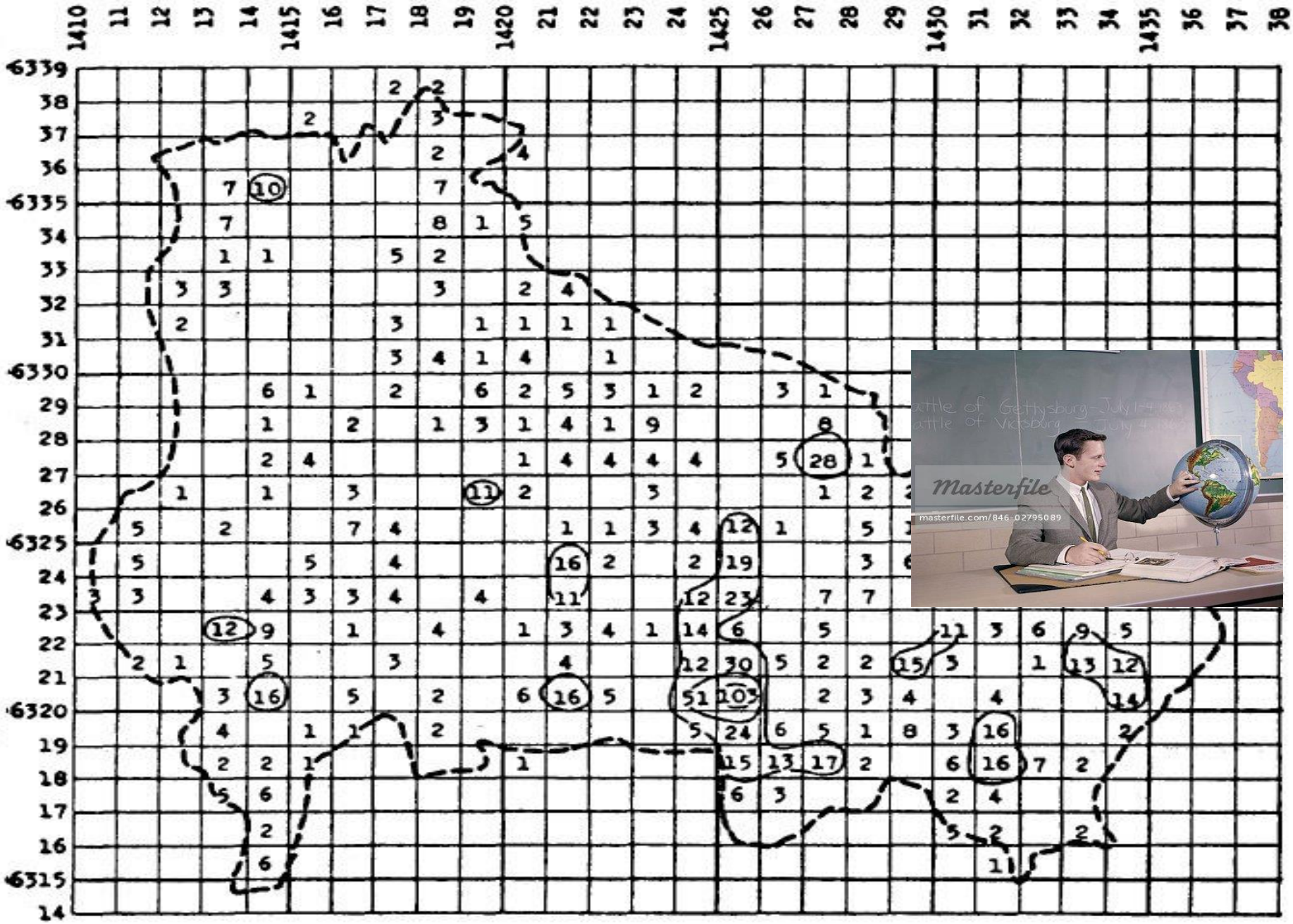
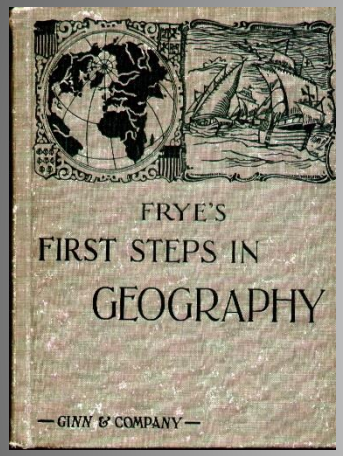


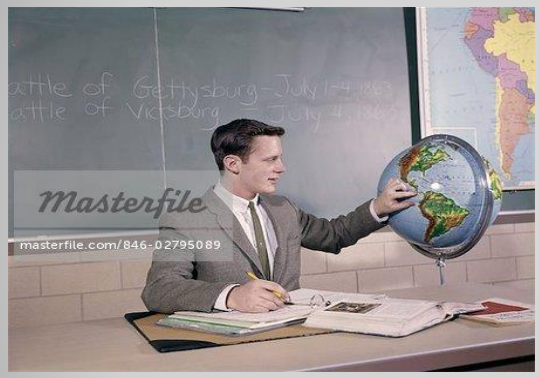
FIGURE 3—Children under 15 years of age in 1940.


UAR
5 M

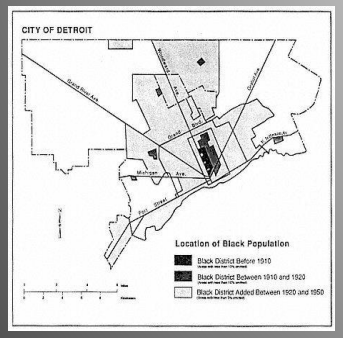

OCÉAN ATLA
Newcastle
Liverpool
Birmingham
Cardiff
Londres
Hambourg
Amsterdam
Rotterdam
Anvers
Le Havre
Paris
Nantes St-Nazaire
Bordeaux
Marseille
Milan
Trieste
Gênes
Madrid
Barcelone
Rome


UNIVAC


FRYE'S
FIRST STEPS IN
GEOGRAPHY
—GINN & COMPANY—


Masterfile
masterfile.com/846-02795089


IBM

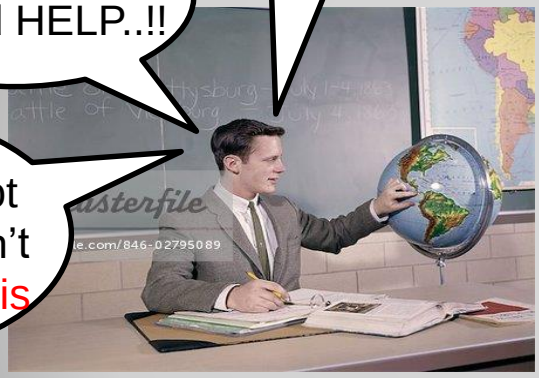

CITY OF DETROIT
Location of Black Population
Black District Before 1910
Black District Between 1910 and 1920
Black District Added Between 1920 and 1950


Masterfile
masterfile.com/846-02793618

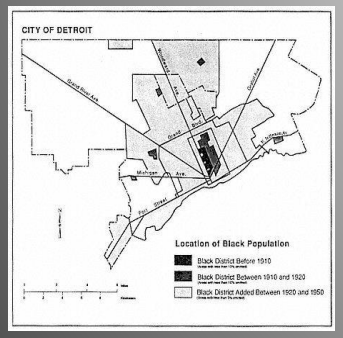
Cool computer technology..!! Can I use it in my application?

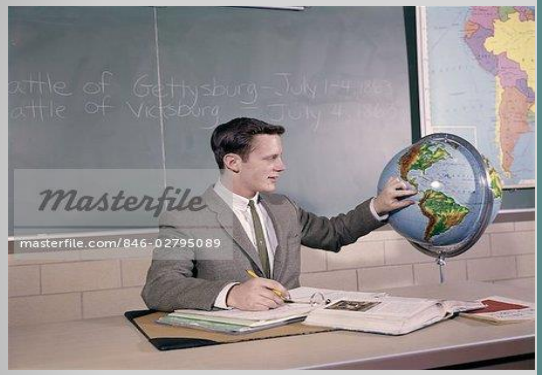
I have **BIG** data. I need HELP..!!

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



My pleasure. Here it is.

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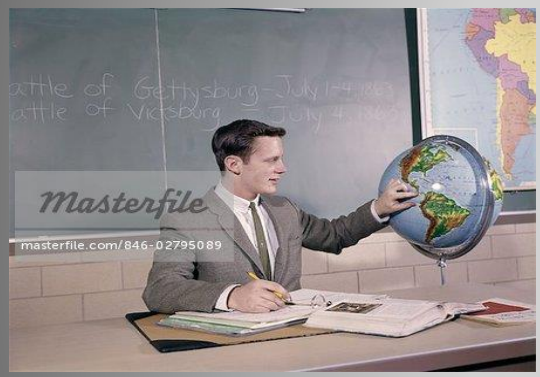
masterfile.com/846-02795089


IBM

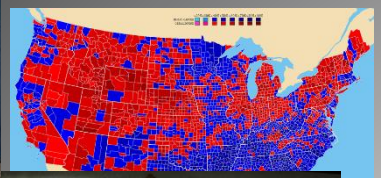
1969

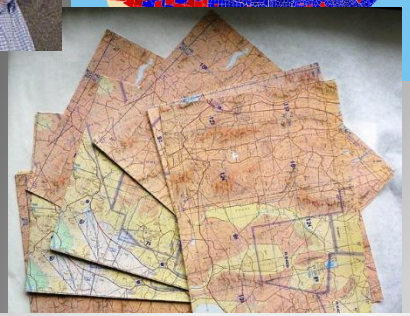
Kindly let me understand your needs

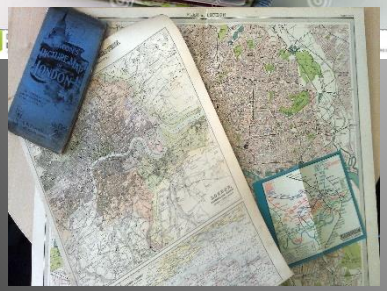


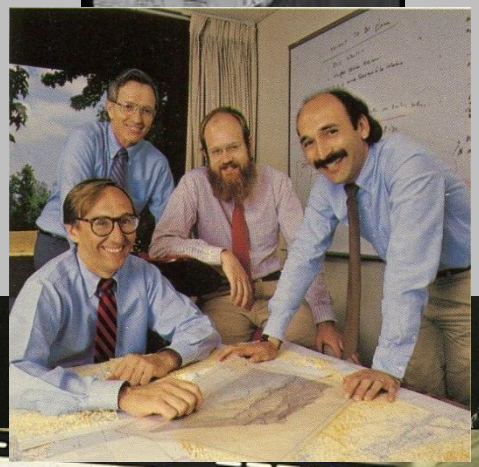
Kindly let me get the technology you have

ESRI







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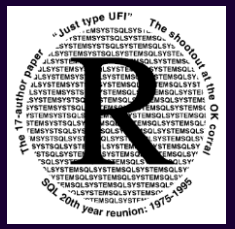

"Just type UFI"
The 17-author paper
The shootout at the OK corral
SQL 20th year reunion: 1975-1995


DATABASE
MANAGEMENT
SYSTEMS

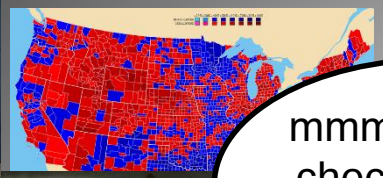

Informix

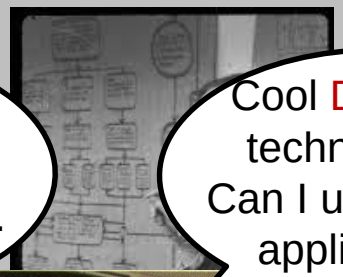

ORACLE
DATABASE
ORACLE

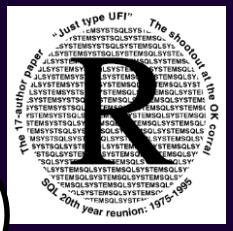
PostgreSQL


AIRLINE BOOKING


Banking







mmm…Let me check with my good friends there.

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

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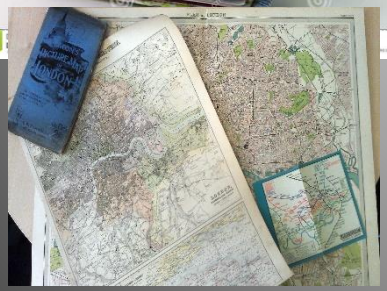
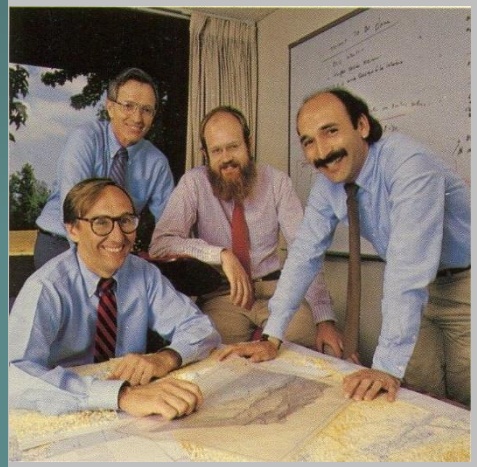
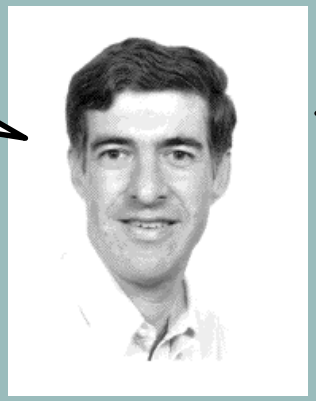


Informix

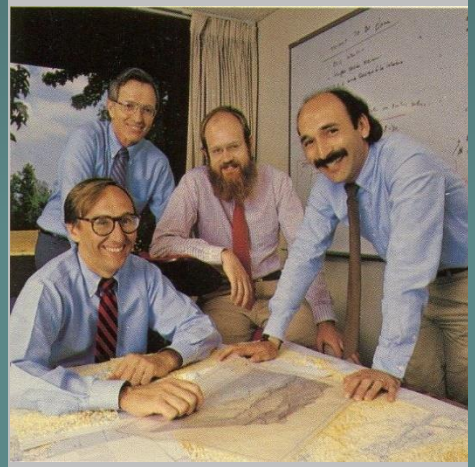
PostgreSQL

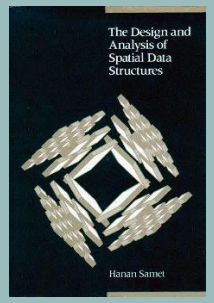


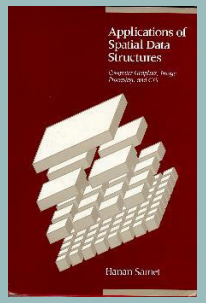
Kindly let me understand your needs

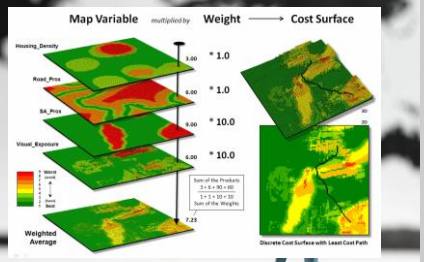


Kindly let me get the technology you have

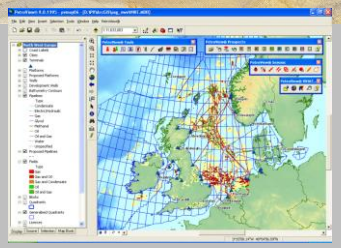







Map Variable
multiplied by
Weight
Cost Surface
Housing_Density
Road_Prox
BA_Prox
Visual_Exposure
* 1.0
* 1.0
* 10.0
* 10.0
Weighted Average
Discrete Cost Surface with Least Cost Path


