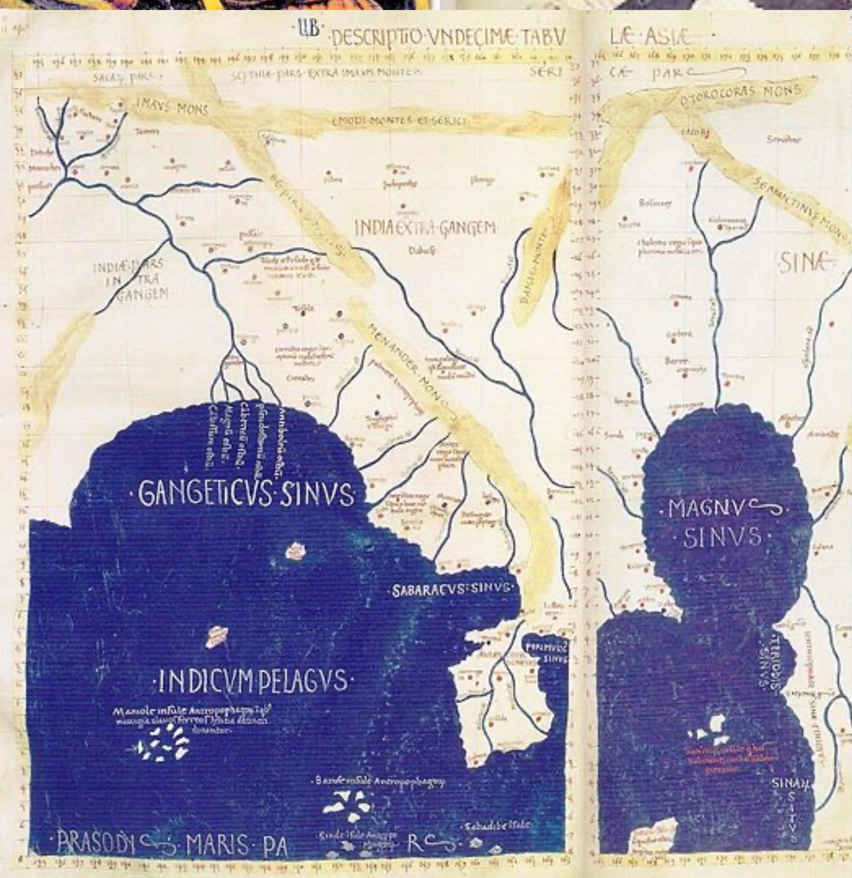
Big Spatial Data Management

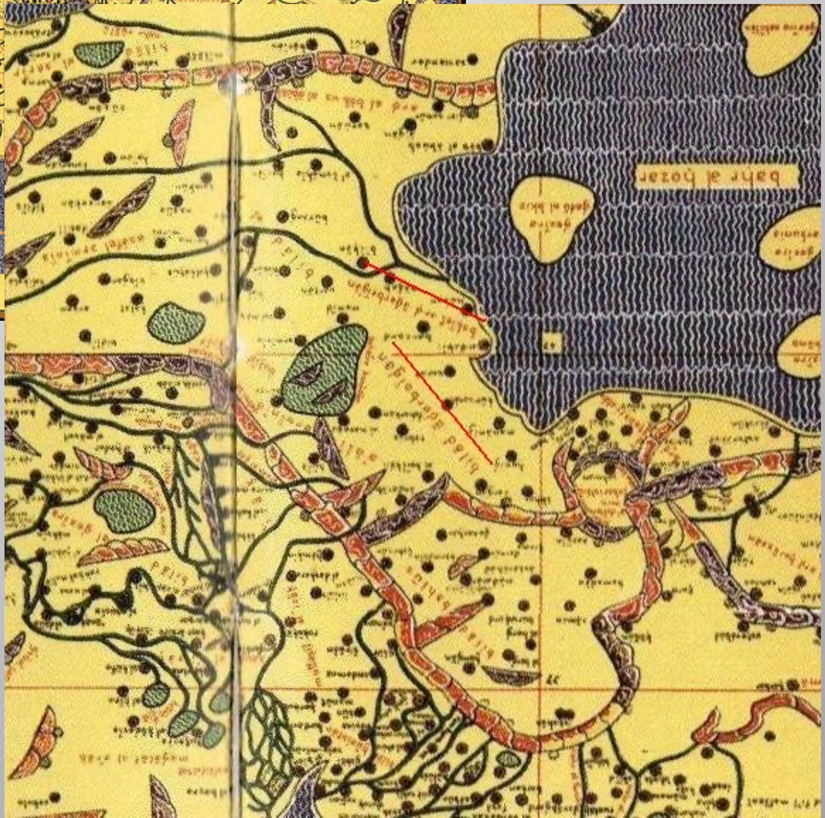
CELEBRATING 30 YEARS
Marlan and Rosemary Bourns
College of Engineering


Once upon a time...

Claudius Ptolemy (AD 90 – AD 168)



Al Idrisi (1099–1165)




Mar Atlantico
EVROPA
AFRICA
INDIA
Tropicus Cancer
Mar do Sul
Mar Indico
Mar Pacifico
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.
SAVROMATAE.
SCYTHAE.
BASTARNAE.
ALANI.
MAEOTIS PALVS.
PARS.
AXENVM Aequor, Iasonio pulsatum remige primum.
CAVCASEVM MARE.
CELTAE.
THRACIA.
CAPPADOCIA.
ASIAE.
SARDOVM PELAGVS.
TYRRHENVM AEQVOR.
THESSALIA.
ACHAIA.
IONIVM MARE.
PELOPIS REGIO.
LIBYSTICVM MARE.
CRETA
Ex conatibus Geographicis Abrah. Ortelij Antuerp.
ILLVSTRISSIMO PRINCIPI CAROLO COMITI ARENBERGIO, BARONI SEPTIMONTII, DOMINO MIRVARTII, EQVITI AVREI VELLERIS, ETC.
ABRAH. ORTELIVS DEDICABAT.
Syrtes.
CYRENE
ATLANTICVS Ager.
Hesperides.
LIBYAE PARS.
MERIDIES.
PROPONTIS.
BITHYNIA.

Cholera cases in the London epidemic of 1854

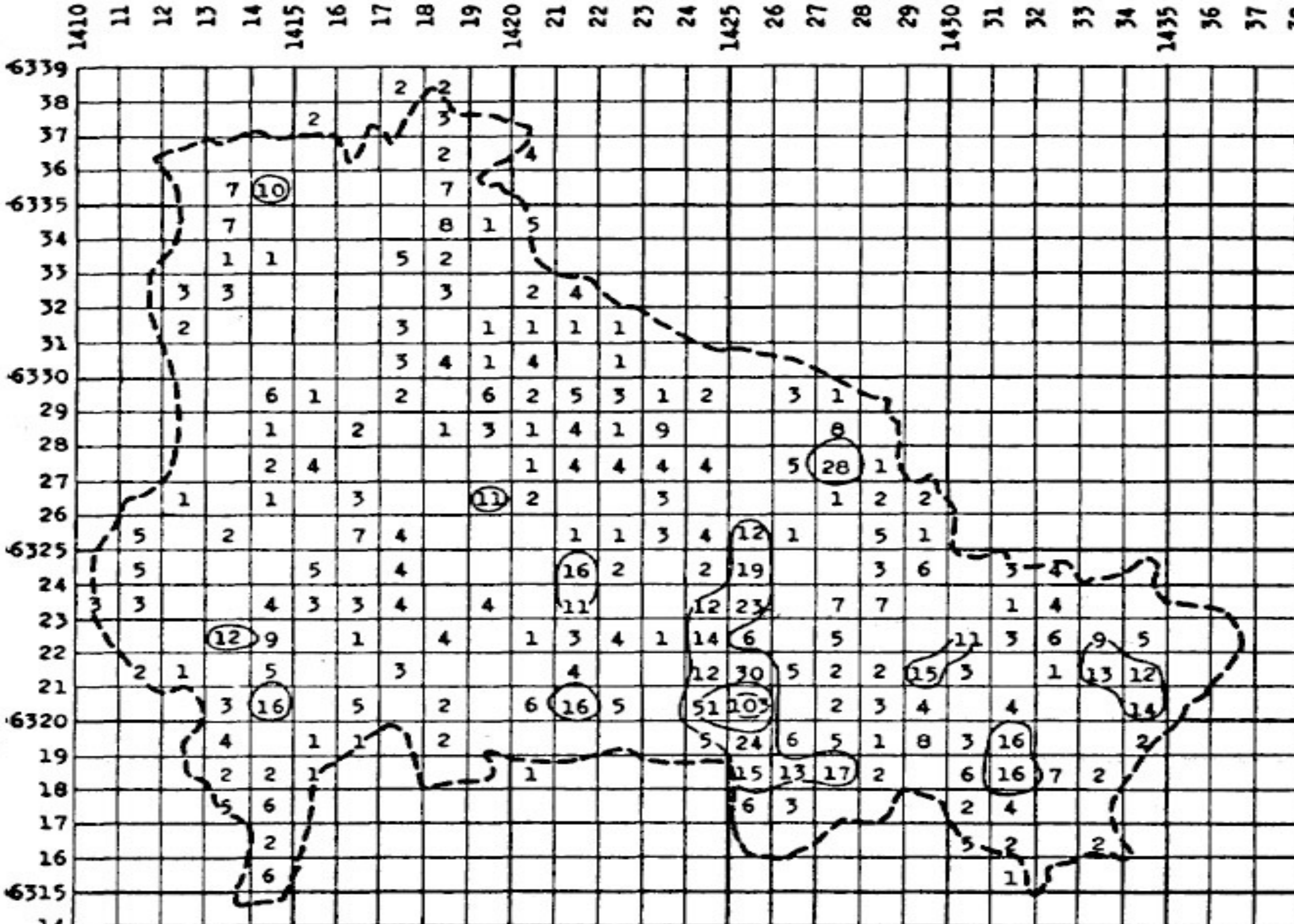


FIGURE 3—Children under 15 years of age in 1940.

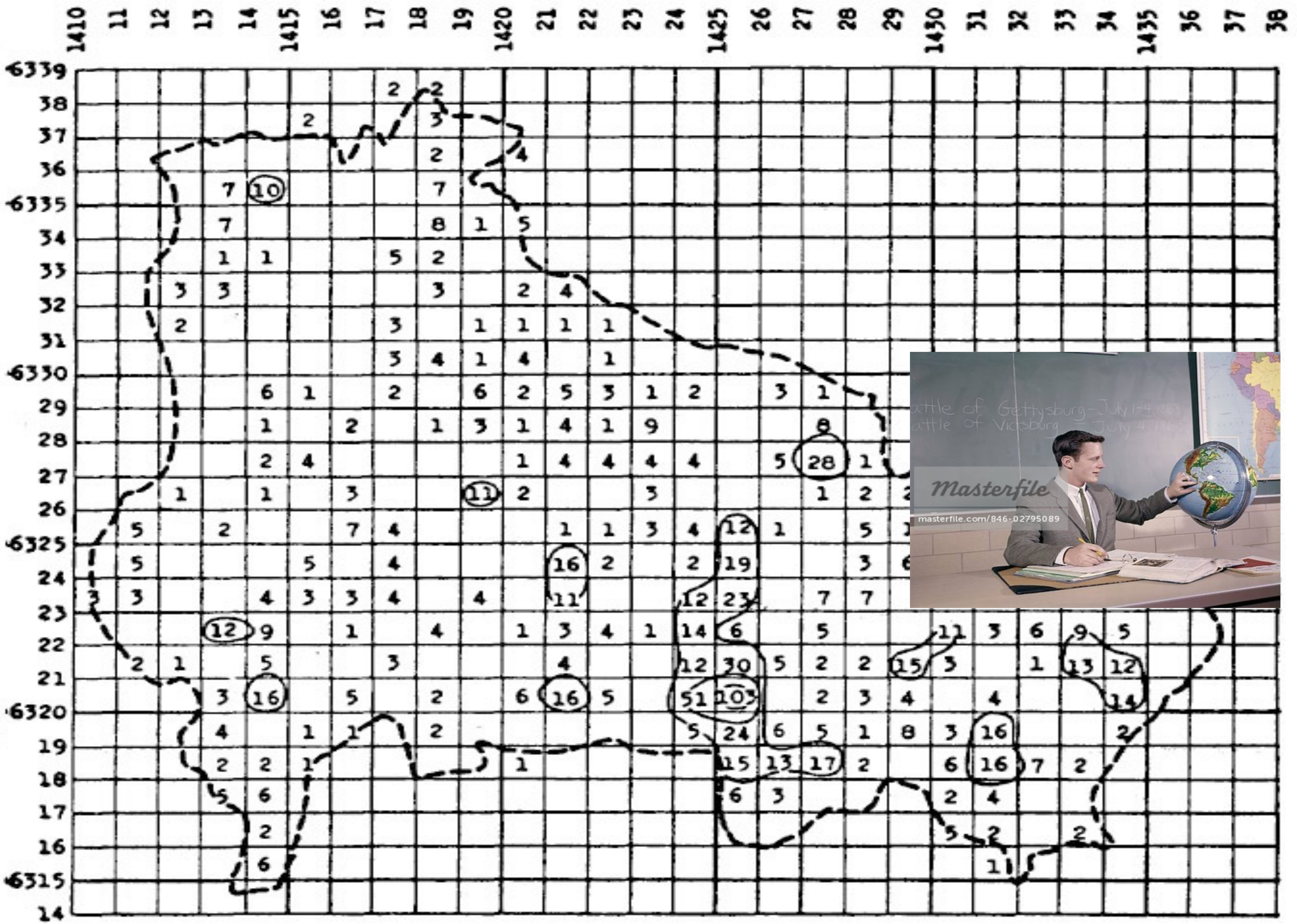


FIGURE 3—Children under 15 years of age in 1940.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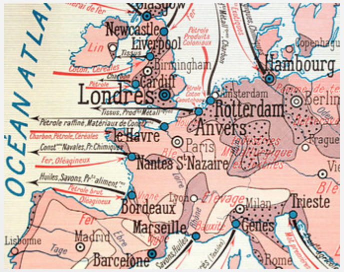
5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Trieste
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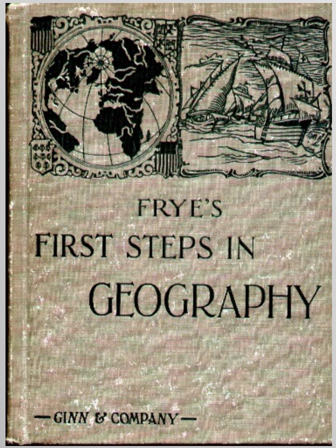
Rome


FRYE'S
FIRST STEPS IN
GEOGRAPHY
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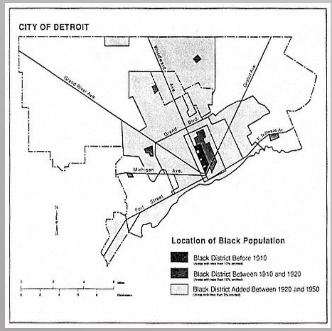
CITY OF DETROIT
Location of Black Population
Black District Before 1910
Black District Between 1910 and 1920
Black District Added Between 1920 and 1950


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UNIVAC


IBM


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.
CITY OF DETROIT
Location of Black Population


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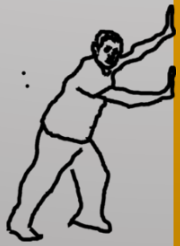
IBM

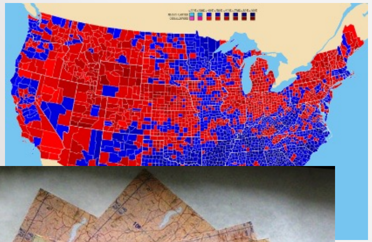


1969

Kindly let me understand your needs

Kindly let me get the technology you have

ESRI





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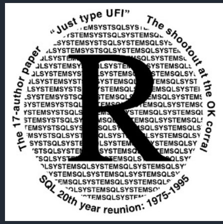
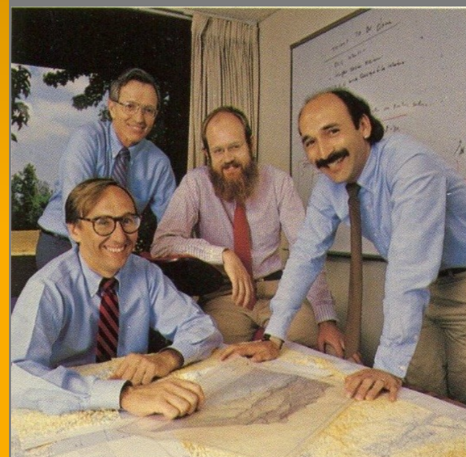




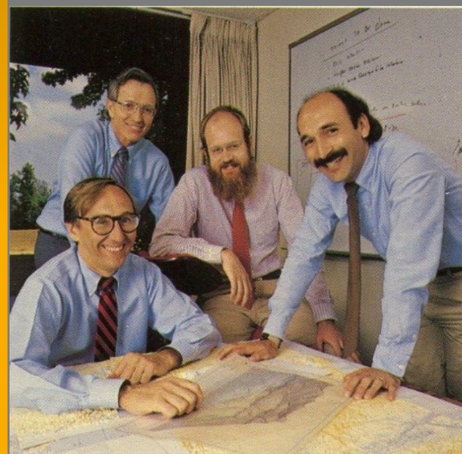
PostgreSQL
Informix

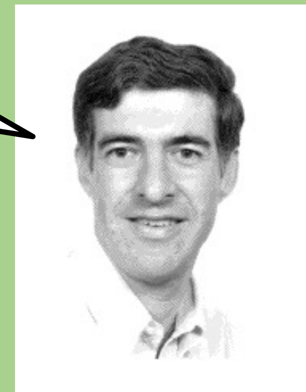


HELP..!! I have BIG data. Your technology is not helping me
mmm…Let me check with my good friends there.
Cool Database technology..!! Can I use it in my application?
Oh..!! But, it is not made for me. Can't make use of it as is
My pleasure. Here it is.
PostgreSQL
Informix
ORACLE
AIRLINE BOOKING
Banking
ESRI

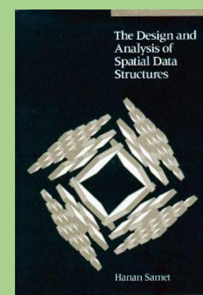


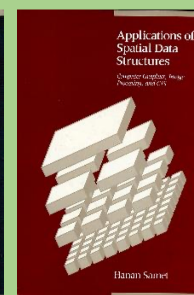
Kindly let me understand your needs

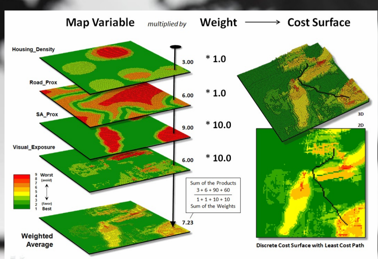


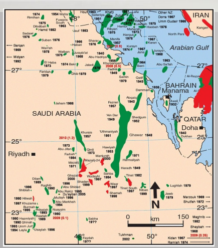


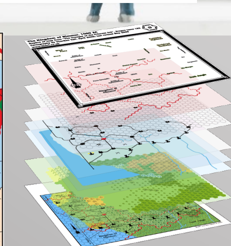
Kindly let me get the technology you have

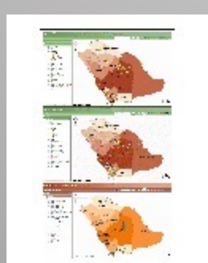












Arc GIS
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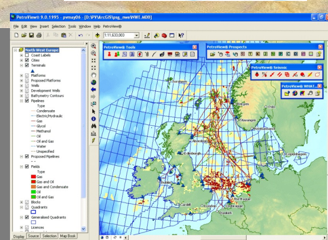

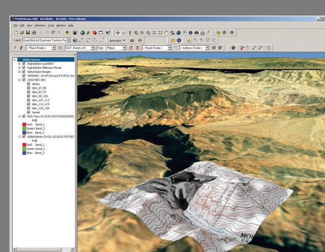

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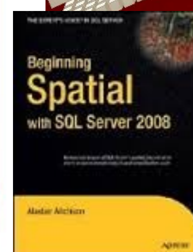
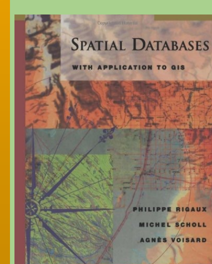
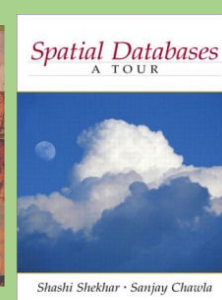
Geospatial Objects for PostgreSQL







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Microsoft SQL Server

PostgreSQL
the world's most advanced open source database

MySQL

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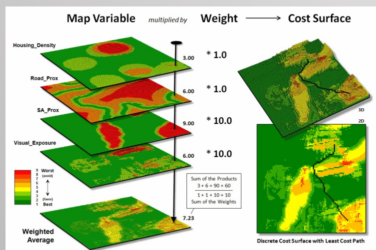

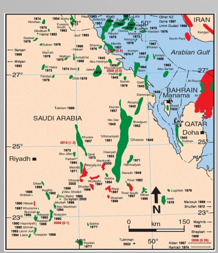

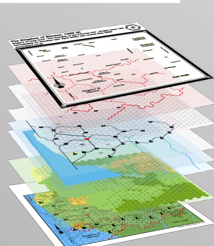

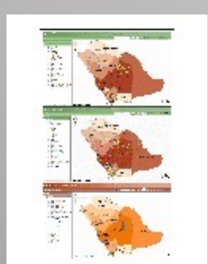

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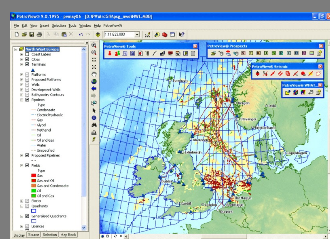

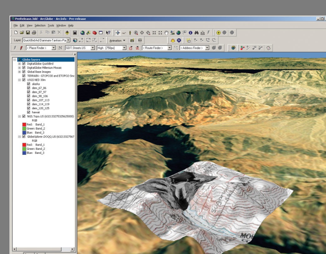

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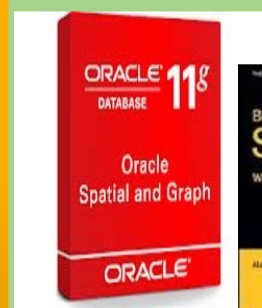

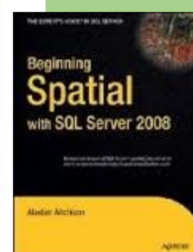

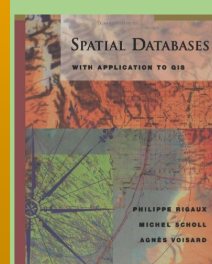

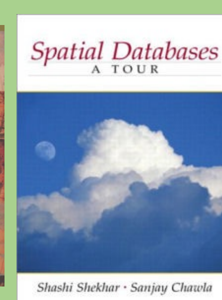

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HELP..!! Again, I have BIG data. Your technology is not helping me
Sorry, seems like the DBMS technology cannot scale more
Let me check with my other good friends there.
Cool Big Data technology..!! Can I use it in my application?
My pleasure. Here it is.
Oh..!! But, it's not made for me. Can't make use of it as is
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Big Spatial Data Management

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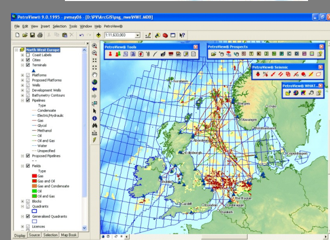

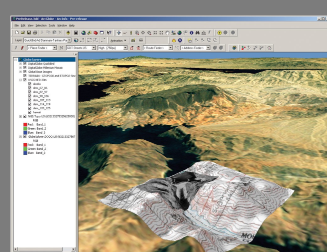

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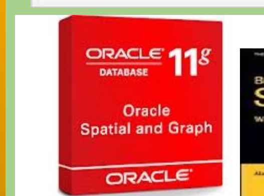
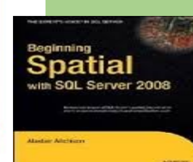
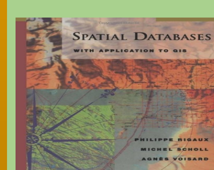
Geospatial Objects for PostgreSQL







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MapReduce
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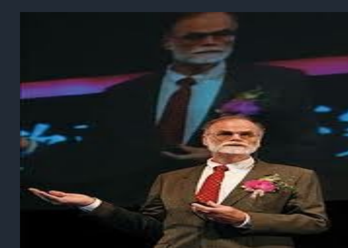
HIVE
Spark



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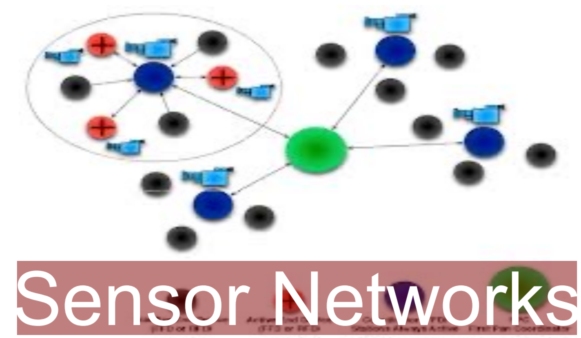
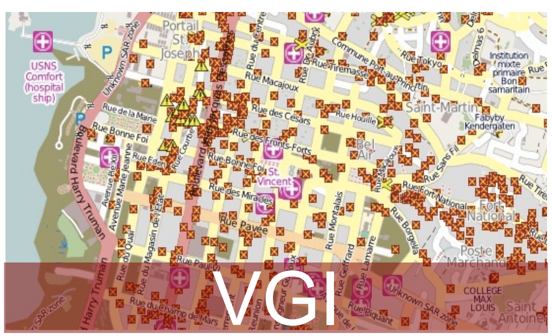
Tons of Spatial data out there…