ArcGIS
ESRI




IRAN
Arabian Gulf
BAHRAIN
Manama
SAUDI ARABIA
QATAR
Doha
Riyadh
N
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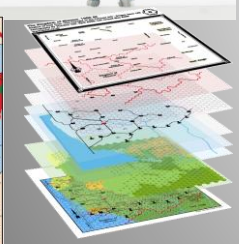

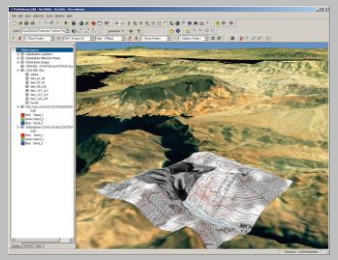

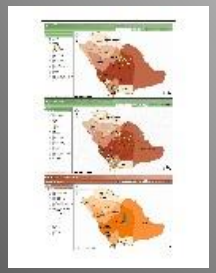


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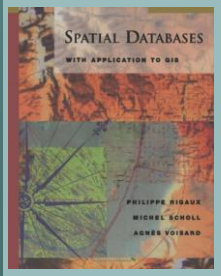
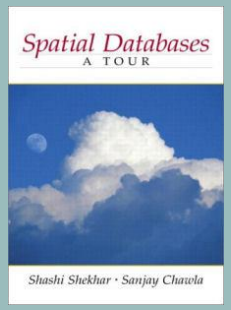
The Design and Analysis of Spatial Data Structures
Applications of Spatial Data Structures
PostGIS
Geospatial Objects for PostgreSQL
ORACLE 11g
DATABASE
Oracle Spatial and Graph
ORACLE
Beginning Spatial with SQL Server 2008
Alastair Aitchison


Spatial Databases
WITH APPLICATION TO GIS
PHILIPPE RIGAUX
MICHEL SCHOLL
AGNÈS VOISARD


Spatial Databases
A TOUR
Shashi Shekhar · Sanjay Chawla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IBM
DB2


Microsoft
SQL Server


PostgreSQL
the world's most advanced open source database


MySQL


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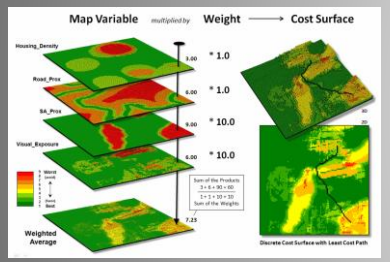

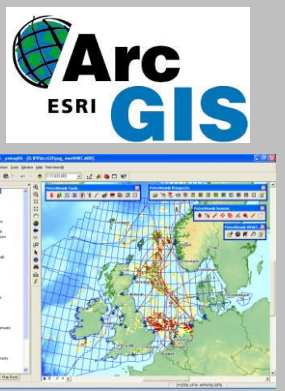

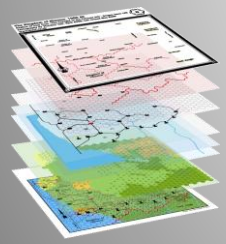

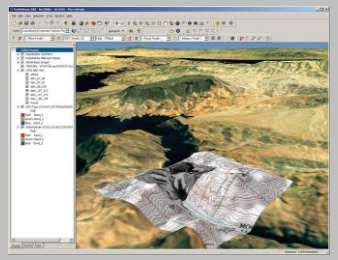

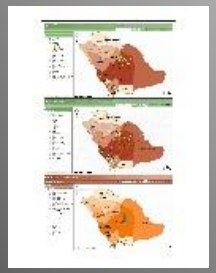

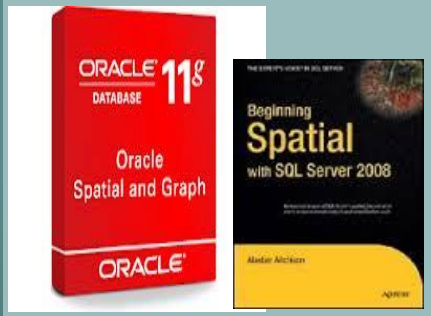

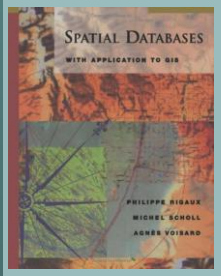

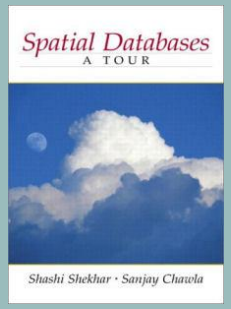

PostGIS
Geospatial Objects for PostgreSQL

ORACLE®

IBM DB2

Microsoft SQL Server

PostgreSQL
the world's most advanced open source database

MySQL

SYBASE | An SAP Company

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Google

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Map Reduce

hadoop

HIVE

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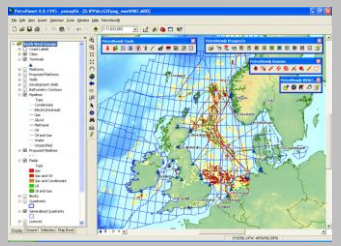
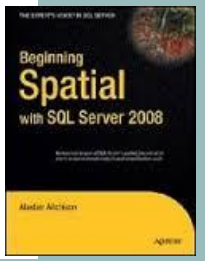
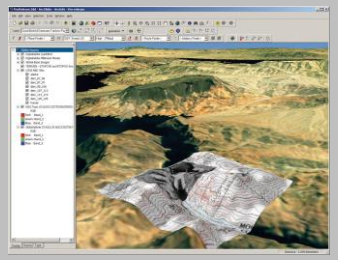
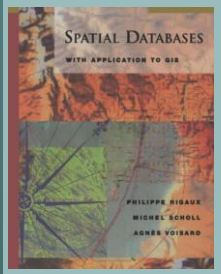
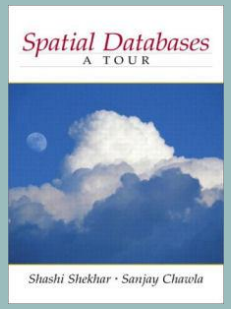


PostGIS
Geospatial Objects for PostgreSQL









ORACLE

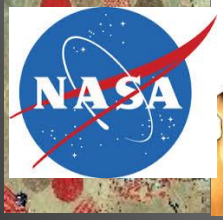
IBM DB2

Microsoft SQL Server

PostgreSQL

MySQL

SYBASE An SAP Company



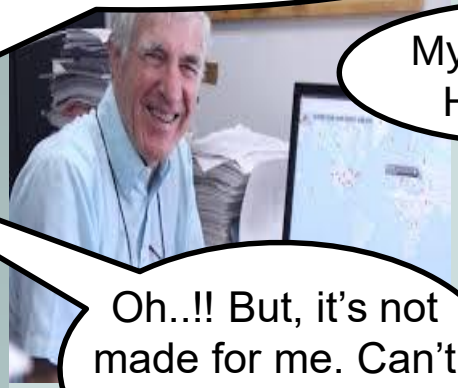
idrisi

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

Let me check with my other good friends there.

Sorry, seems like the DBMS technology cannot scale more

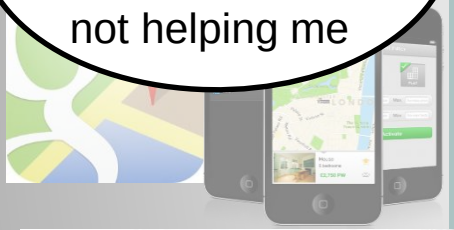
Cool Big Data technology..!!
Can I use it in my application?

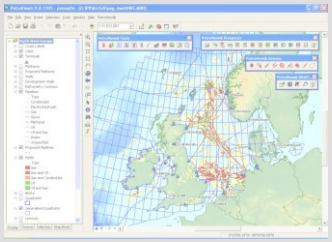


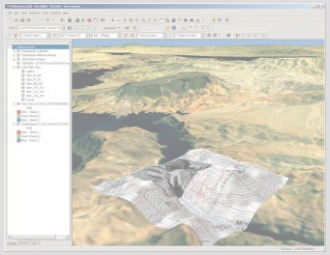
Oh..!! But, it's not made for me. Can't make use of it as is

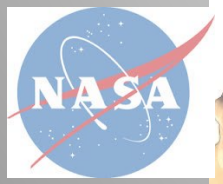
My pleasure.
Here it is.

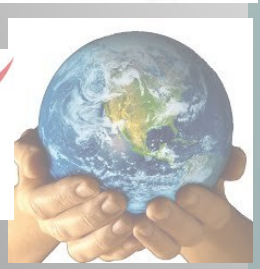
Google
bing
facebook
Map Reduce
hadoop
HIVE
Spark
amazon web services
PostGIS
Geospatial Objects for PostgreSQL
ESRI GIS





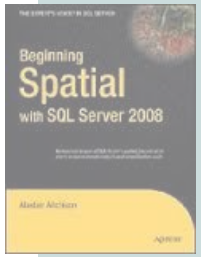




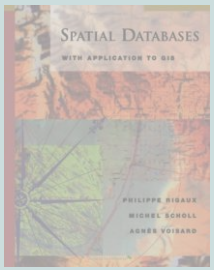


idrisi

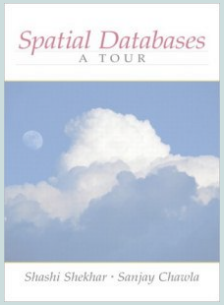
ORACLE 11g DATABASE
Oracle Spatial and Graph
ORACLE



Beginning Spatial with SQL Server 2008



Spatial Databases
WITH APPLICATION TO GIS



Spatial Databases
A TOUR
Shashi Shekhar · Sanjay Chawla

ORACLE
IBM DB2
Microsoft SQL Server
PostgreSQL
MySQL
SYBASE An SAP Company

Google

bing

twitter

facebook

Map Reduce

hadoop

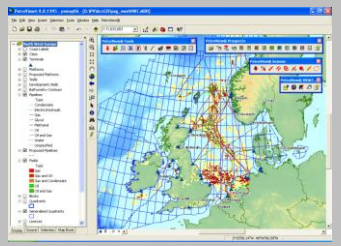
amazon web services

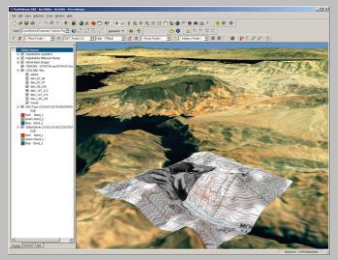
HIVE

Spark

PostGIS
Geospatial Objects for PostgreSQL

ESRI ArcGIS





idrisi

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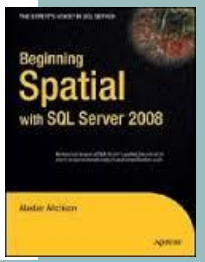
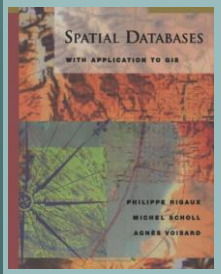
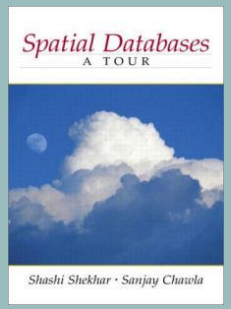
Oracle Spatial and Graph
ORACLE







ORACLE

IBM DB2

Microsoft SQL Server

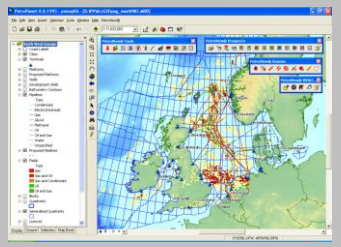
PostgreSQL

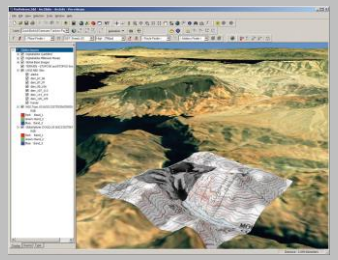
MySQL

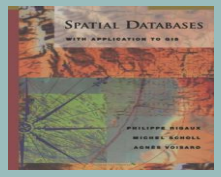
SYBASE An SAP Company

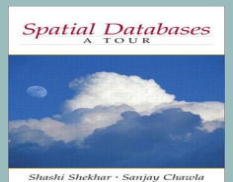
Kindly let me understand your needs

Kindly let me get the technology you have

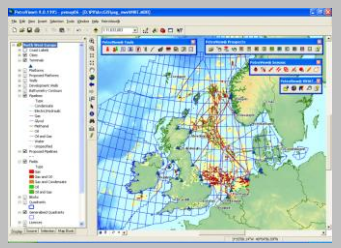


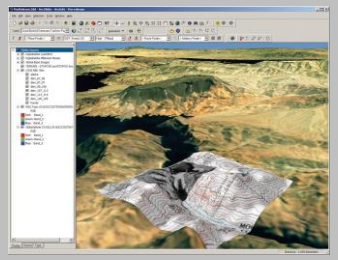


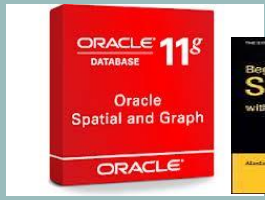


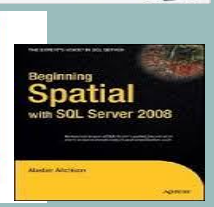


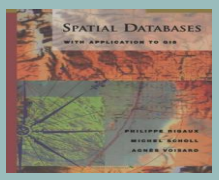
Big Spatial Data

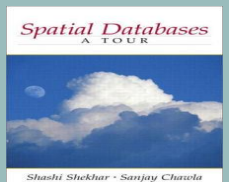








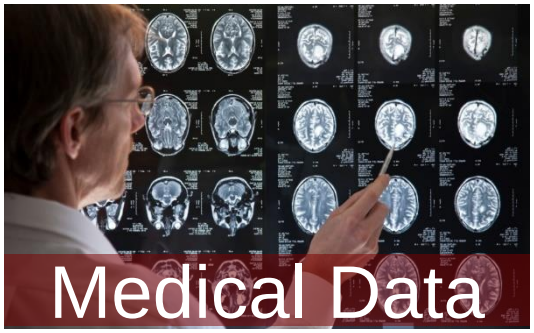




Tons of Spatial data out there…

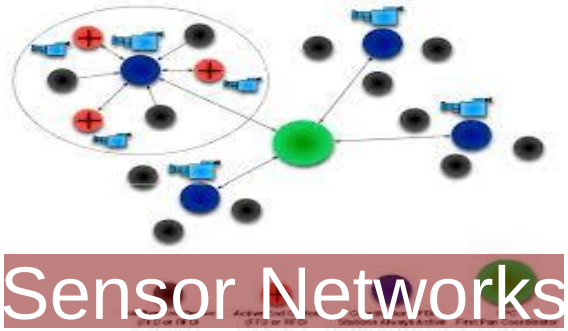
Geotagged Microblogs

Geotagged Pictures

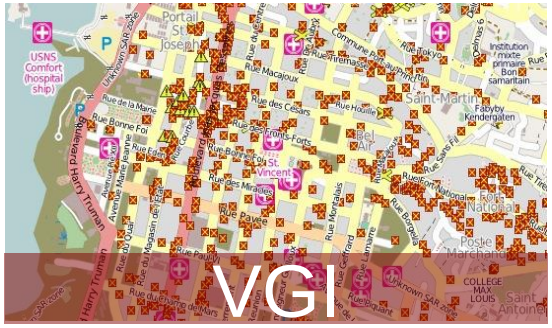


Medical Data

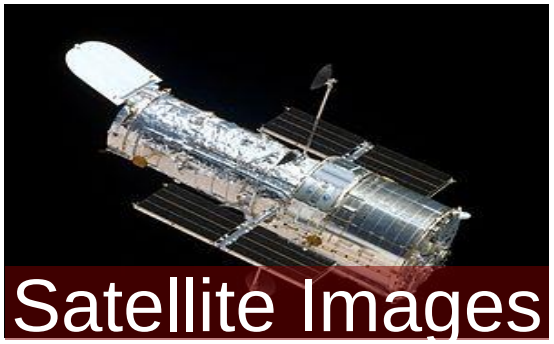
Smart Phones



Sensor Networks



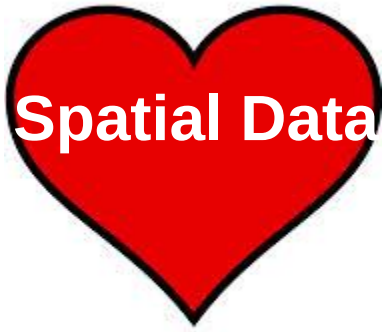
VGI



Satellite Images

Traffic Data

Spatial Data & Hadoop ➔ SpatialHadoop




```
points = LOAD 'points' AS
     (id:int, x:int, y:int);
result = FILTER points BY
  x < xmax AND x >= xmin AND
  y < ymax AND y >= ymin;
```

```
points = LOAD 'points' AS
     (id:int, location:point);
result = FILTER points BY
  Overlap(location, rectangle
    (xmin, ymin, xmax, ymax));
```