Spatial Data on Spark

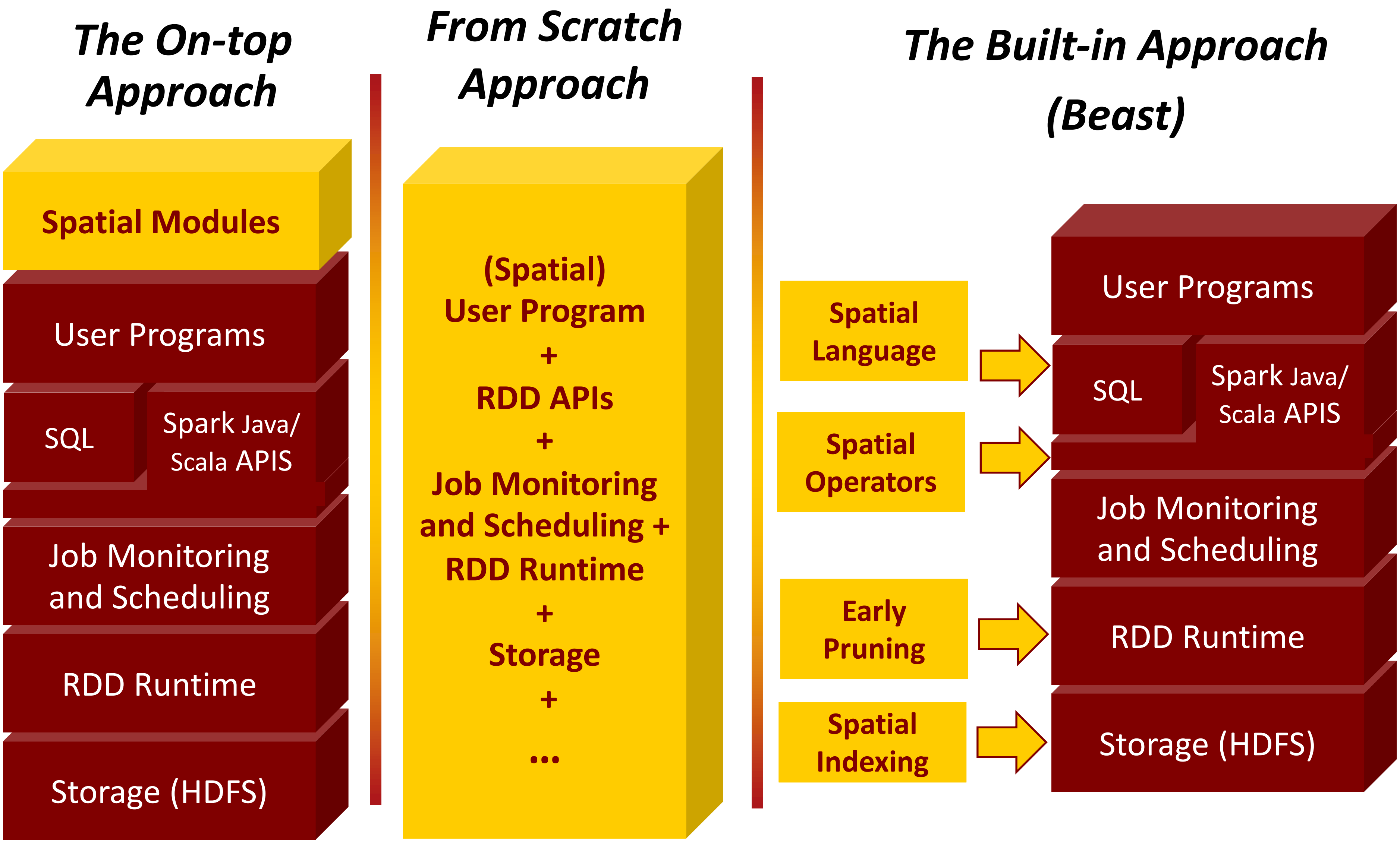
```scala
val points: RDD[(Double, Double)] = sc.textFile("points.csv")
  .map(l => {
    val coords = l.split(",").map(_.toDouble)
    (coords(0), coords(1))
  })
val xmin, ymin, xmax, ymax: Double = null
val result = points.filter(point => {
  point._1 >= xmin && point._1 < xmax &&
    point._2 >= ymin && point._2 < ymax
})
result.map(pt => s"${pt._1},${pt._2}")
  .saveAsTextFile("output")
```

193 seconds

```scala
val points: RDD[IFeature] = sc.readCSVPoint("points.csv")
val range = new GeometryFactory().toGeometry(
  new Envelope(xmin, xmax, ymin, ymax))
val results = points.rangeQuery(range)
results.saveAsCSVPoints("output.csv")
```

2 seconds

The Built-in Approach of Beast



Domain-specific Big-data

- Spark and similar frameworks are general purpose systems
- They can be customized for a specific domain
- This part is an example of how to customize a big-data system for the domain of spatial data

Beast Architecture

Big Spatial Data Apps

BEAST

Visualization Framework

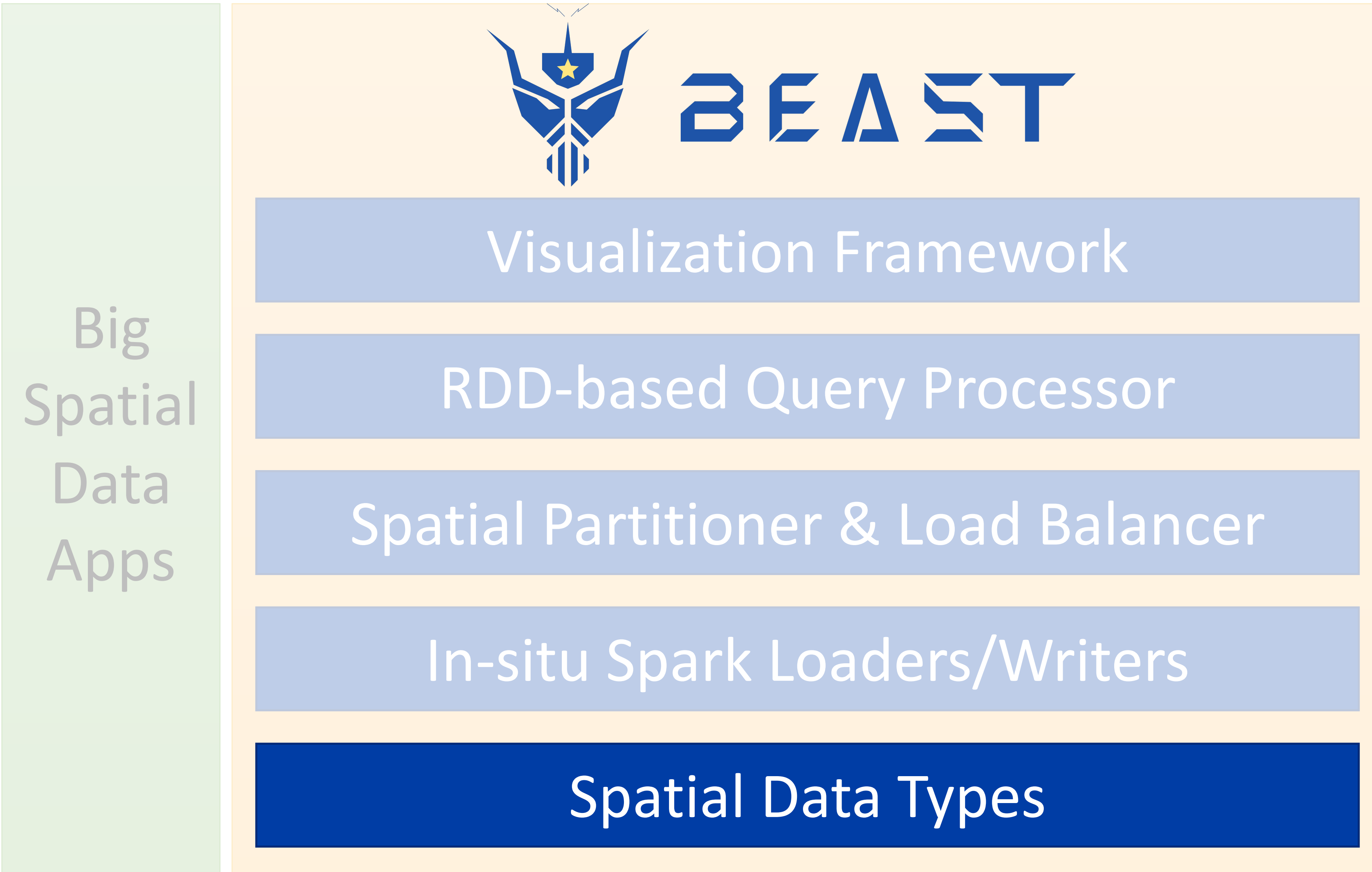
RDD-based Query Processor

Spatial Partitioner & Load Balancer

In-situ Spark Loaders/Writers

Spatial Data Types

Beast Architecture



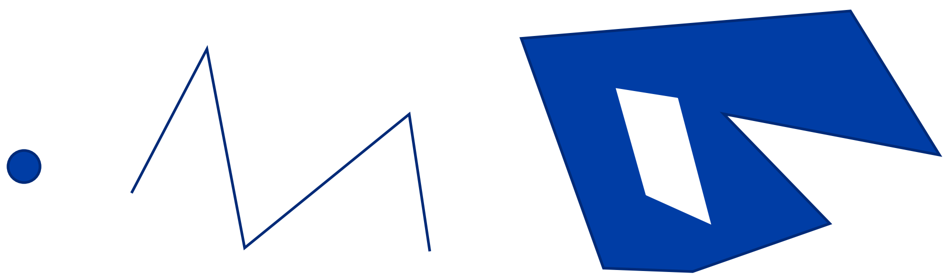
Spatial Data Types

- RDD is flexible enough to allow any user-defined class to be used with RDD
- In Beast, we define the following types
  - Point: n-dimensional point
  - Envelope: n-dimensional box
  - Geometry: Any vector-based geometry
  - Feature: Geometry + attributes

Spatial Data Types

Point

Envelope



Geometry

Feature

Code Samples

```
import org.apache.spark.rdd.RDD
import edu.ucr.cs.bdlab.beast.geolite.IFeature
val buildings: RDD[IFeature] = sc.geojsonFile("buildings.geojson")
```

```
val polygons: SpatialRDD = sc.shapefile("us_counties")
val randomPoints: SpatialRDD = sc.generateSpatialData.
  mbr(polygons.summary).uniform(1000000)
val sjResult = polygons.spatialJoin(randomPoints)
```

Code Samples

```
val counties: SpatialRDD = sc.shapefile("us_counties")
counties.toDataFrame(spark).createOrReplaceTempView("counties")
val counties_areas = spark.sql(
  "SELECT NAME, g, ST_Area(g) FROM counties")
counties_areas.toSpatialRDD.saveAsGeoJSON("us_counties_areas")
```

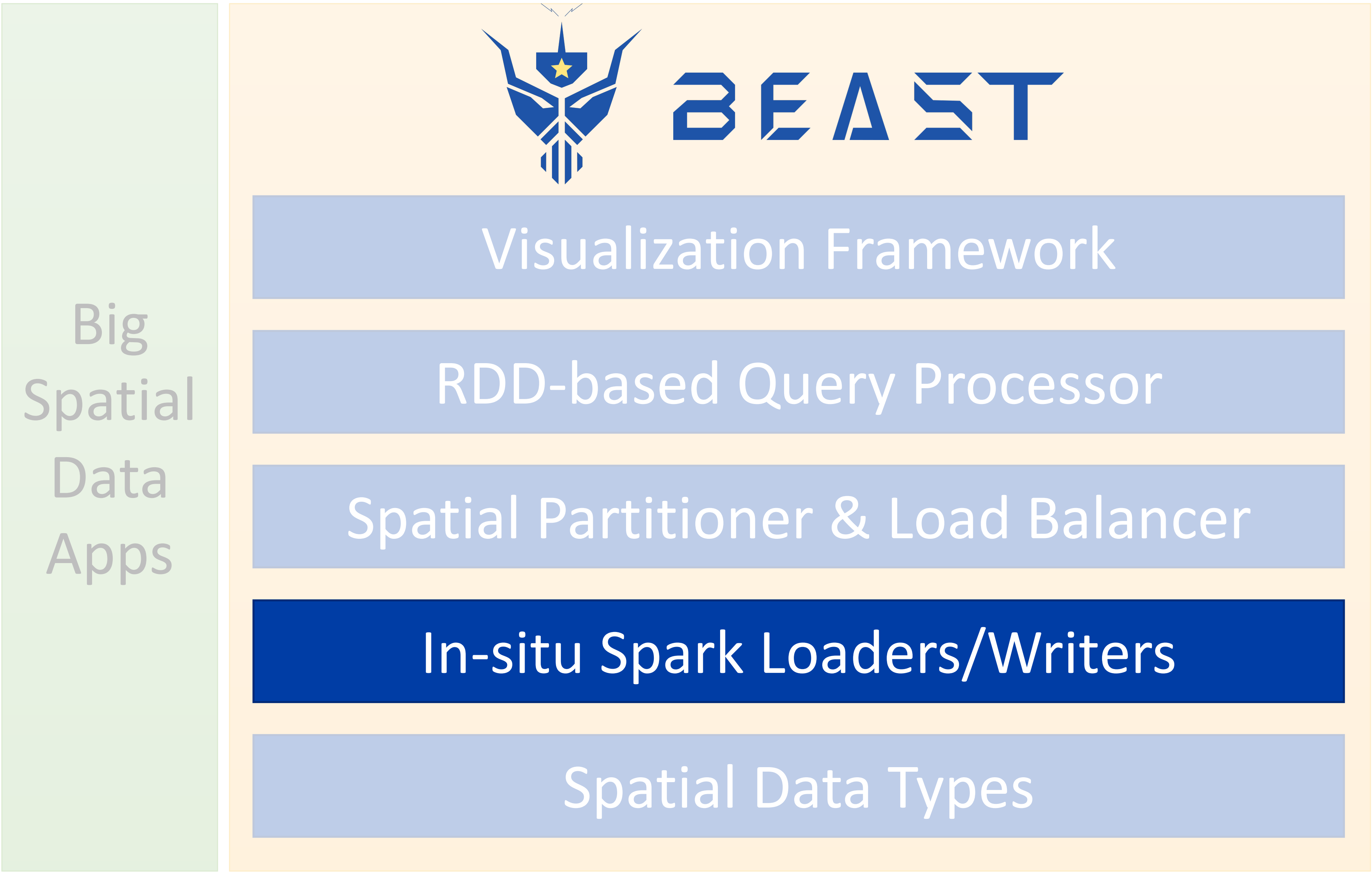
```
import edu.ucr.cs.bdlab.beast.indexing.RSGrovePartitioner
val partitioned: RDD[(Int, IFeature)] = sc.shapefile("points.shp").
  partitionBy(classOf[RSGrovePartitioner])
```

Code Samples

```
partitioned.saveAsIndex("partitioned_data", "shapefile")
// To load the data back in another Spark application
val loadedPartitioned = sc.shapefile("partitioned_data")
```

```
sc.shapefile("us_counties")
  .plotImage(2000, 2000, "counties.png")
```

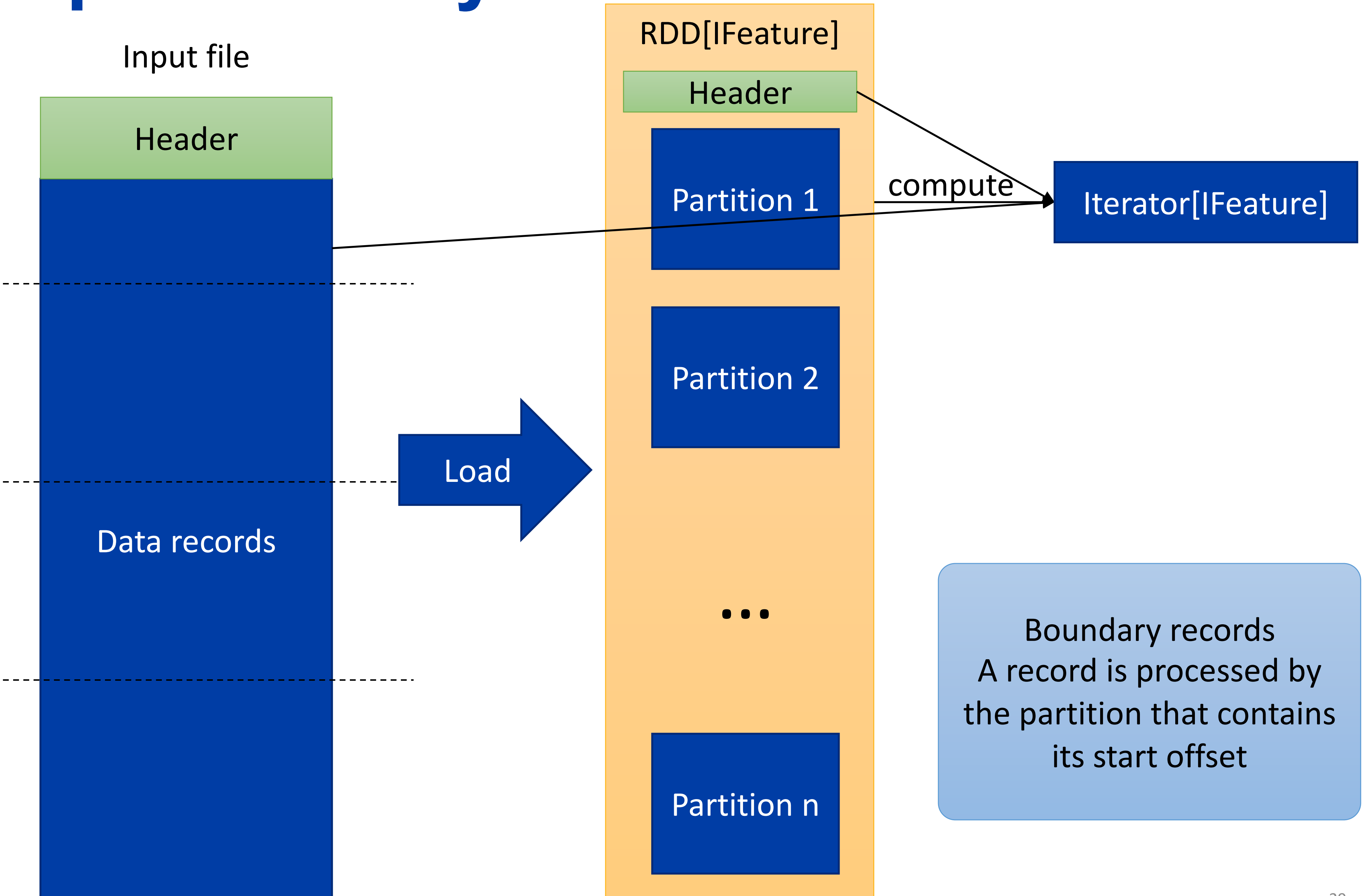
Beast Architecture



Spark Loaders

- In Spark, a data loader is a top-level RDD that does not depend on any other RDD
- To load data in an input path:
  - Define partitions based on the input metadata
  - Provide a parser for one partition that extracts all records

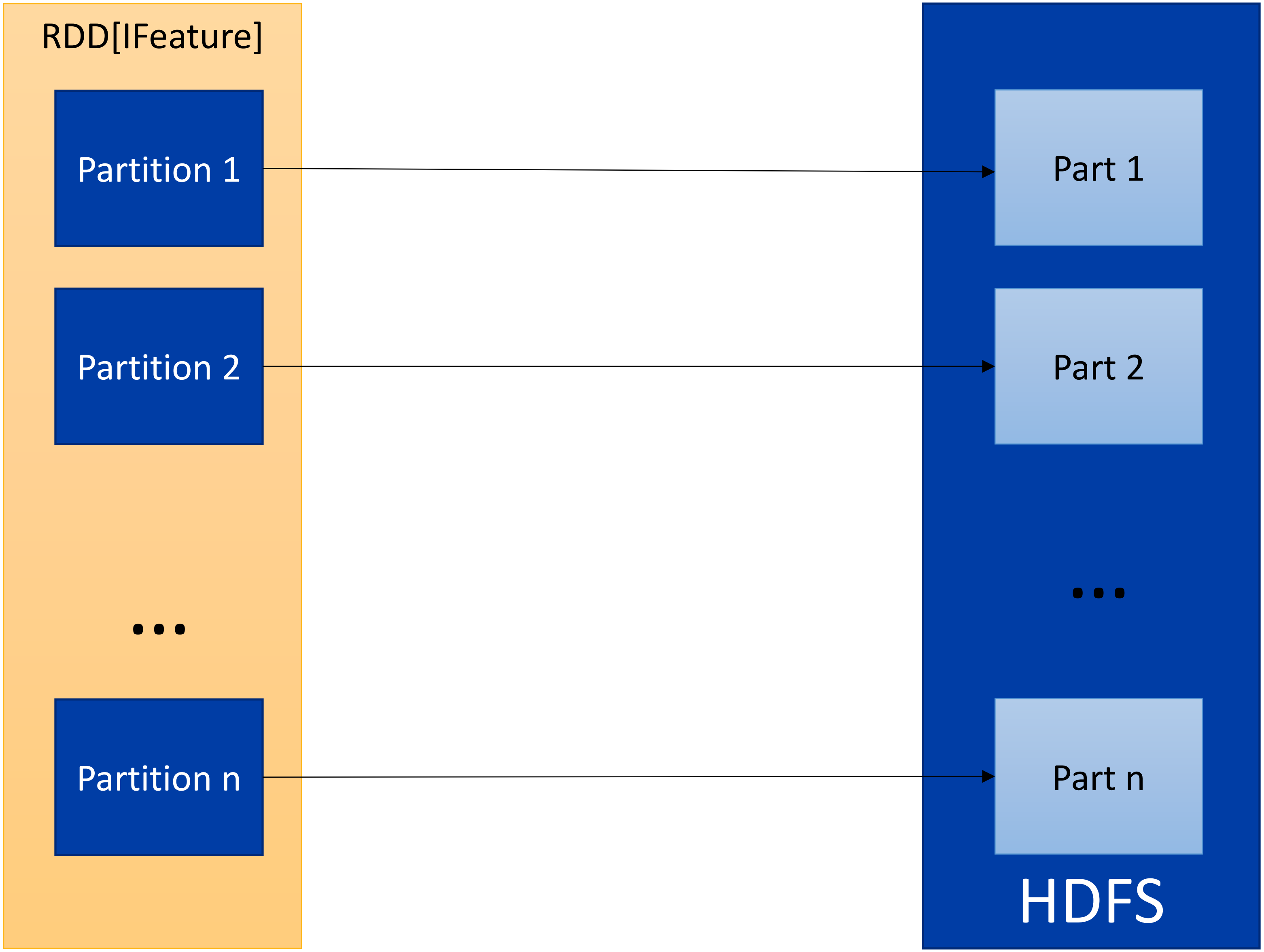
Spatial binary files



Spark Writer

- Implemented as an action
- Operates on RDD[IFeature] and writes all its contents to an output path
- Each partition is written to a separate file