Takes 193 seconds

Finishes in 2 seconds

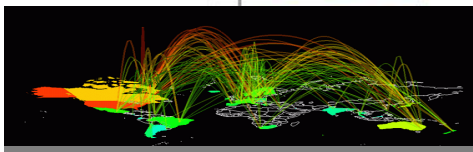
Spatial Hadoop

UCR

Spatial Language


Spatial Indexes


Spatial Operations


Visualization

80,000 downloads in one year

Conducted more than seven keynotes, tutorials, and invited talks

Industry

Microsoft
ORACLE
esri
GEOSYS Growing agriculture
3M
Hortonworks
XEROX PARC
BlackBerry

Academia

Students Projects

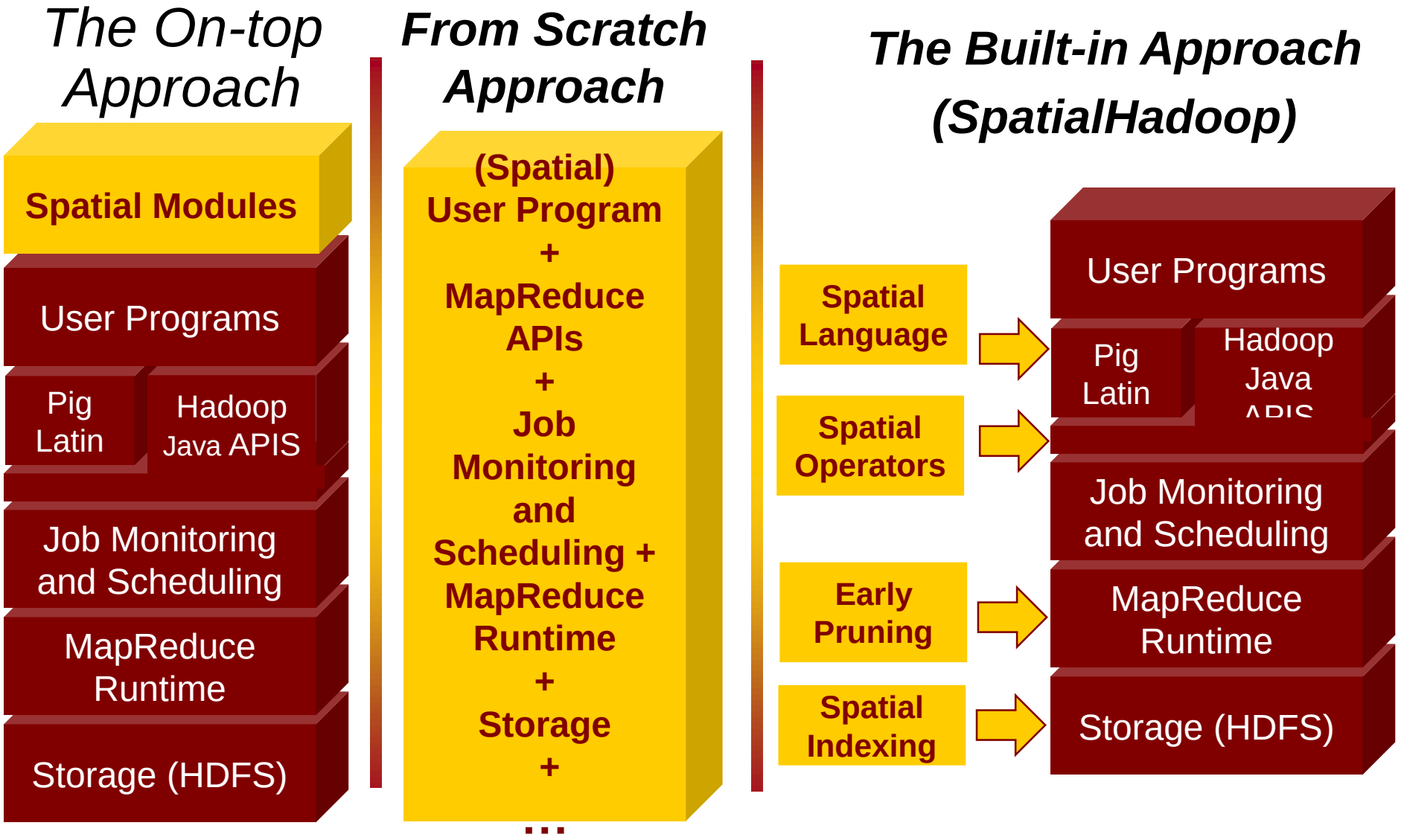
UT DALLAS
Salisbury University
Indian Institute of Technology Bombay
Université de Versailles St-Quentin-en-Yvelines
Sogang University
Alexandria University
Wuhan University
National and Kapodistrian University of Athens

Collaboration

The Cornell Lab of Ornithology
University of Maryland
UC Irvine
GIS Innovation Center
Kunsan National University
University of Genova

>500GB public datasets for benchmarking and testing

The Built-in Approach of SpatialHadoop



Agenda

- The ecosystem of SpatialHadoop
  - ~~Motivation~~
  - Internal system design
  - Applications
  - Related work
  - Performance results
- Open Research Problems

SpatialHadoop Architecture

UCR

Applications: SHAHED [ICDE'15] – MNTG [SSTD'13, ICDE'14]
TAREEG[SIGMOD'14, SIGSPATIAL'14]

VLDB'13
ICDE'15

Language
Pigeon [ICDE'14]

Visualization
[VLDB'15, ICDE'16]

Operations
Basic operations – CG_Hadoop [SIGSPATIAL'13]

MapReduce
Spatial File Splitter
Spatial Record Reader

Indexing
Grid – R-tree – R+-tree – Quad tree
[VLDB'15]

ST-Hadoop

Indexing

UCR

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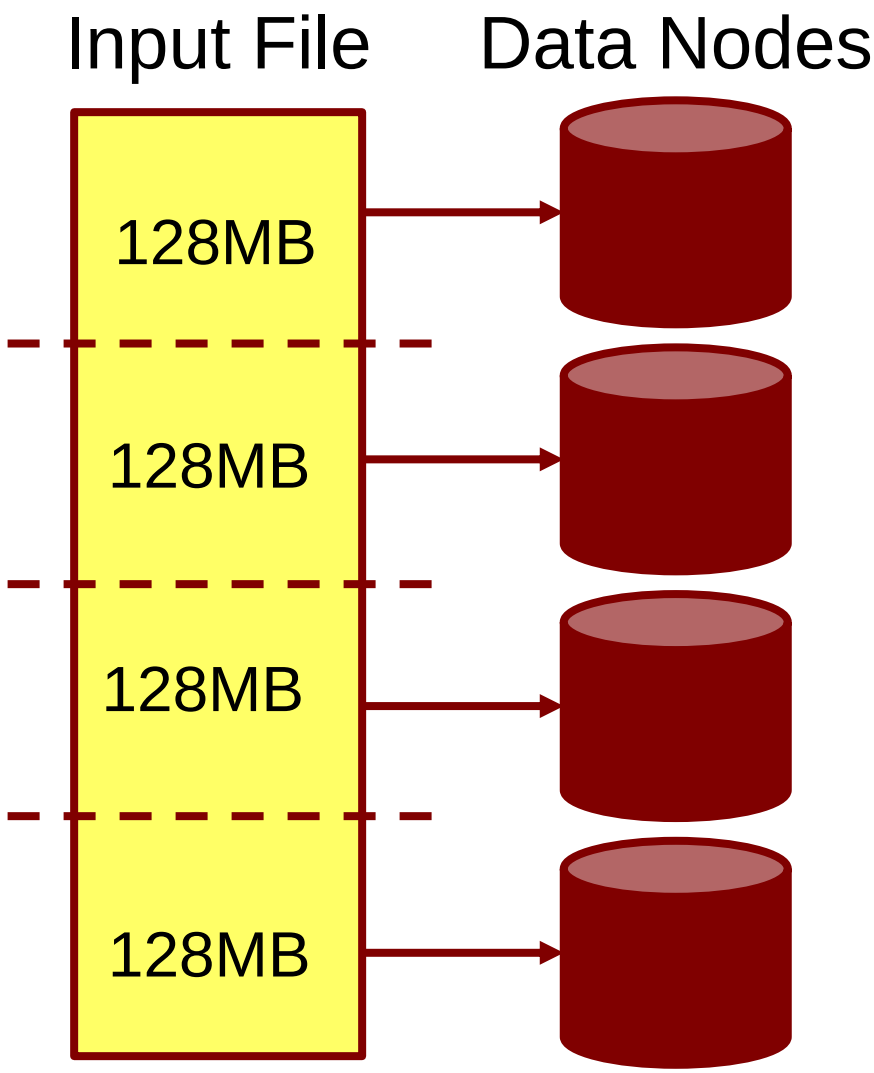
Grid – R-tree – R+-tree – Quad tree
[VLDB'15]

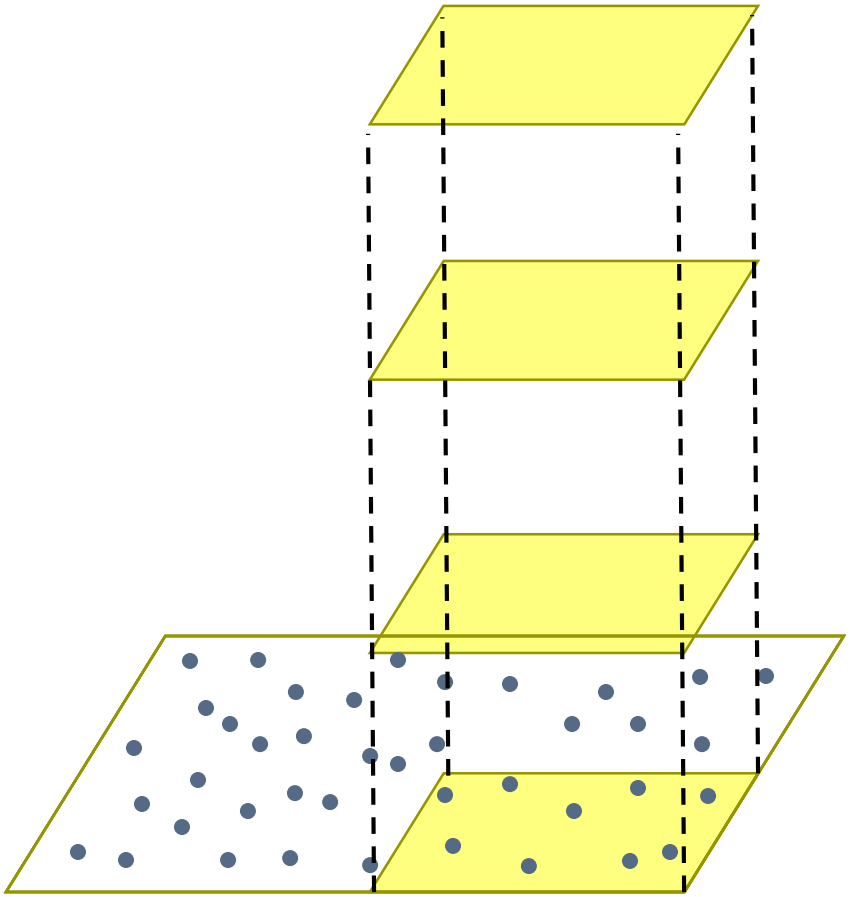
ST-Hadoop

Data Loading in Hadoop

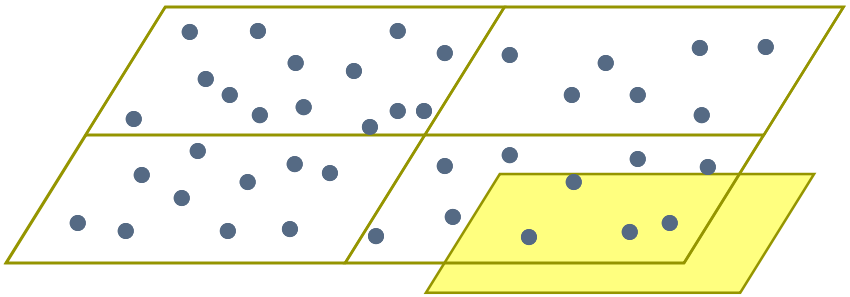
- Blindly chops down a big file into 128MB chunks
- Values of records are not considered
- Relevant records are typically assigned to two different blocks
- HDFS is too restrictive where files cannot be modified