Spark Writer



Beast Architecture

Big Spatial Data Apps

BEAST

Visualization Framework

RDD-based Query Processor

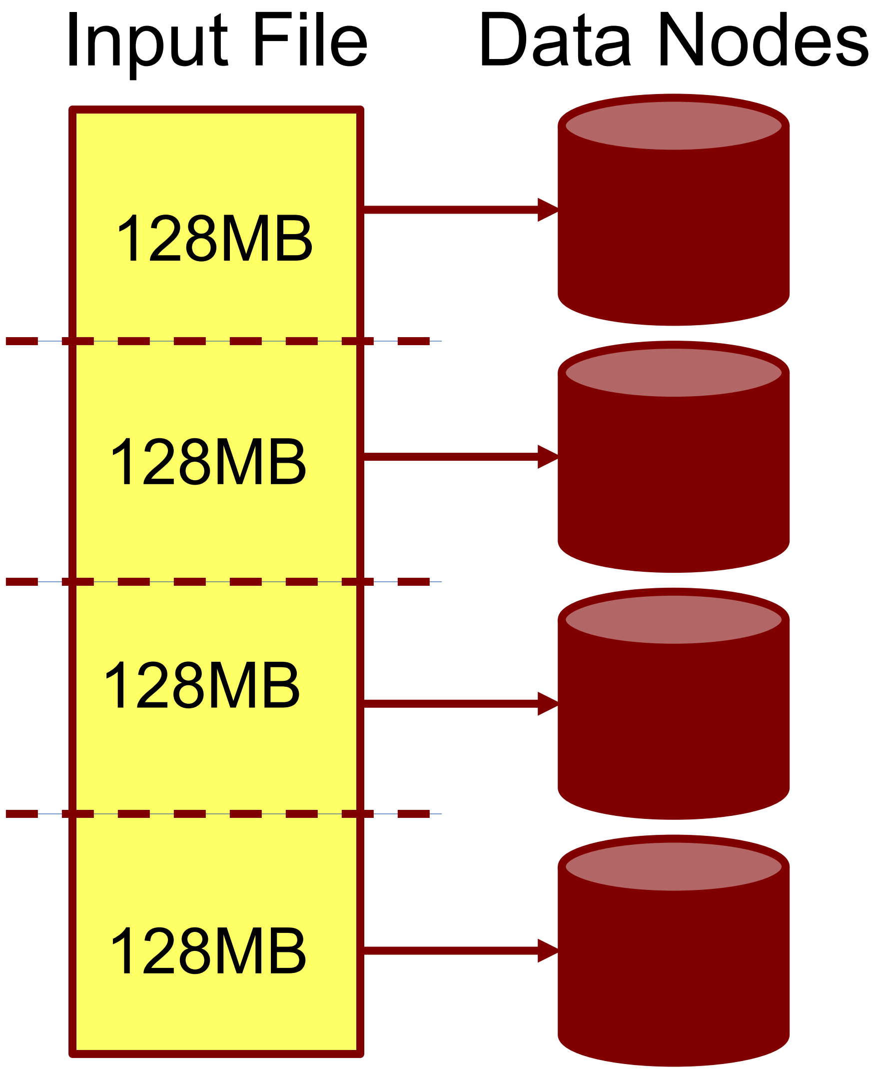
Spatial Partitioner & Load Balancer

In-situ Spark Loaders/Writers

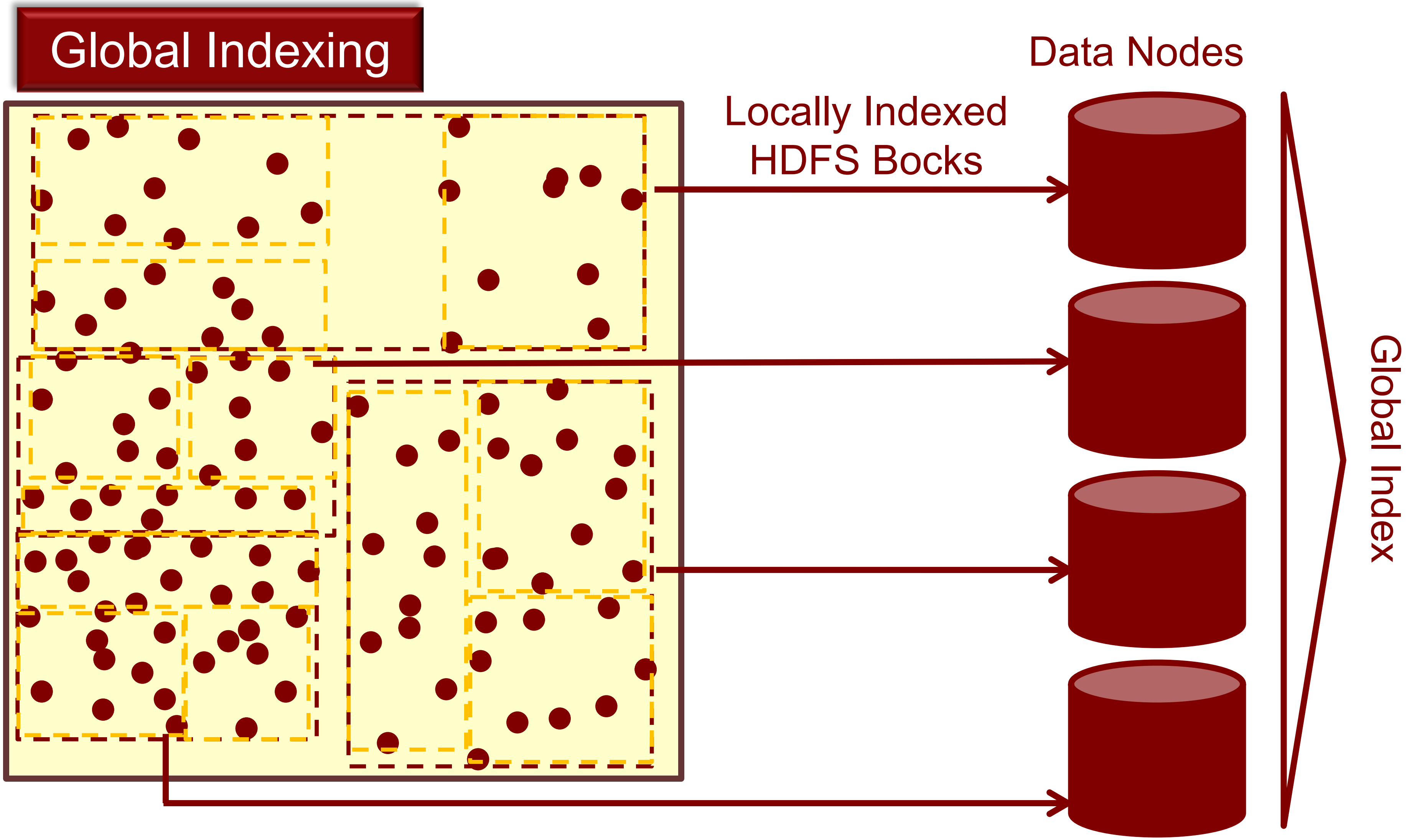
Spatial Data Types

Data Loading in HDFS

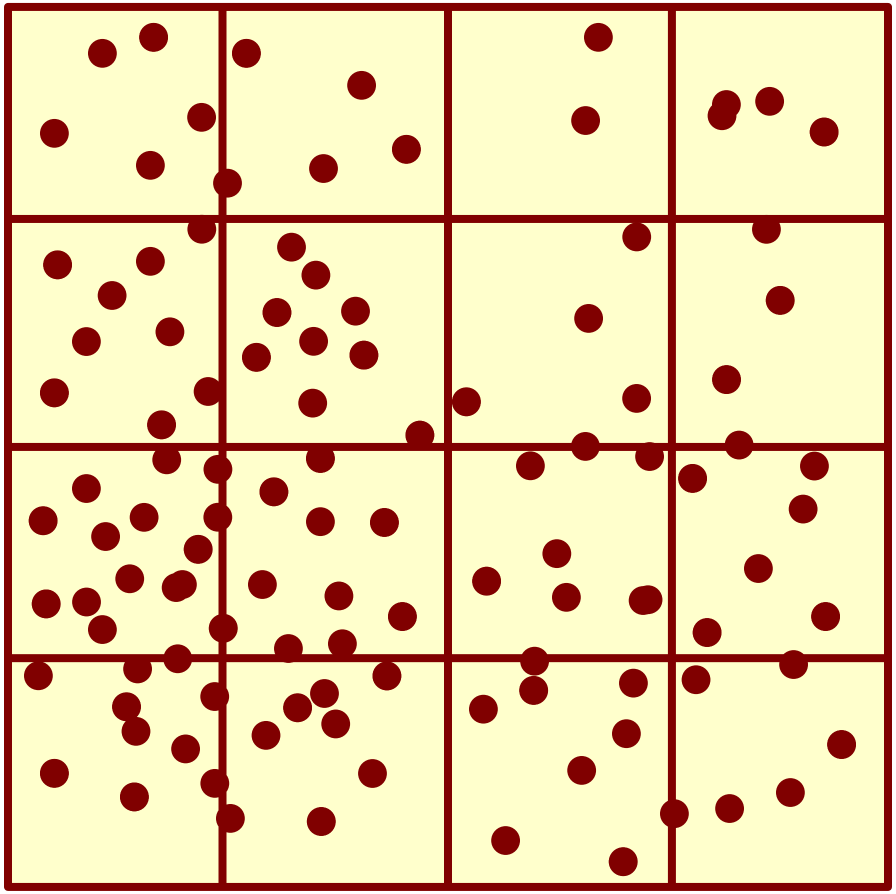
- Blindly chops down a big file into 128MB chunks
- Values of records are not considered
- Relevant records are typically assigned to two different blocks
- HDFS is too restrictive where files cannot be modified



Two-layer Index Layout



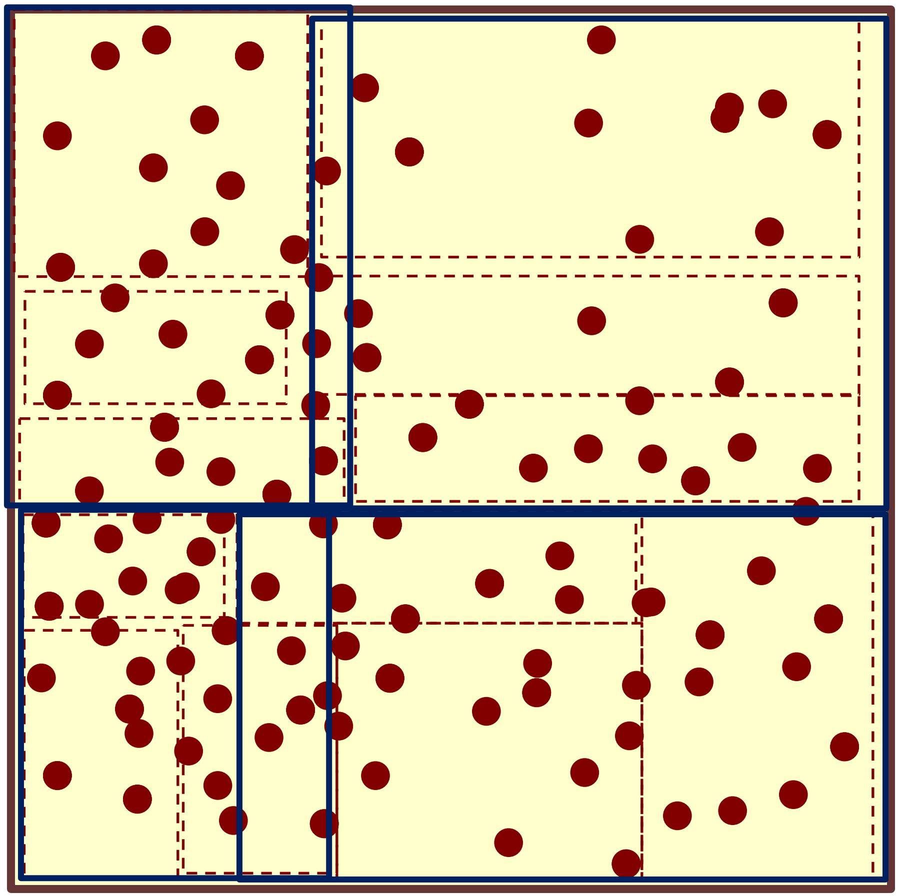
Uniform Grid



Works only for uniformly distributed data

R-tree

- Read a sample
- Partition the sample using an R-tree index
- Use MBR of leaf nodes as partition boundaries for all the data