Spatial Distributed File System

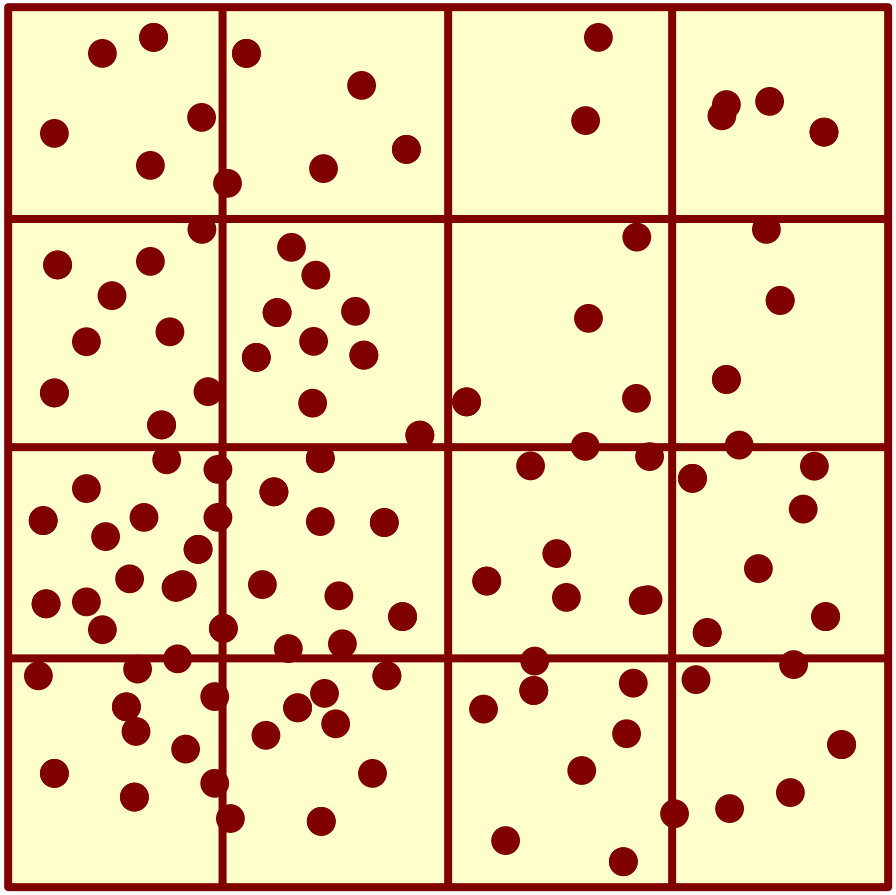


Default Partitioning



Spatial Partitioning

Uniform Grid



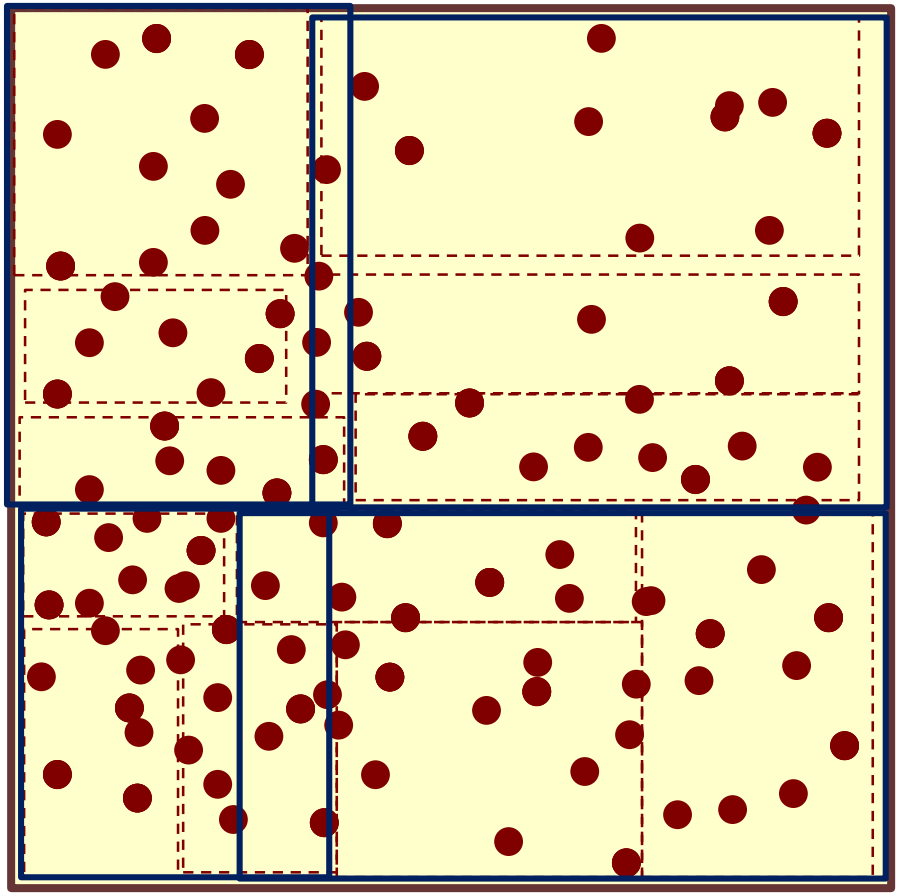
Works only for uniformly distributed data

R-tree

- Read a sample
- Bulk load the sample into an R-tree
  - Leaf node capacity C

$$C = \frac{k.B}{|R|(1+\alpha)}$$

  - k: Sample size
  - B: HDFS Block capacity
  - |R|: Input size
  - α: Index overhead
- Use MBR of leaf nodes as partition boundaries



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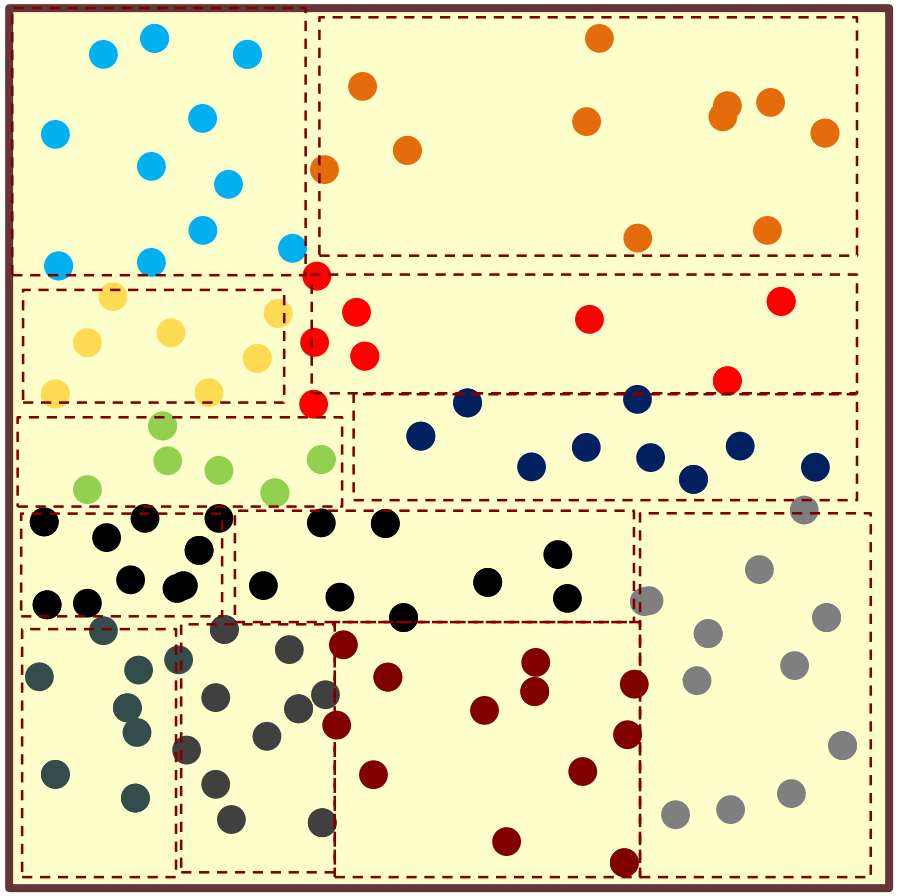

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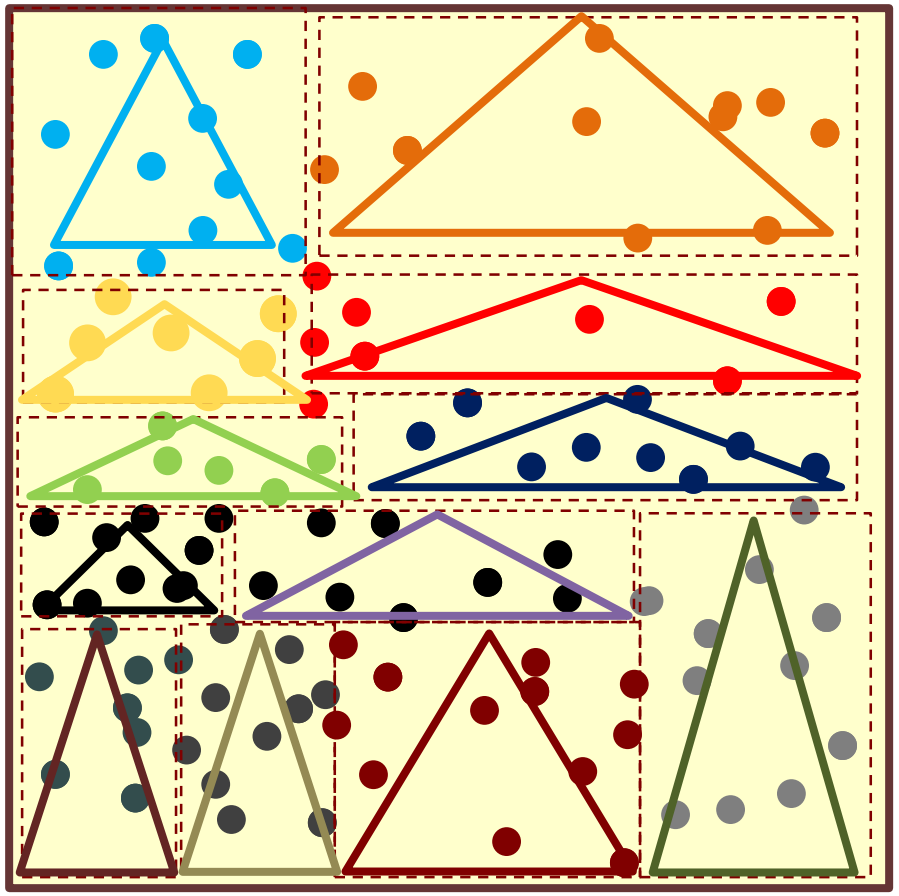
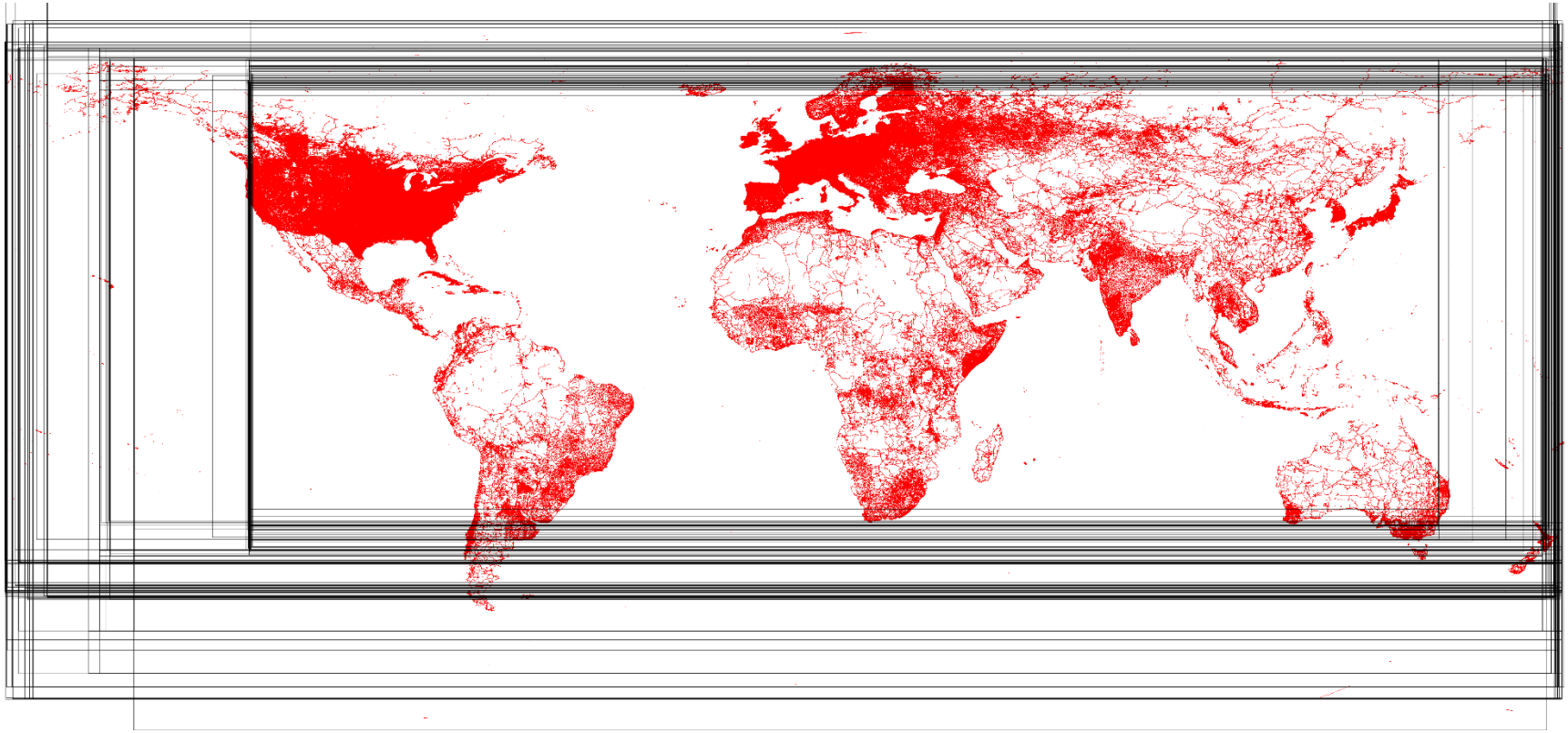
  - |R|: Input size
  - α: Index overhead
- Use MBR of leaf nodes as partition boundaries
- Partition the data
- Optional: Build R-tree Local indexes



R-tree-based Index of a 400 GB road network

Non-indexed Heap File



Operations

UCR

Applications: SHAHED [ICDE'15] – MNTG [SSTD'13, ICDE'14]
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[VLDB'15]

ST-Hadoop

Operations Layer

- Basic Operations: e.g, Range query and KNN
- Spatial Join Operations
- Computational geometry operations: e.g., Polygon Union, Voronoi diagram, Delaunay Triangulation, and Convex Hull
- User-defined operations: e.g., kNN join

Range Query

Use **local indexes** to find matching records

Use the **global index** to prune disjoint partitions

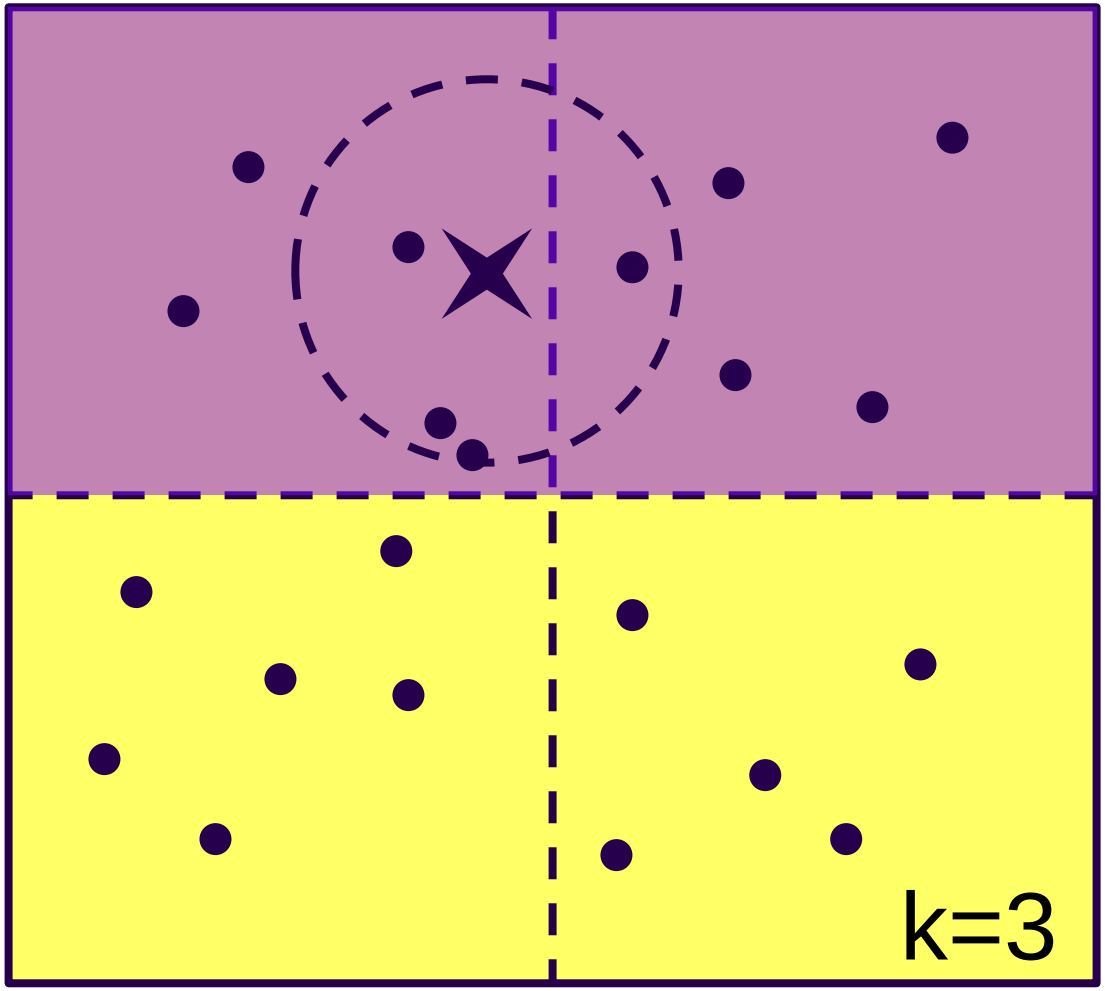
KNN over Indexed Data

First iteration runs as before and result is tested for correctness

✗ Answer is incorrect

Second iteration processes other blocks that might contain an answer

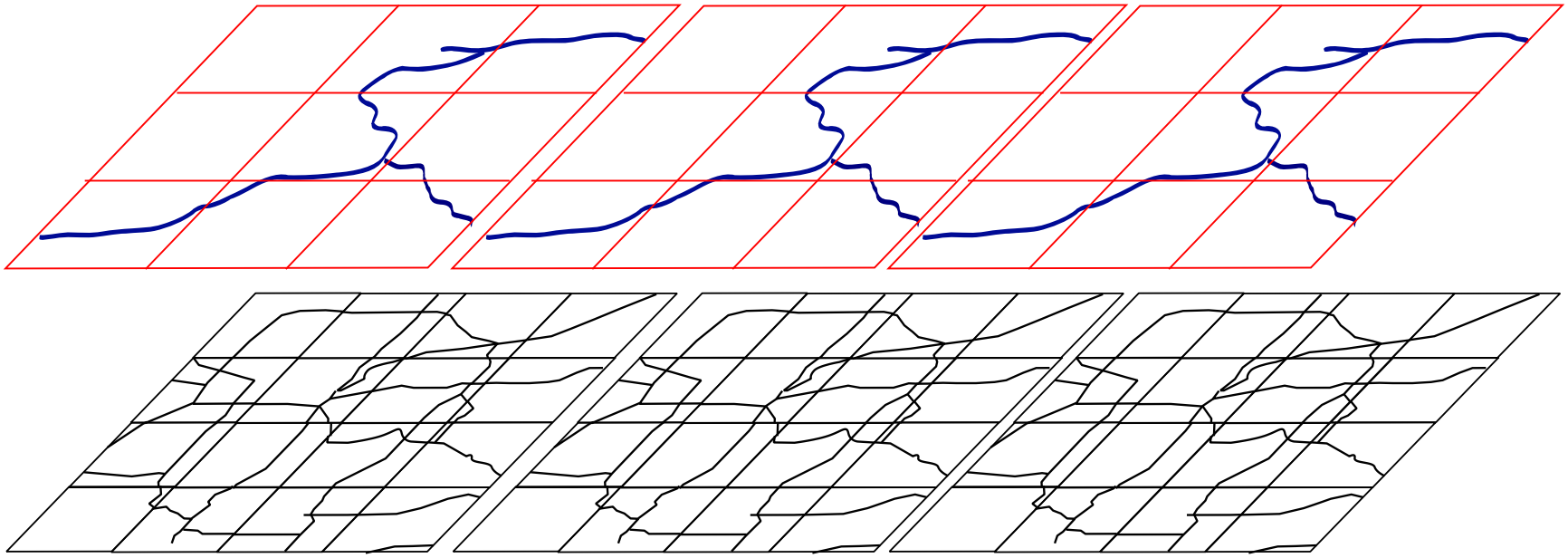
✓ Answer is correct



Spatial Join

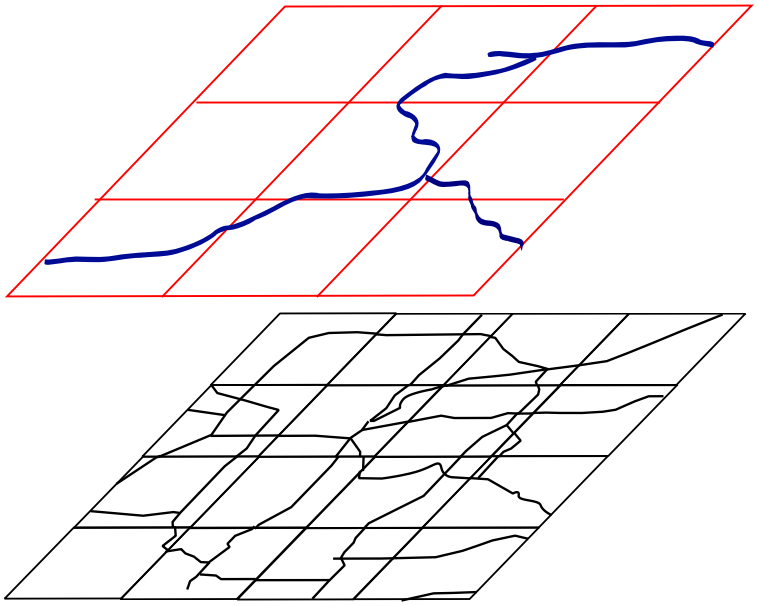
Join Directly

Partition – Join



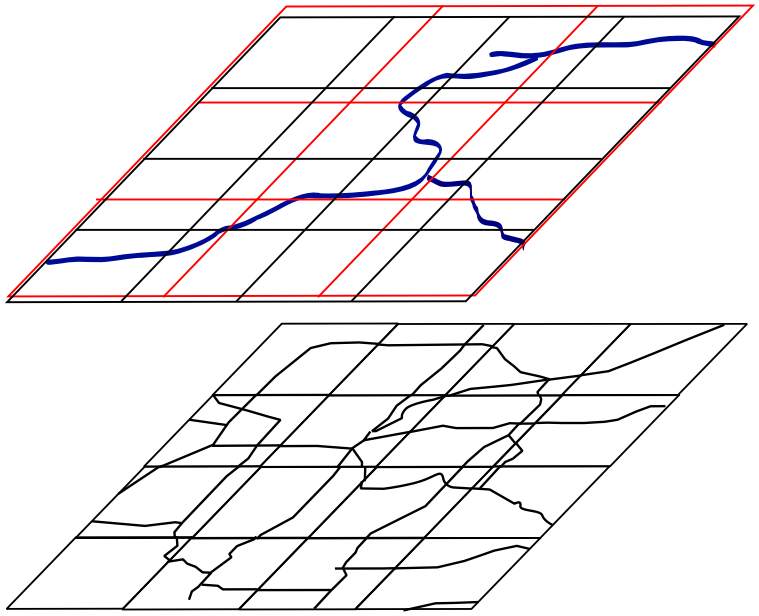
Spatial Join

Join Directly



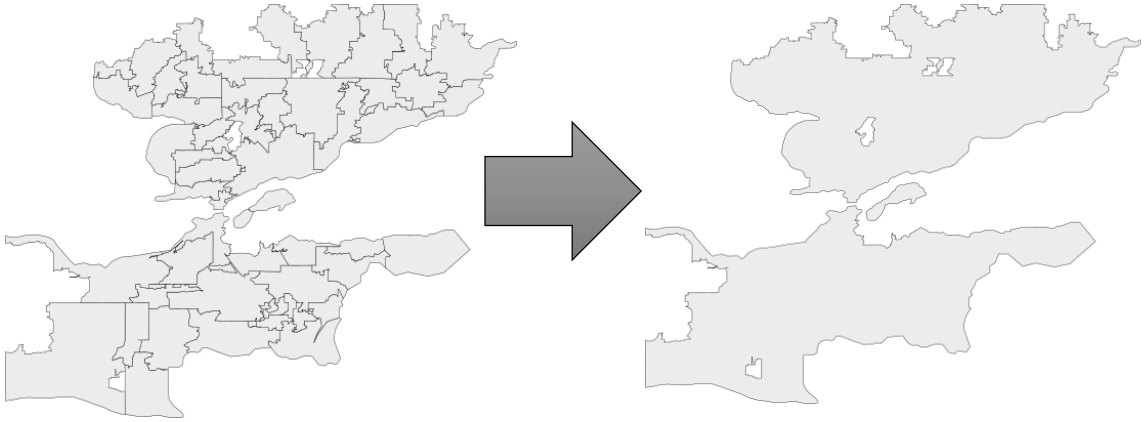
Total of 36 overlapping pairs

Partition – Join

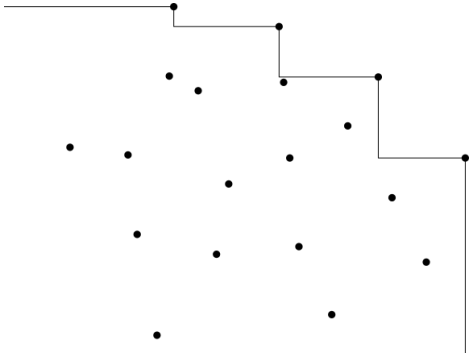


Only 16 overlapping pairs

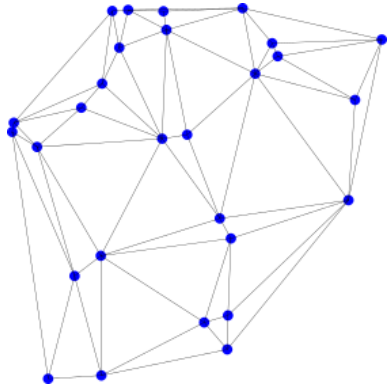
CG_Hadoop



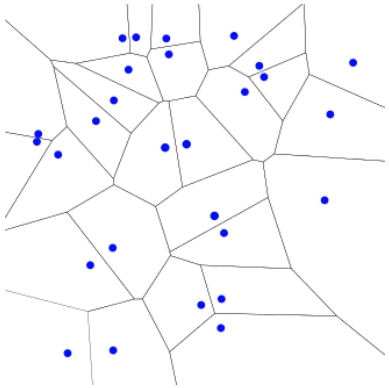
Polygon Union



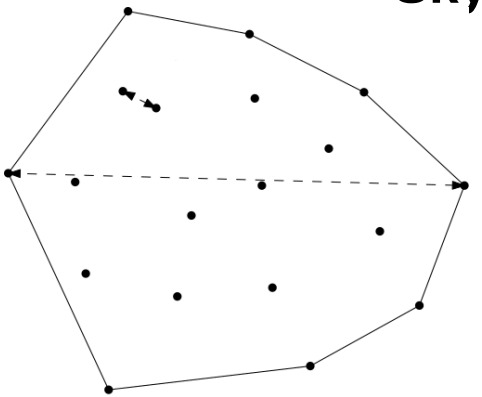
Skyline



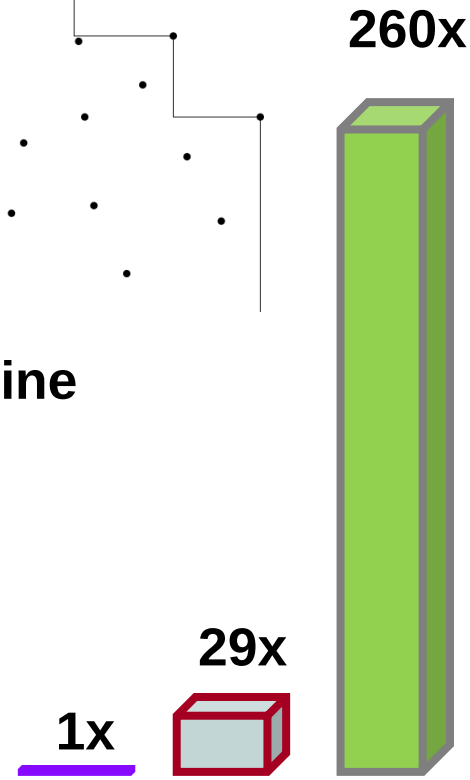
Delaunay Triangulation



Voronoi Diagram



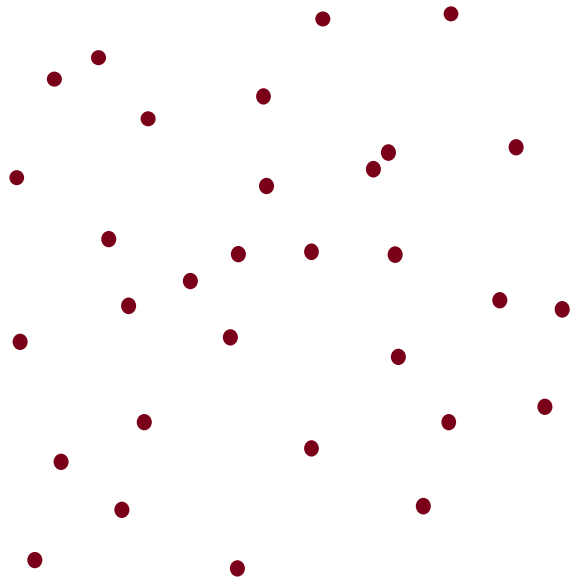
Convex Hull
Farthest/closest pair



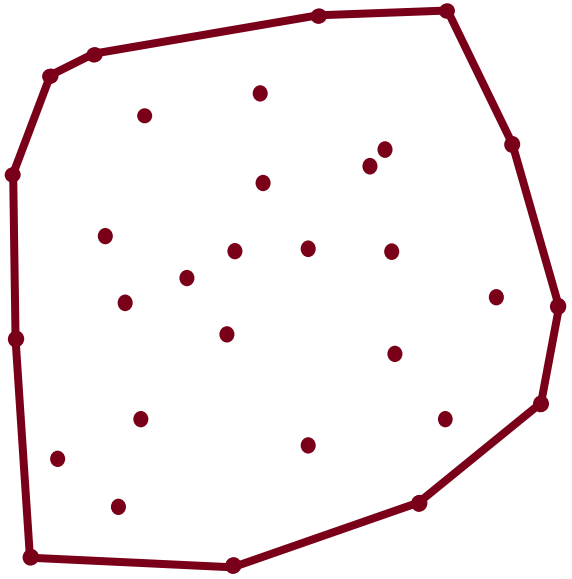
Convex Hull

Find the minimal convex polygon that contains all points

Input



Output



Convex Hull in CG_Hadoop

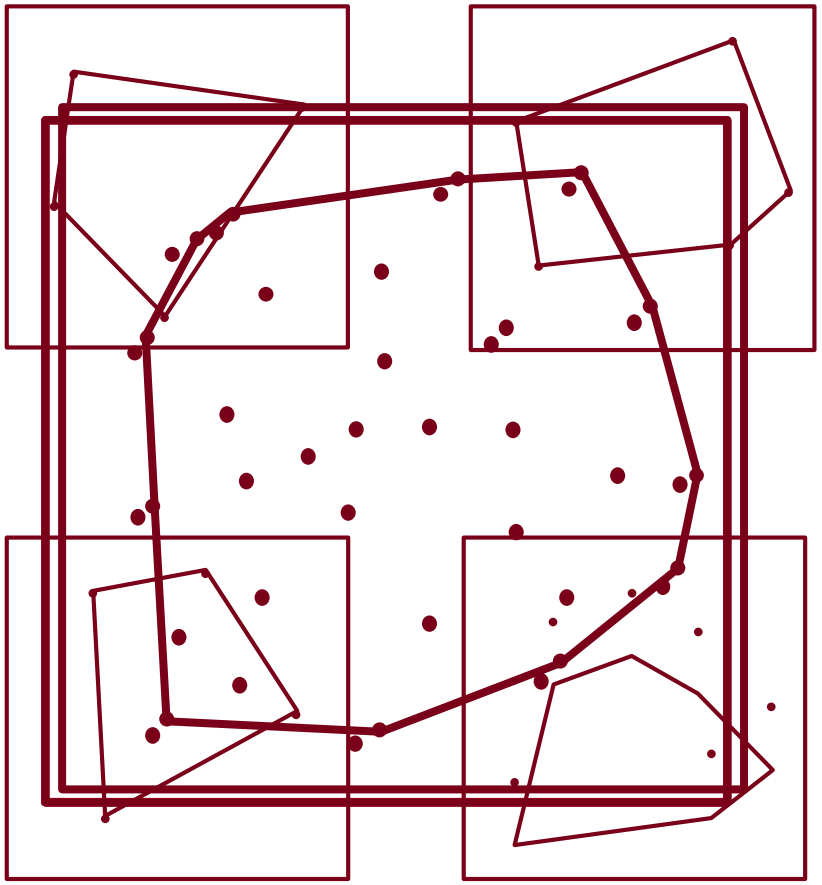
①Partition

②Pruning

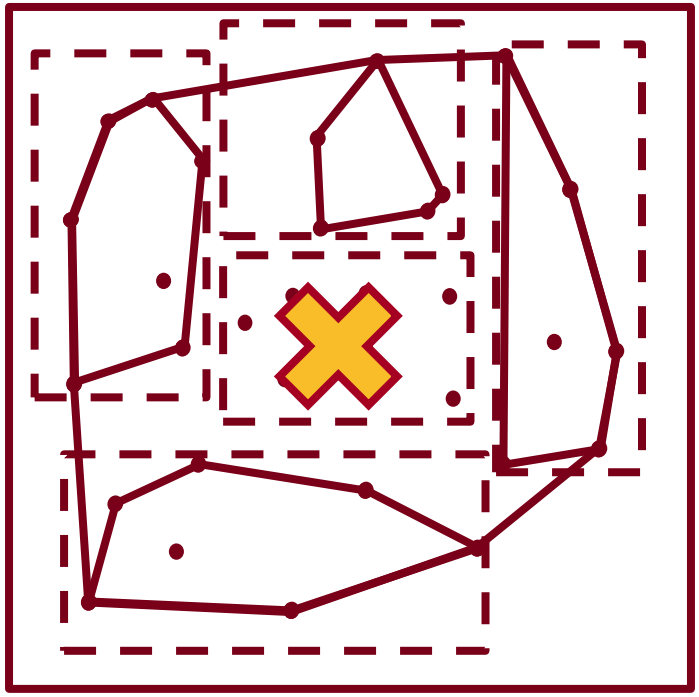
③Local hull

④Global hull

Hadoop



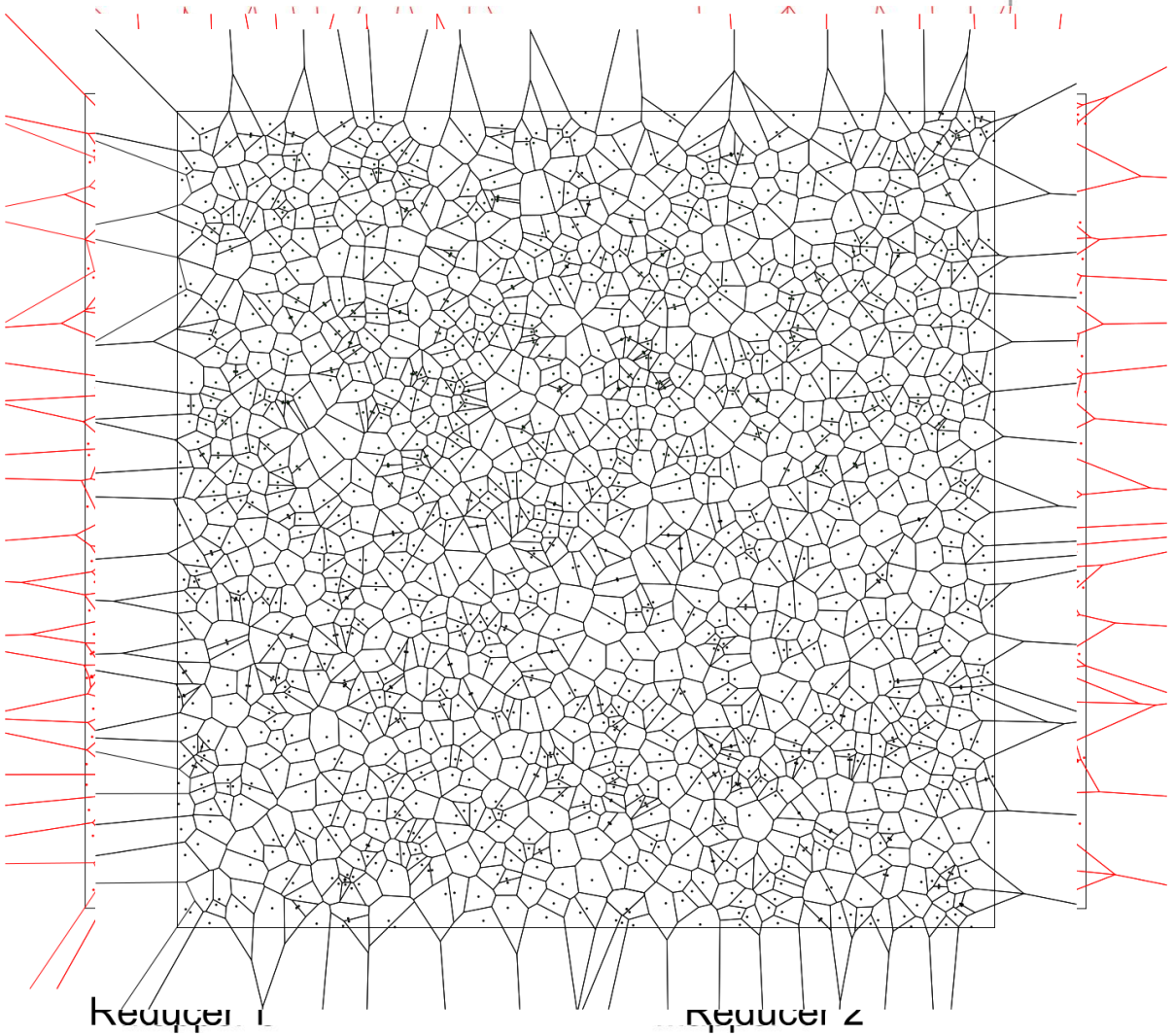
SpatialHadoop



Advanced Analytics

(Ongoing work)

- **Partitioning**
- Local VD
- Pruning
- Vertical Merge
- Pruning
- Horizontal Merge
- Final output



Applications