R-tree

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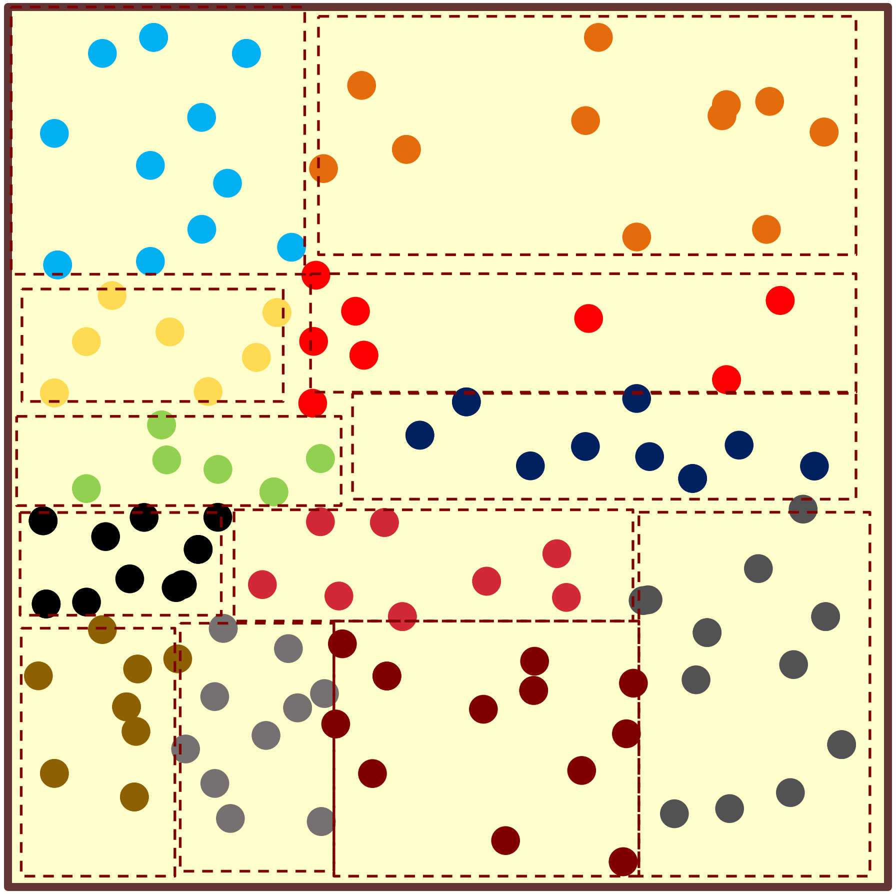
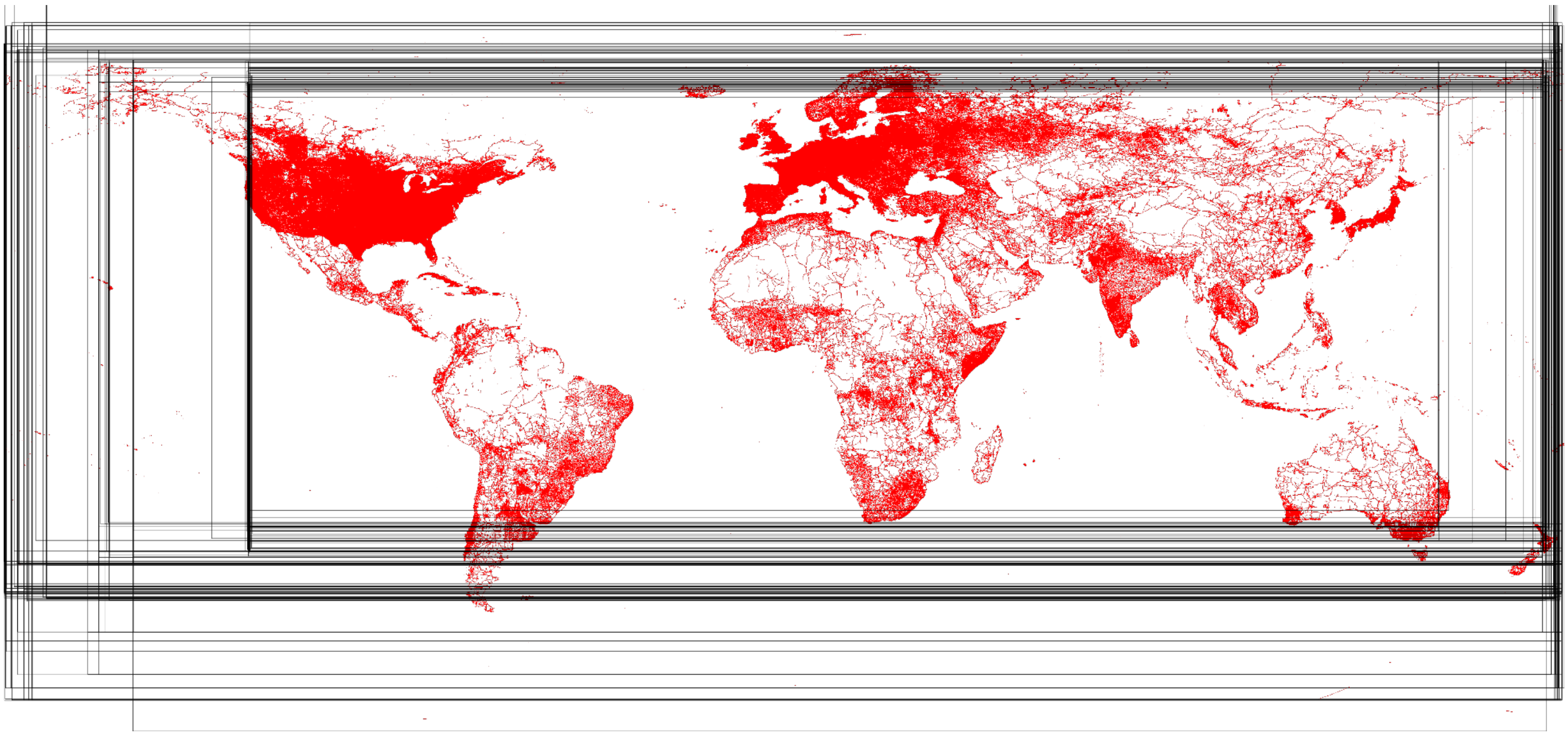


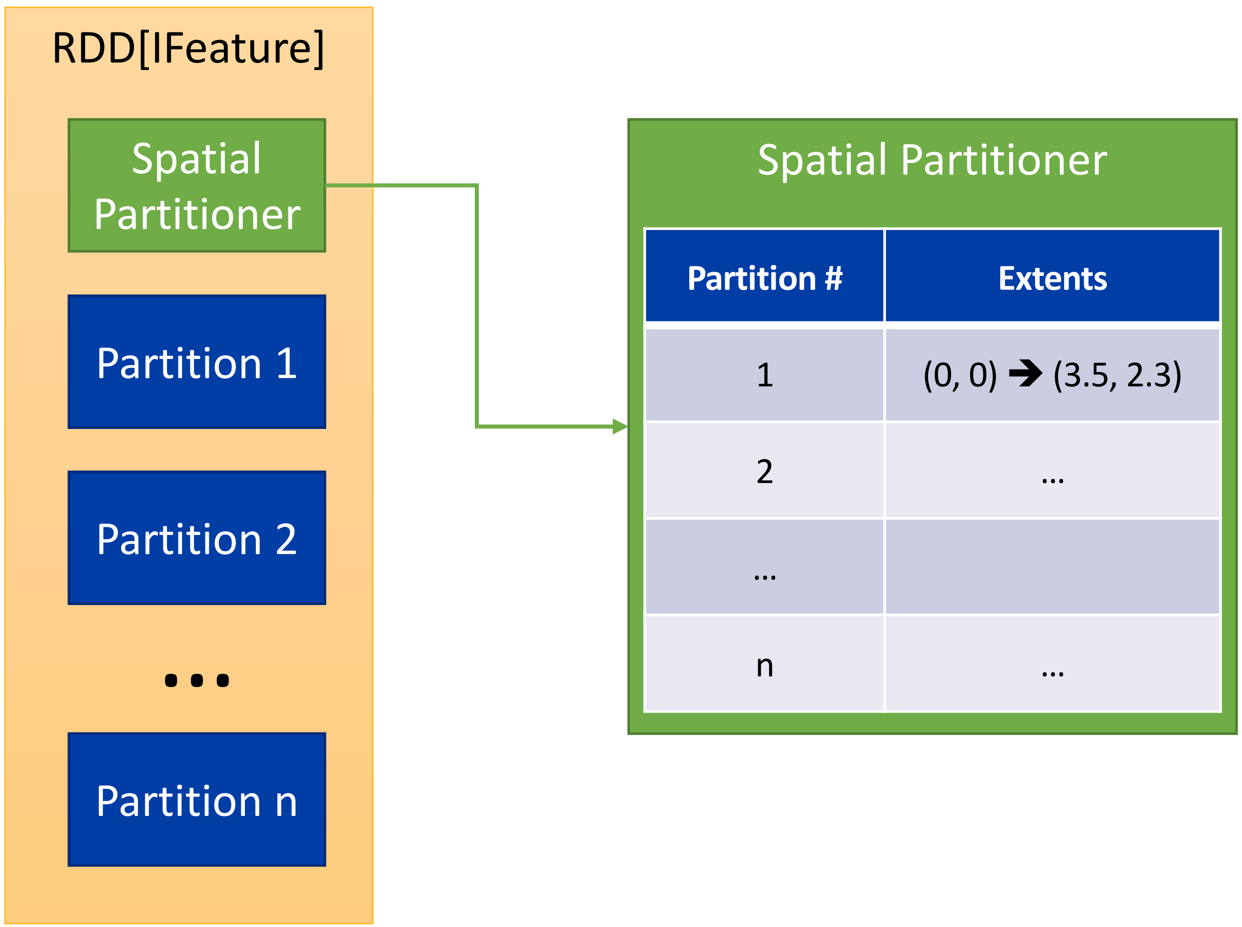
R-tree-based Index of a 400 GB road network