Applications: SHAHED [ICDE'15] – MNTG [SSTD'13, ICDE'14]
TAREEG[SIGMOD'14, SIGSPATIAL'14]

VLDB'13
ICDE'15

Language
Pigeon [ICDE'14]

Visualization
[VLDB'15, ICDE'16]

Operations
Basic operations – CG_Hadoop
[SIGSPATIAL'13,]

MapReduce
Spatial File Splitter
Spatial Record Reader

Indexing
Grid – R-tree – R+-tree – Quad tree
[VLDB'15]

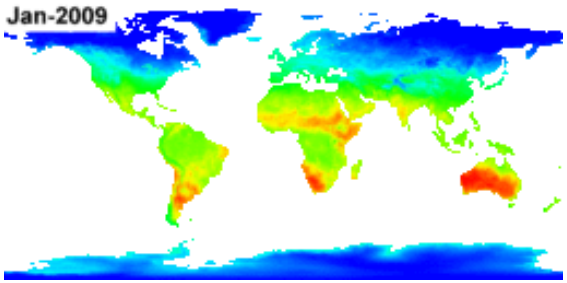
ST-Hadoop

SHAHED – A system for querying and visualizing spatio-temporal satellite data

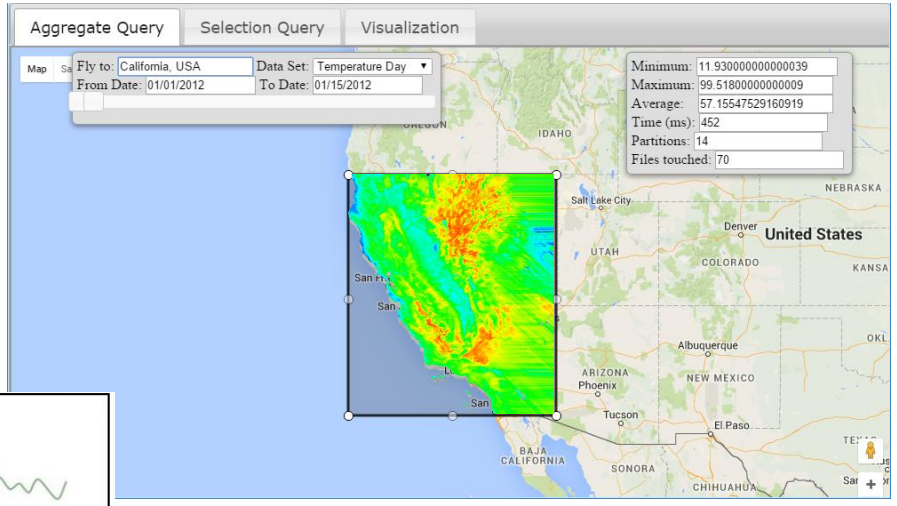
GIS INNOVATION CENTER

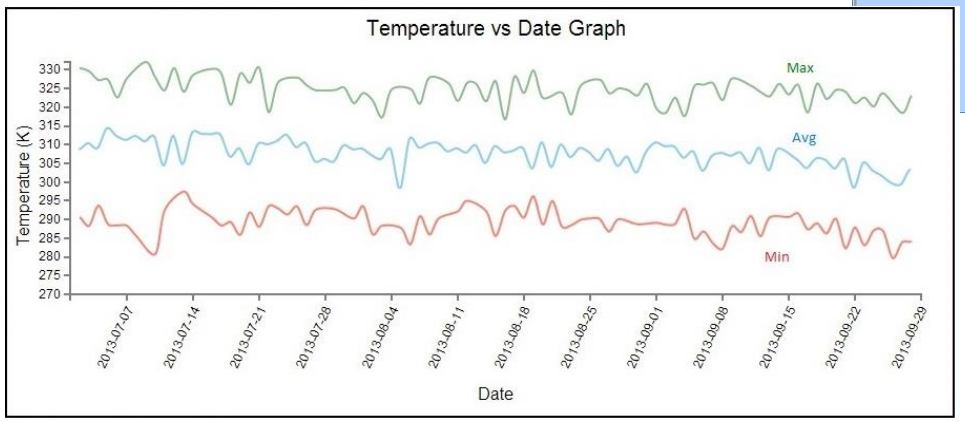
UCR

http://shahed.cs.umn.edu/



Visualize animated heat maps or still images





Run spatio-temporal selection and aggregate queries

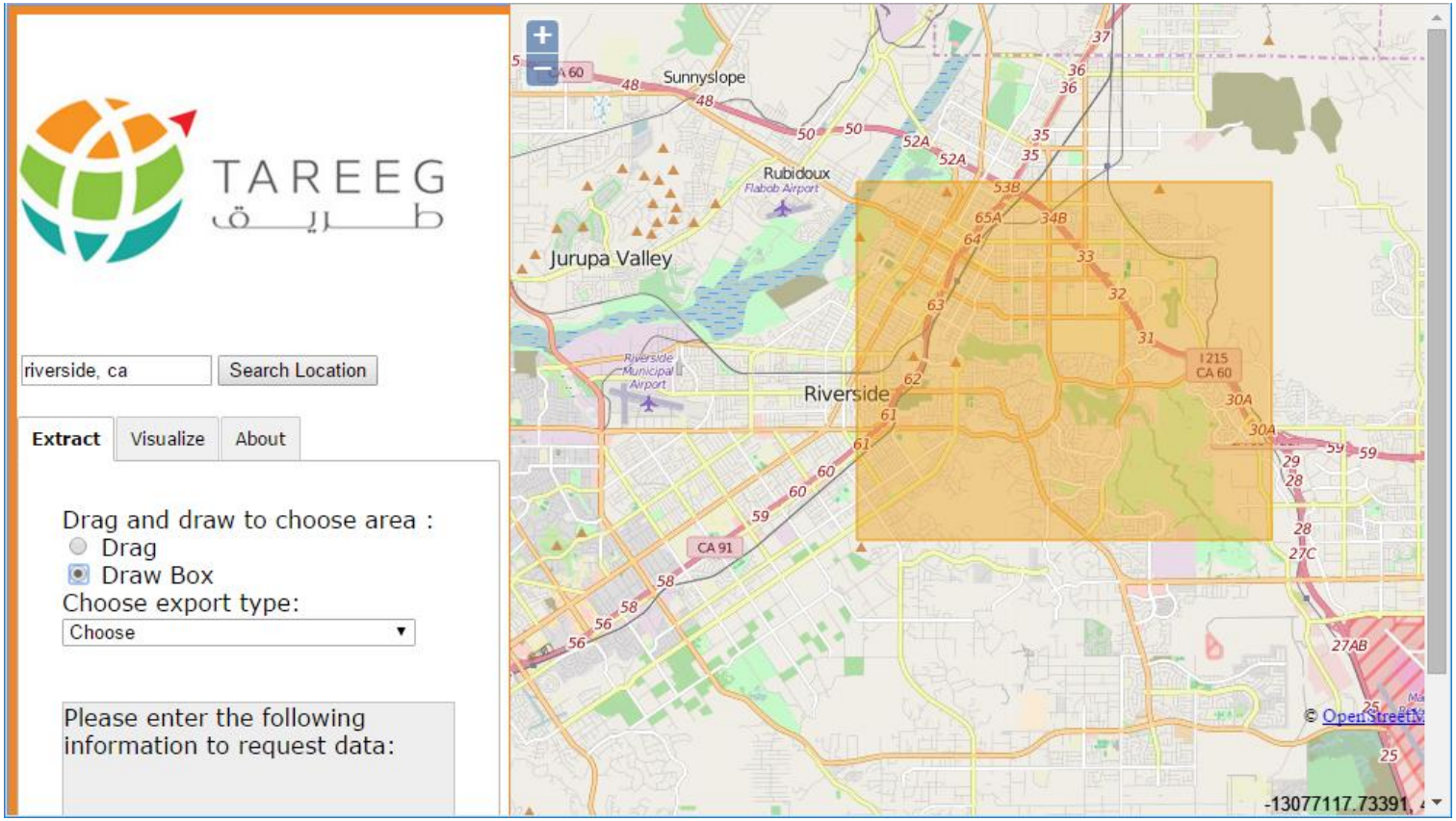
A. Eldawy *et al*. “SHAHED: A MapReduce-based System for Querying and Visualizing Spatio-temporal Satellite Data”, **IEEE ICDE’15 (Best poster runner-up)**

A. Eldawy *et al*. “A Demonstration of SHAHED: A MapReduce-based System for Querying and Visualizing Satellite Data”, **IEEE ICDE’15**

TAREEG – Web-based extractor for OpenStreetMap data using MapReduce

UCR

http://tareeg.net/



L. Alarabi, A. Eldawy, R. Alghamdi, M. F. Mokbel. “TAREEG: A MapReduce-Based System for Extracting Spatial Data from OpenStreetMap”, **ACM SIGSPATIAL’14**

___ “TAREEG: A MapReduce-Based Web Service for Extracting Spatial Data from OpenStreetMap”, **SIGMOD’14**

Agenda

- The ecosystem of SpatialHadoop
  - ~~Motivation~~
  - ~~Internal system design~~
  - ~~Applications~~
  - Related work
  - Performance Results
- Other research projects
- Future work

Other Big Spatial Data Systems

Parallel SECONDO

MD-HBase

GeoSpark

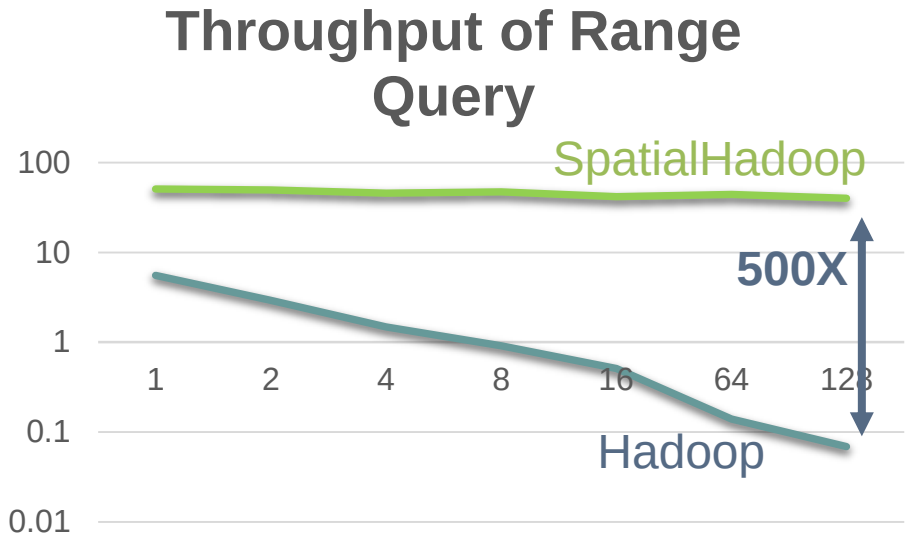
geomesa

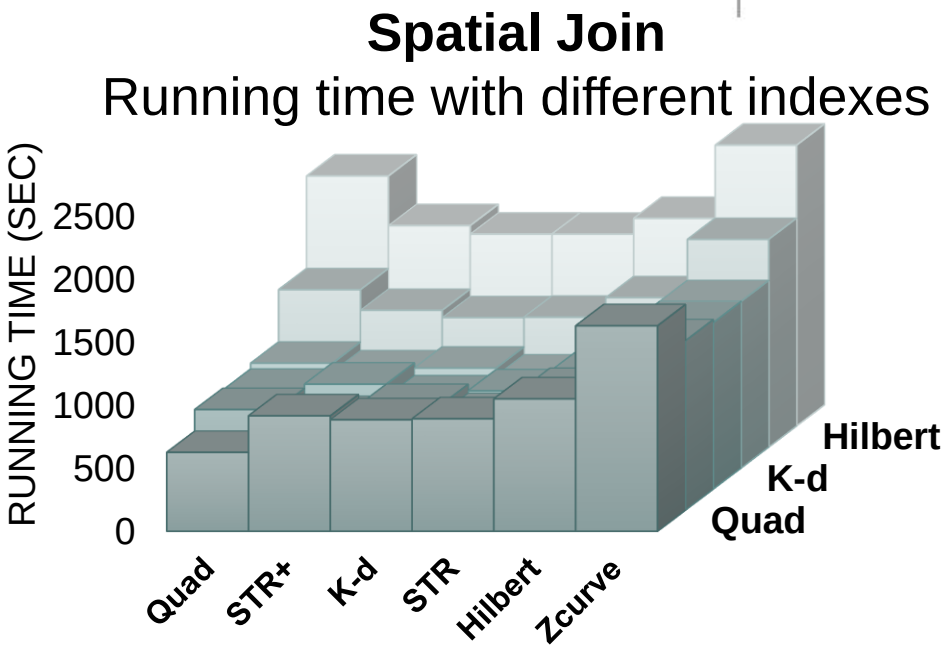
Hadoop-GIS
Spatial Big Data Solutions

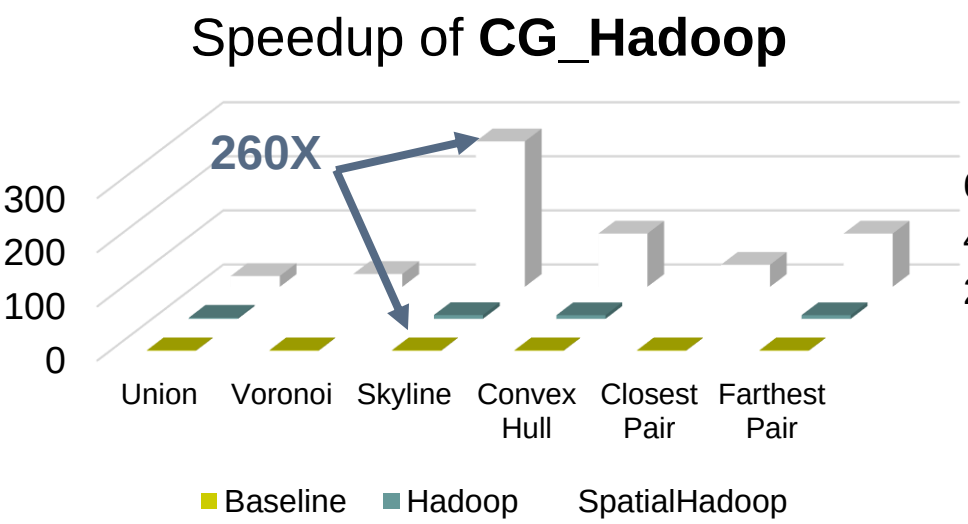
ESRI Tools for Hadoop

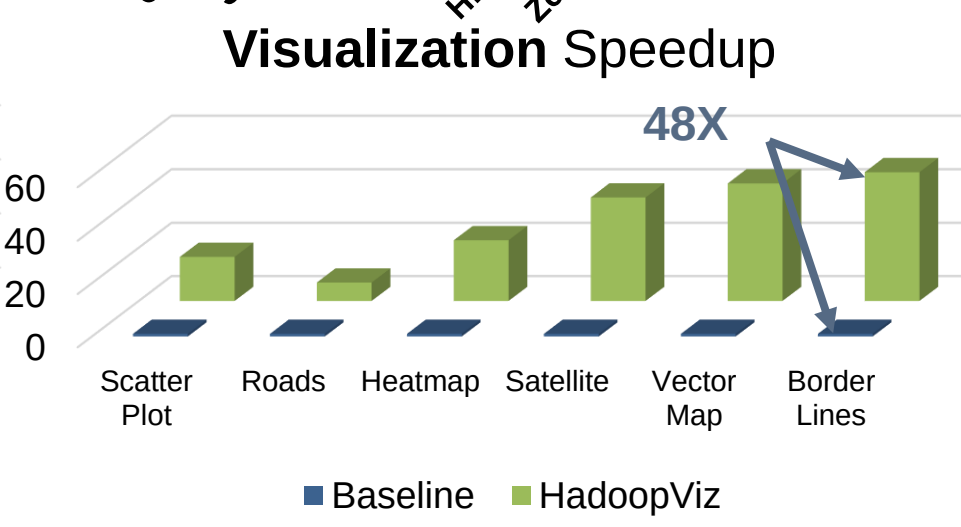
SpatialHadoop is the only extensible system that can be easily expanded by researchers and developers

Performance Results









Agenda

- ~~The ecosystem of SpatialHadoop~~
  - ~~Motivation~~
  - ~~System design~~
  - ~~Applications~~
  - ~~Related work~~
  - ~~Performance results~~
- Future directions

Adaptive Multilevel Visualization

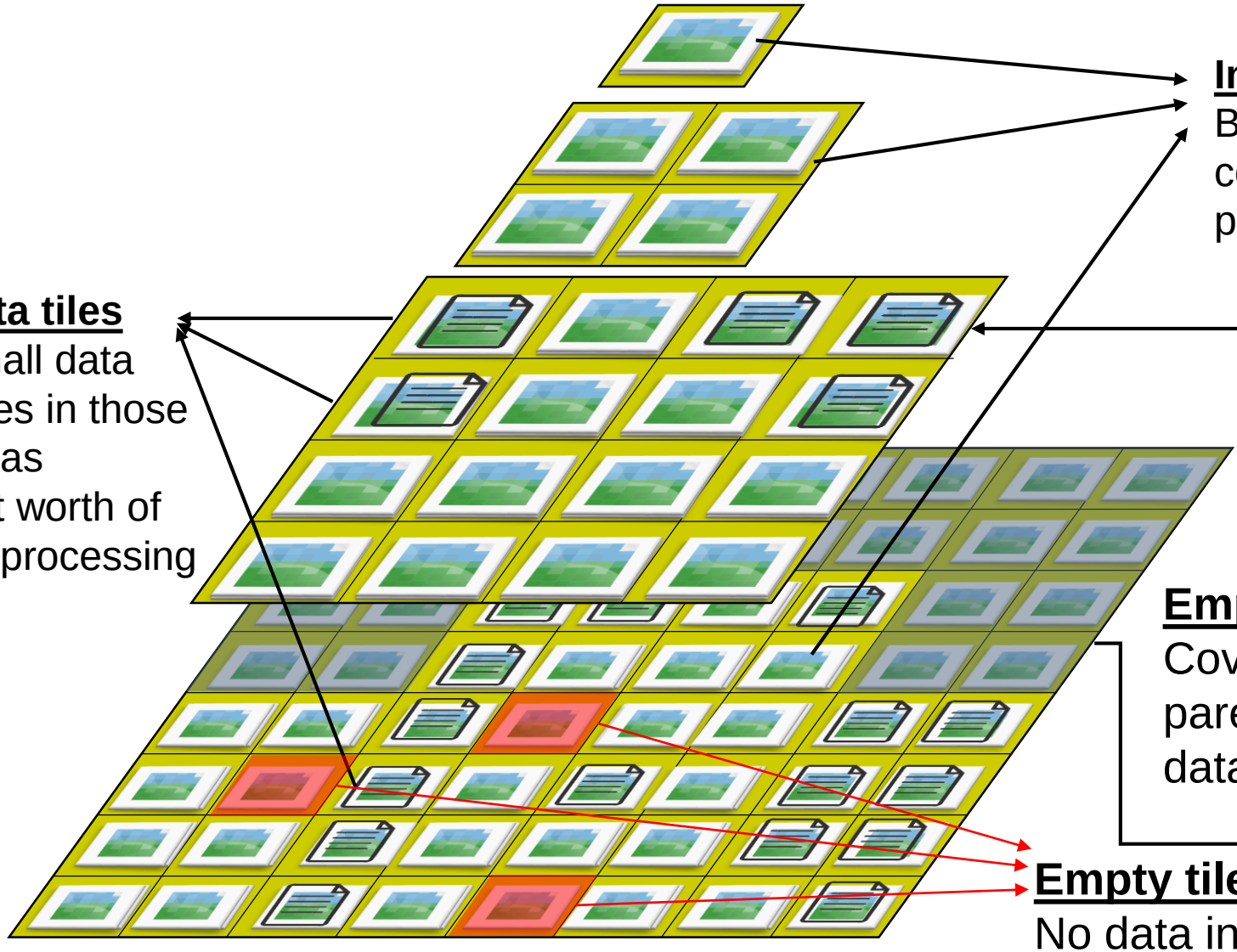


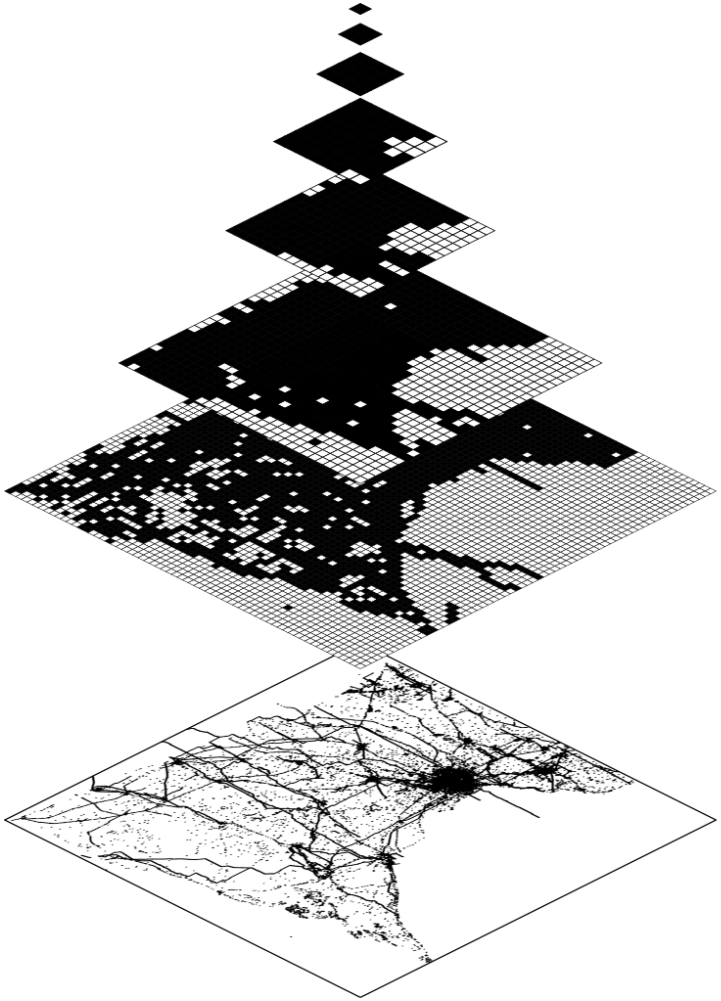
Image tiles
Big enough to consider preprocessing

Data tiles
Small data sizes in those areas
Not worth of preprocessing

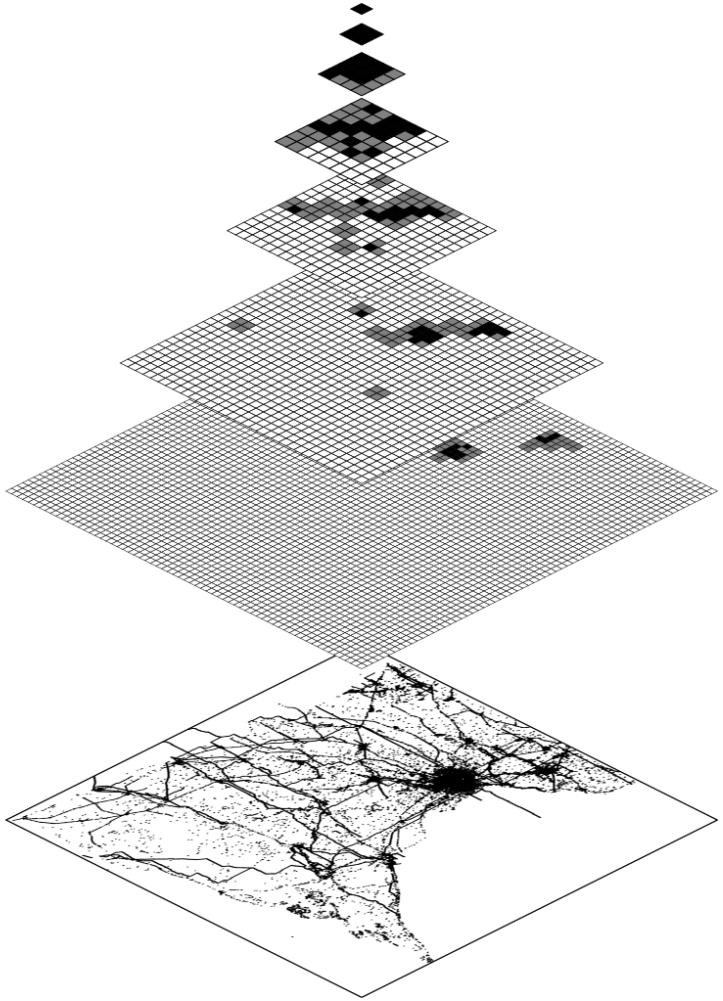
Empty tiles
Covered by parent data tiles

Empty tiles
No data in there

Adaptive Multilevel Images

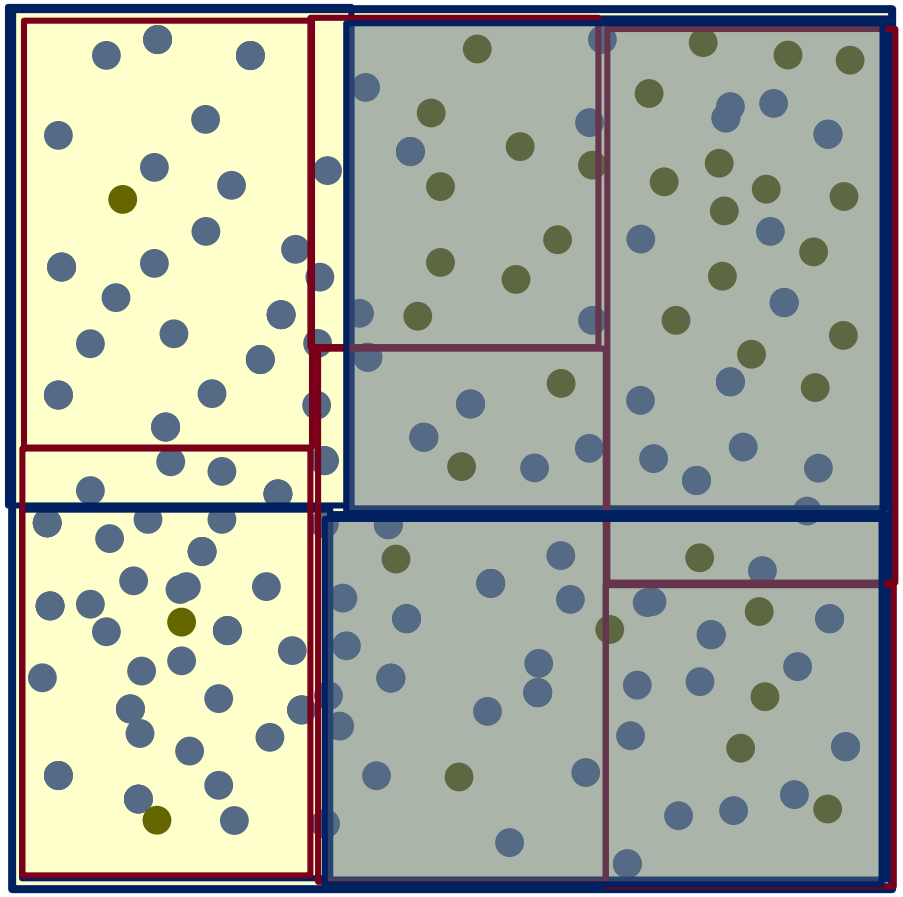


Full Image (3,160 tiles)