Non-partitioned dataset



Spatially Partitioned RDD

- RDD + Partitioner
- Spark allows custom partitioners

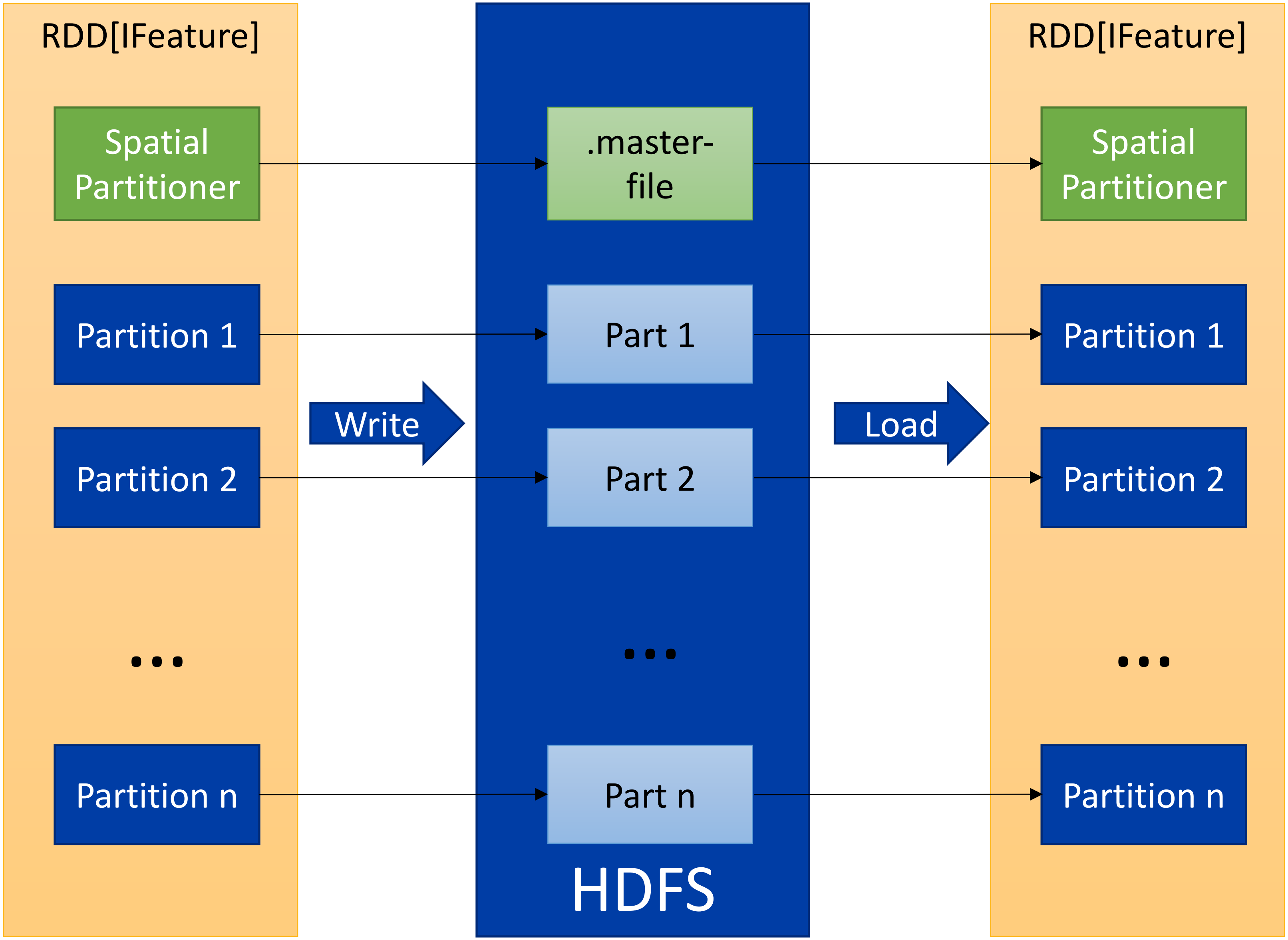


Partition #	Extents
1	(0, 0) ➔ (3.5, 2.3)
2	…
…	
n	…

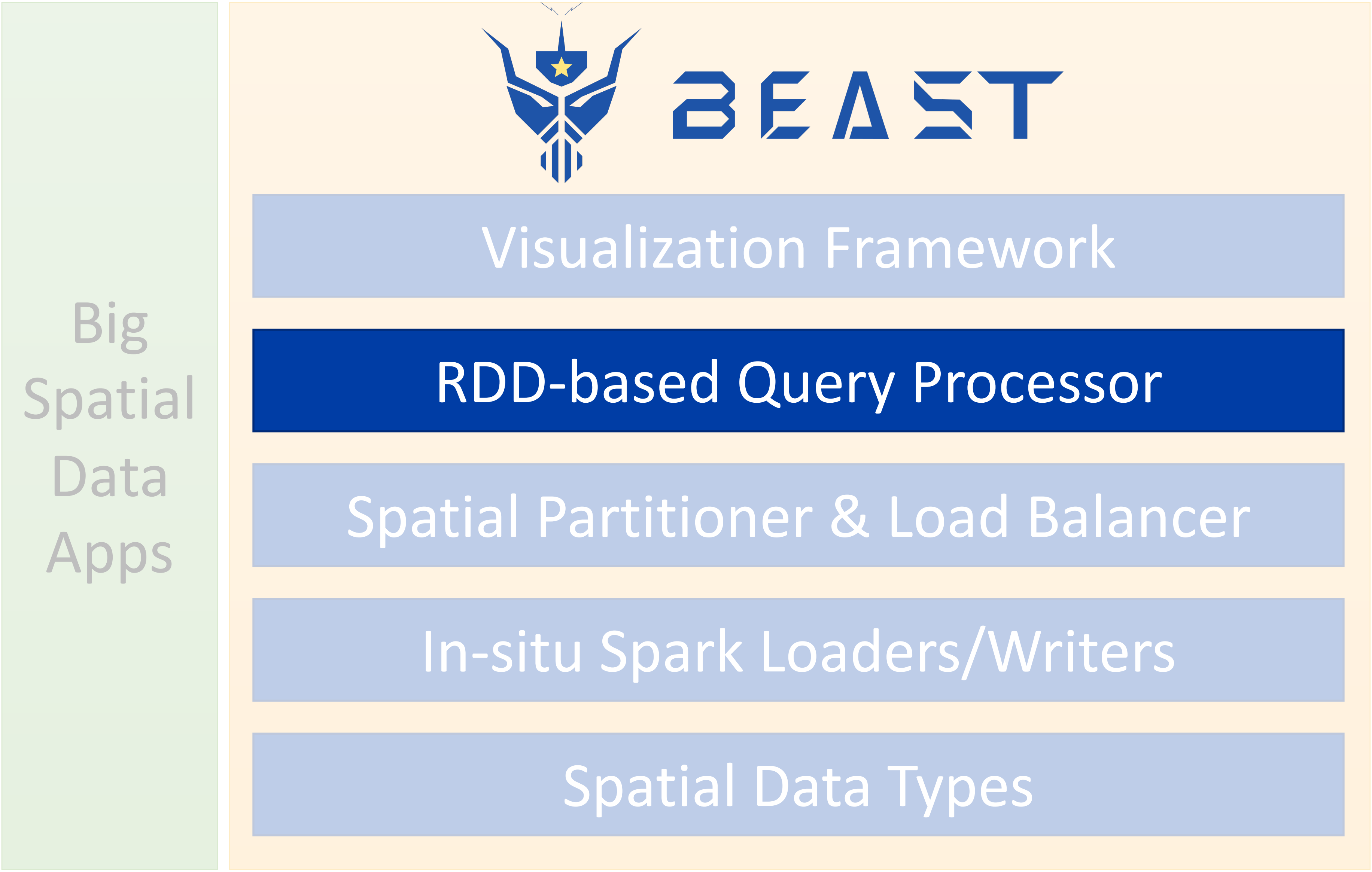
Index Writing and Loading

- Beast provides an option to write an index to disk and read it back
- This gives an option to load an already partitioned RDD

Index Writing and Loading



Beast Architecture



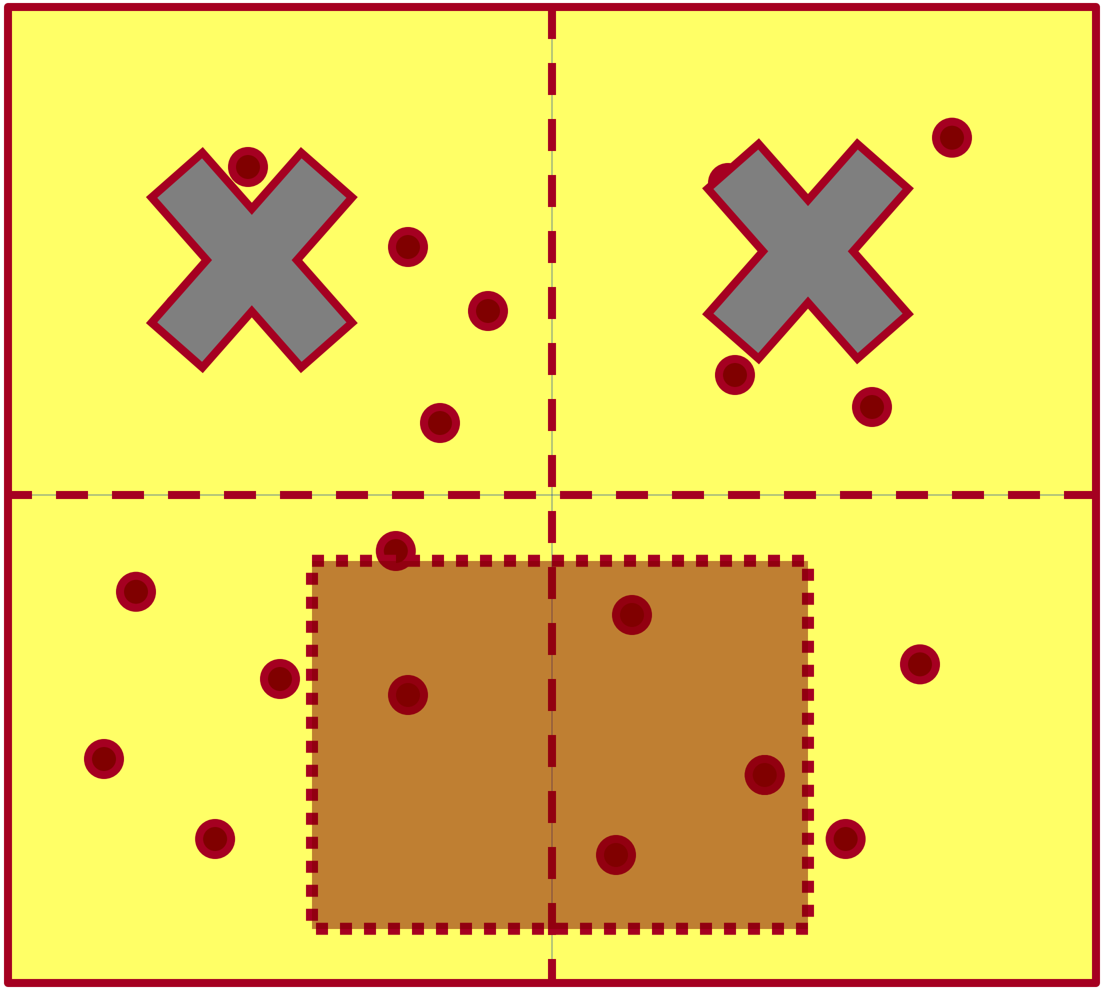
RDD Processing

- Since a spatial RDD is just a regular RDD, all existing transformations and actions can work seamlessly on it
- In addition, we have specialized handling for spatial queries
  - Range Query
  - Spatial Join

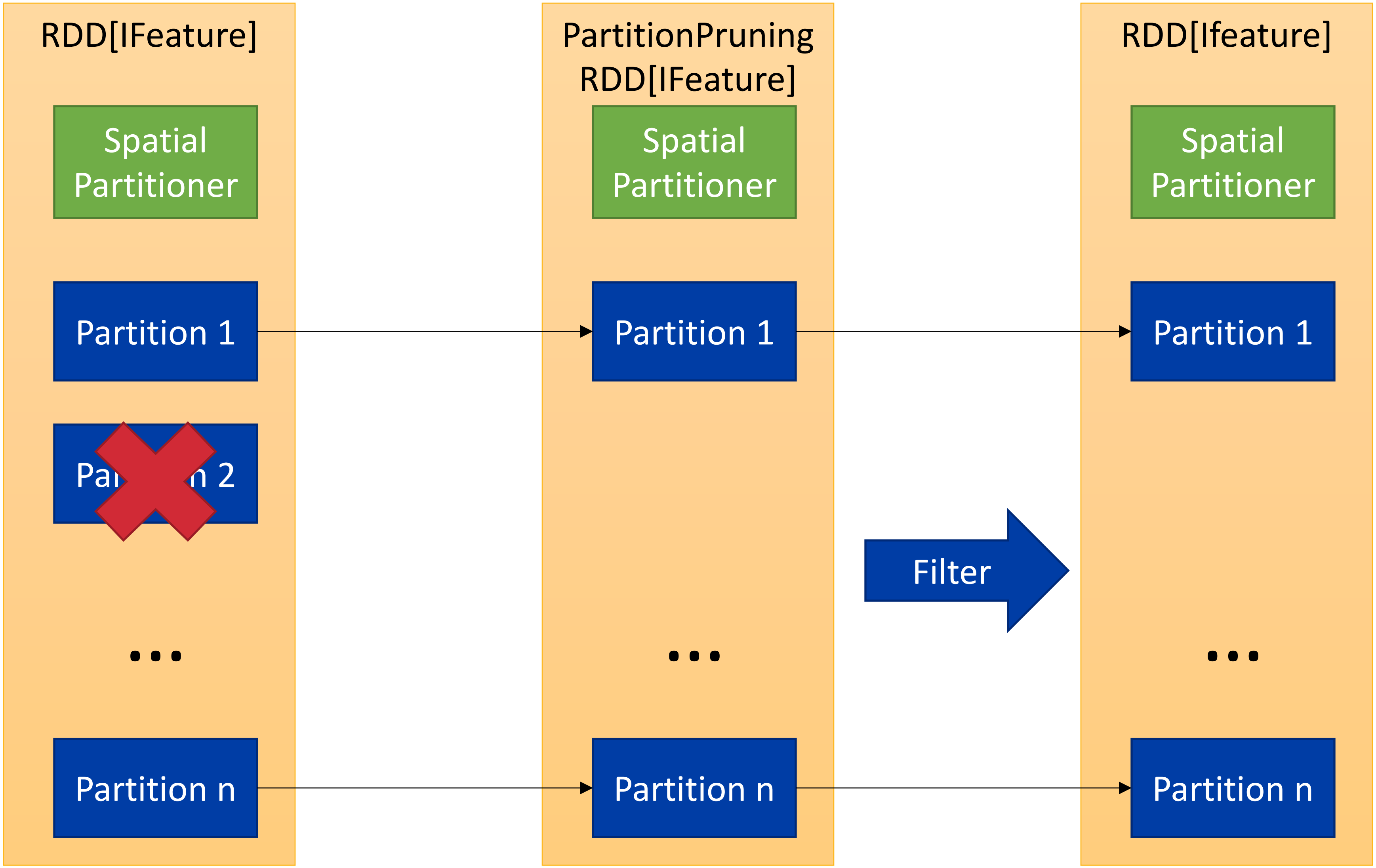
Range Query

Use the **partition information** to prune disjoint partitions

Scan matching partitions in parallel to find matching records



Range Query

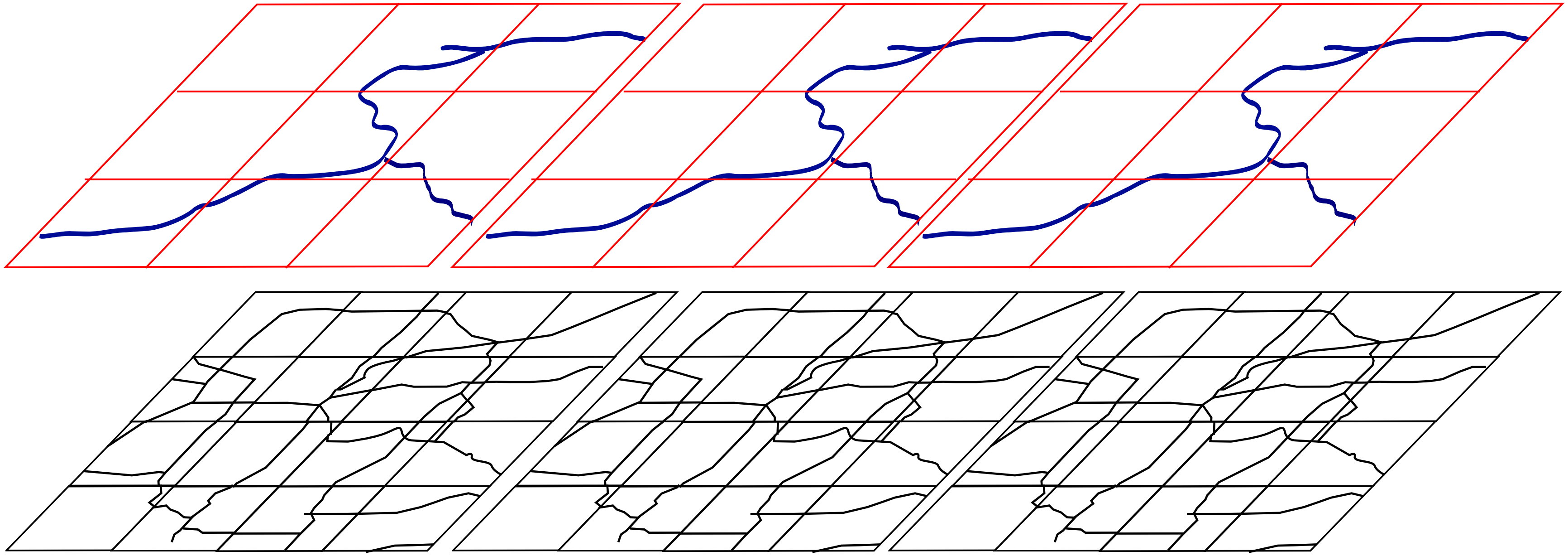


Question: Is this narrow or wide dependency?