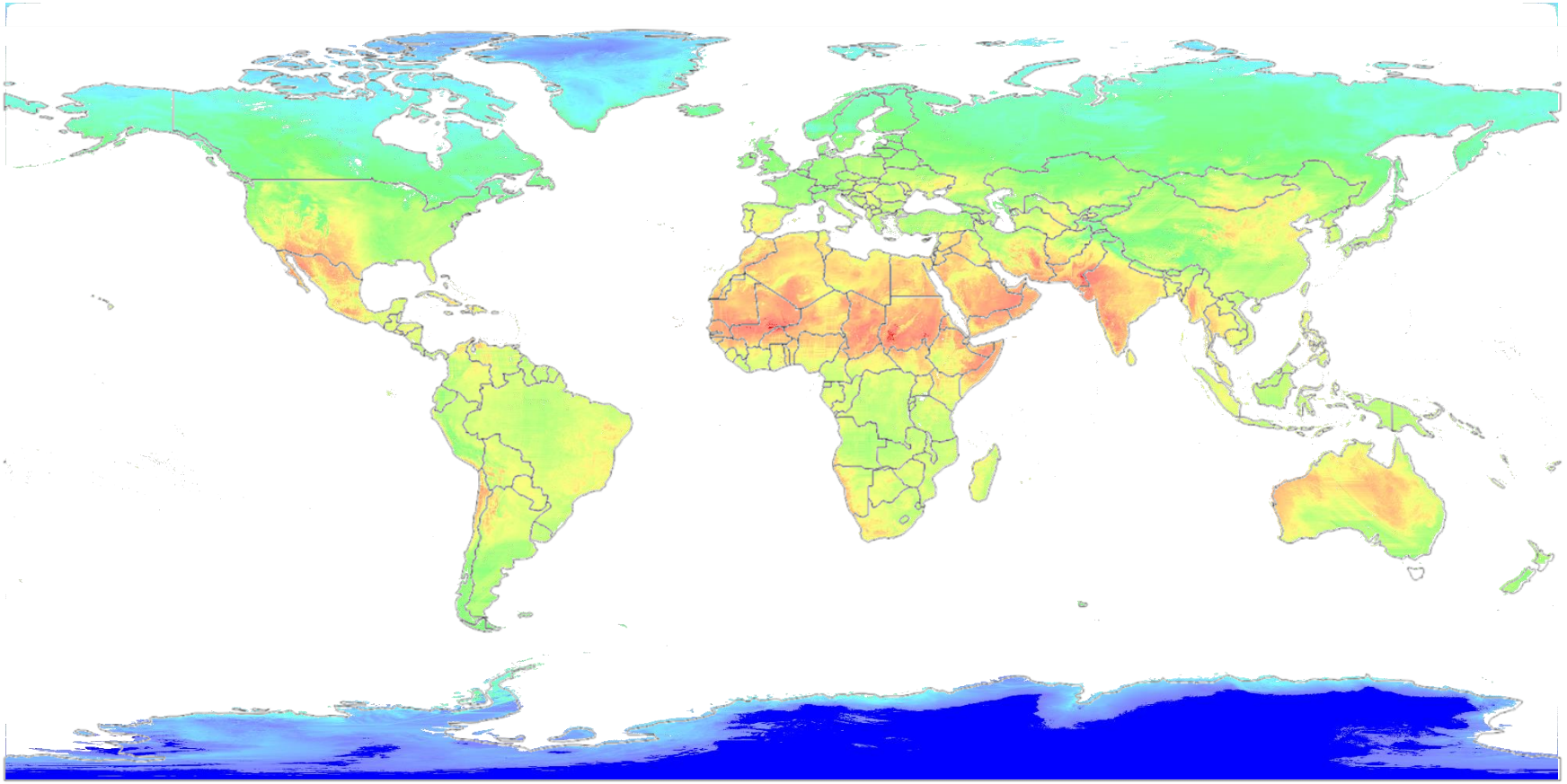


Adaptive Image (231 files)

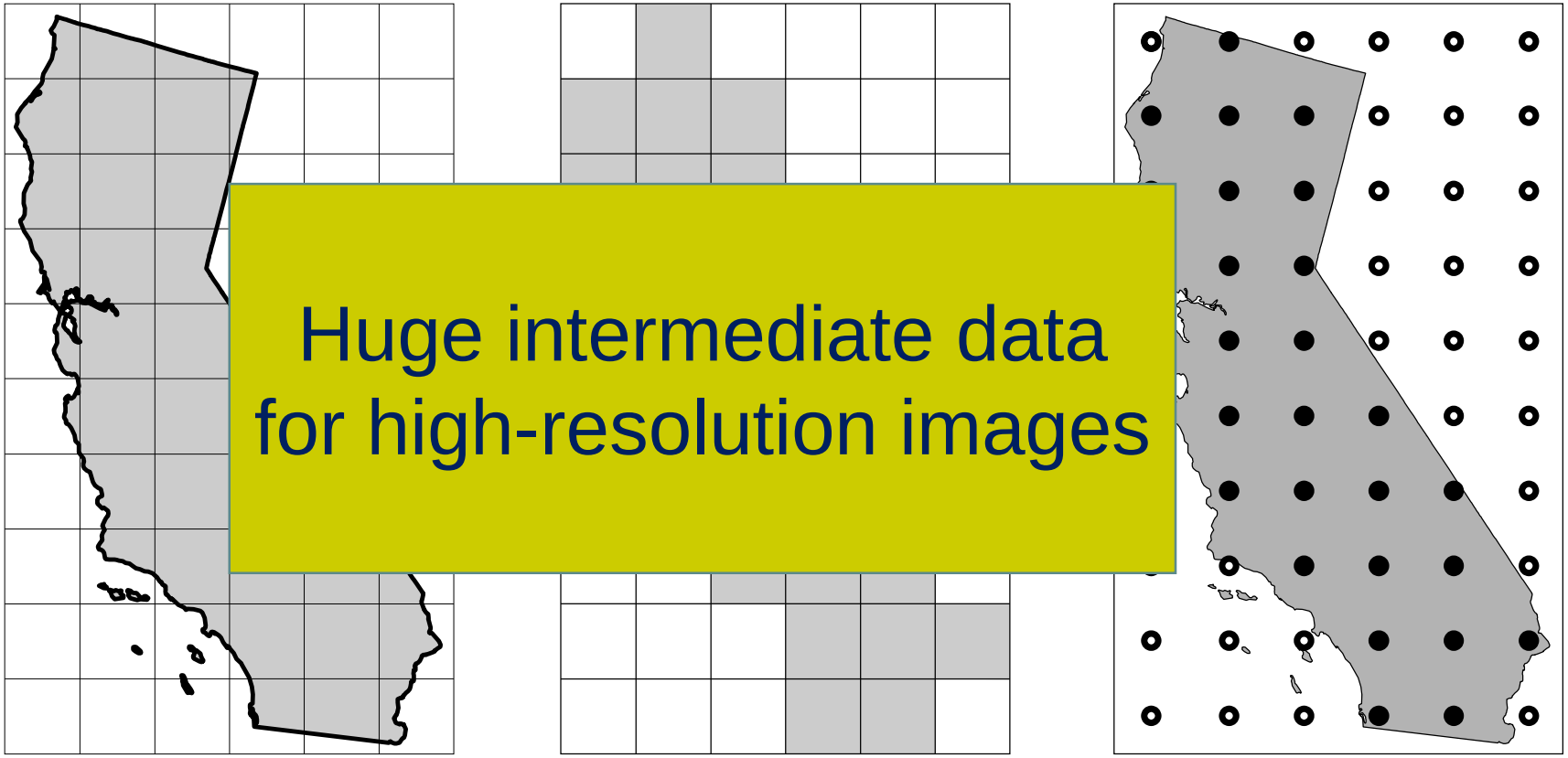
Dynamic Indexes



Analysis of Satellite Data

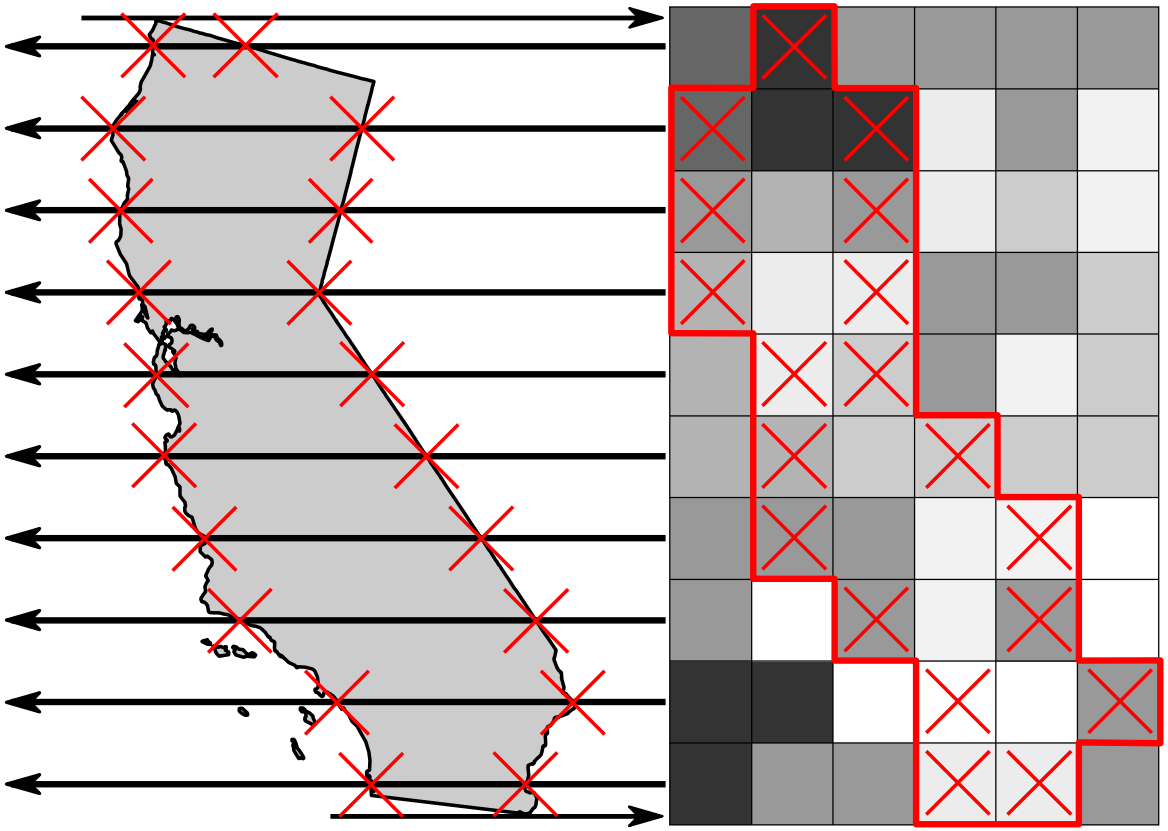


Existing Methods

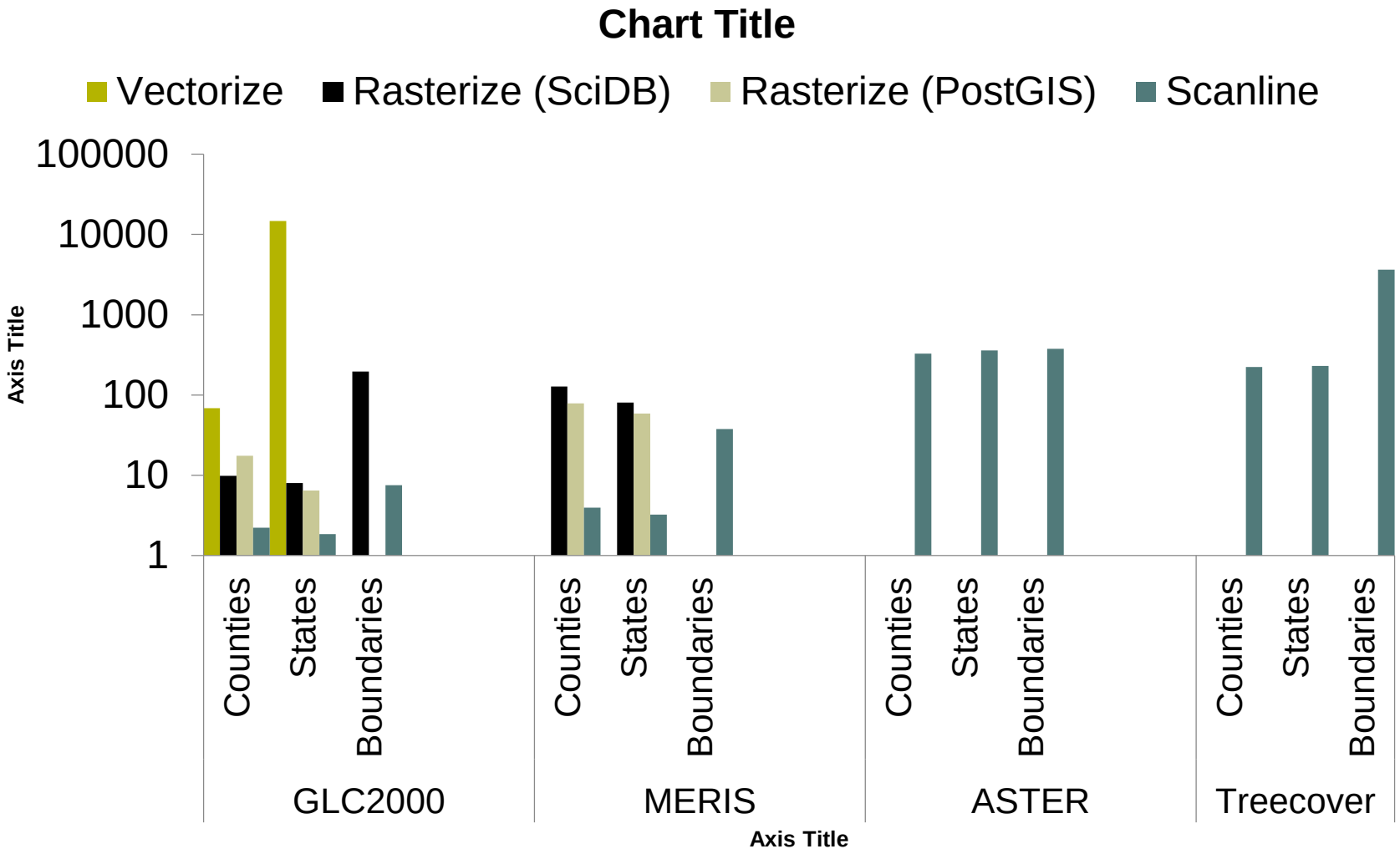


Input Rasterize Vectorize

Scanline Method



Performance



Summary


Spatial Hadoop
Apps
Visualization
(HadoopViz)
Jan-2009
Operations
Indexes

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

Thank You

Questions?