Spatial Join

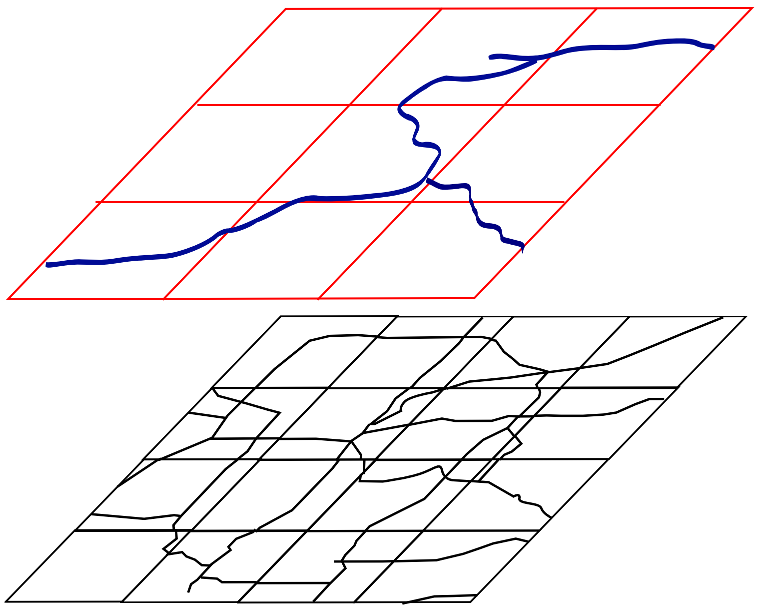
Join Directly

Partition – Join



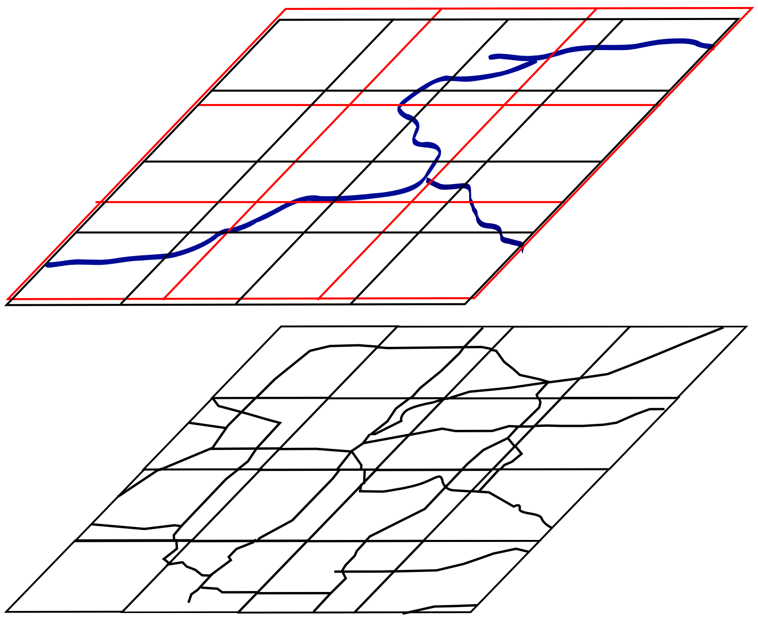
Spatial Join

Join Directly



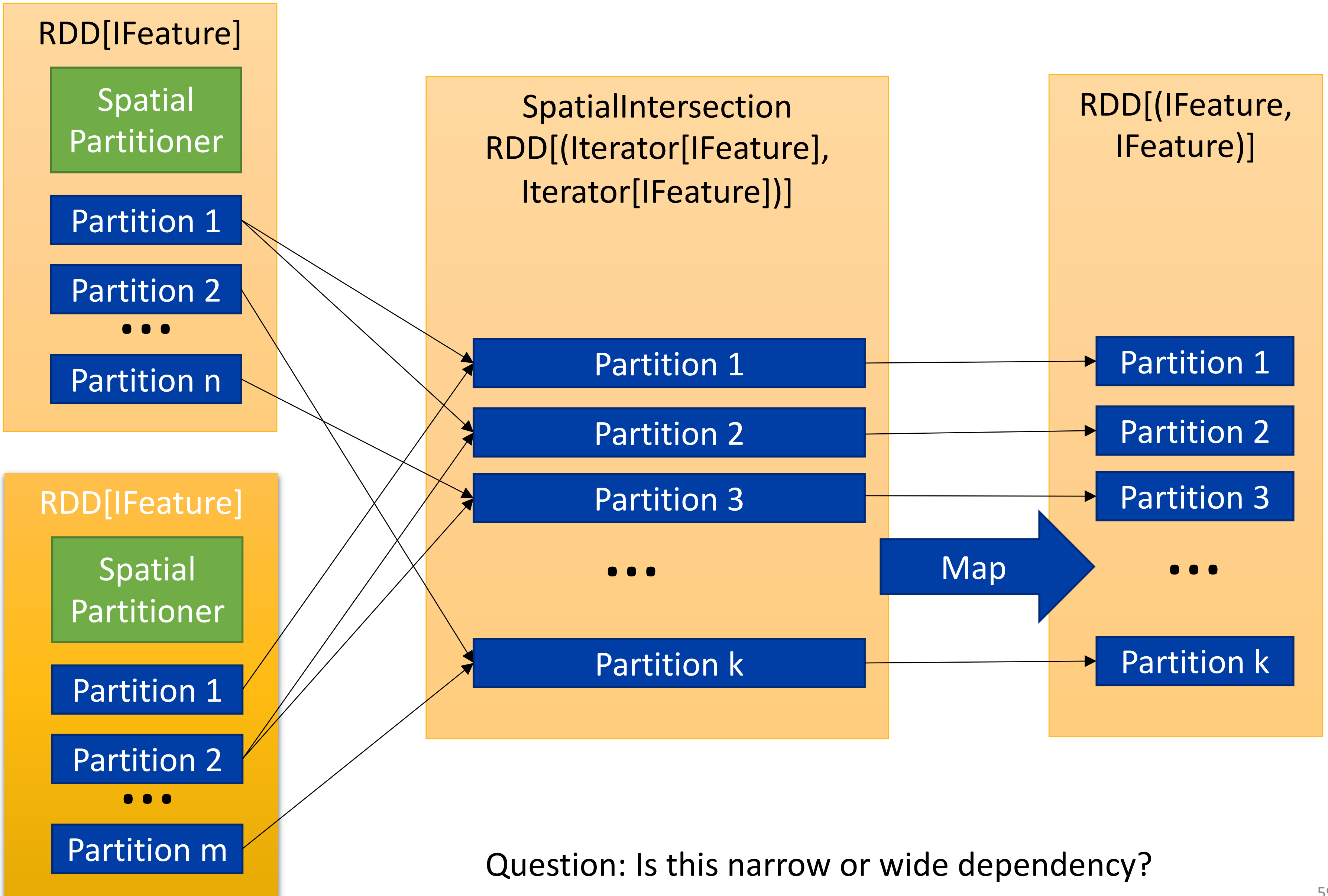
Total of 36 overlapping pairs

Partition – Join



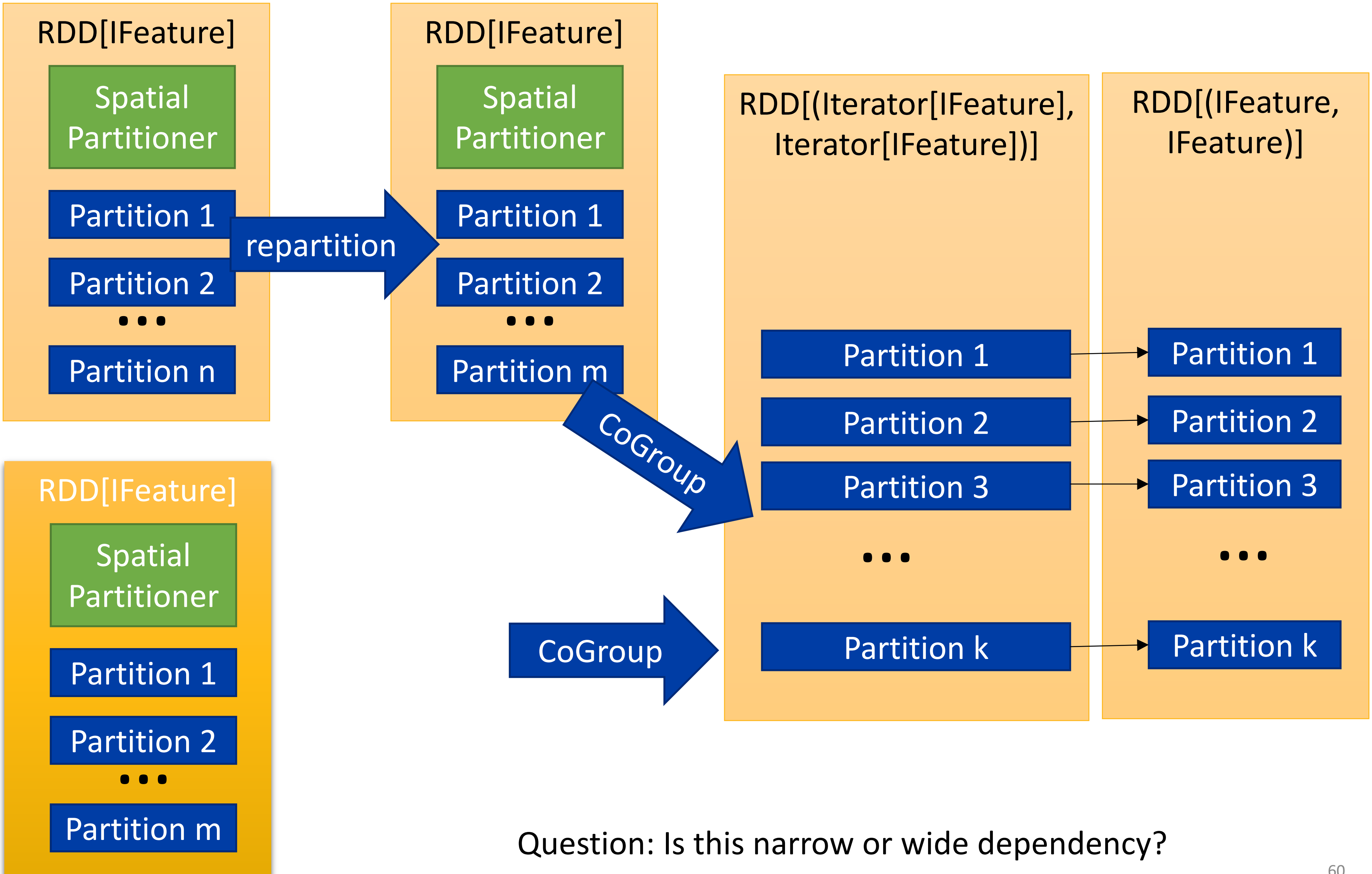
Only 16 overlapping pairs

Join Directly



Question: Is this narrow or wide dependency?

Join Directly



Question: Is this narrow or wide dependency?

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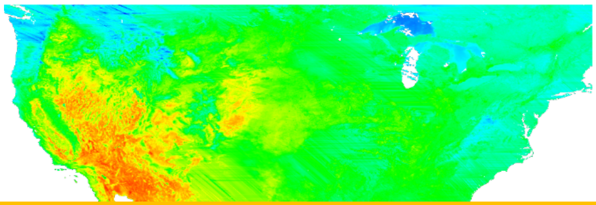
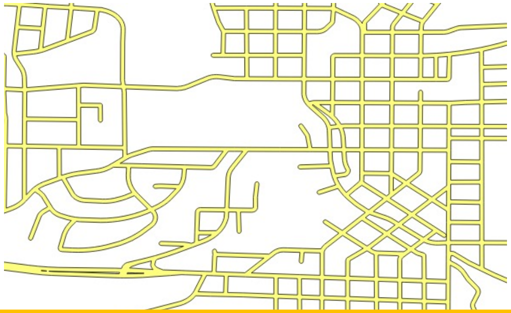
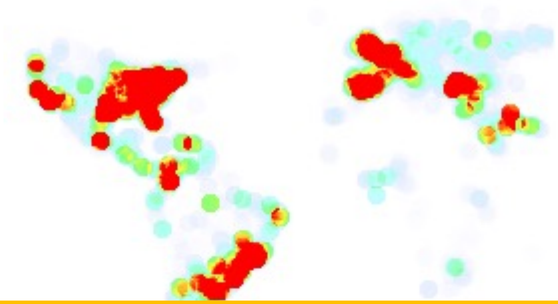
Spatial Data Types

Visualization in HadoopViz

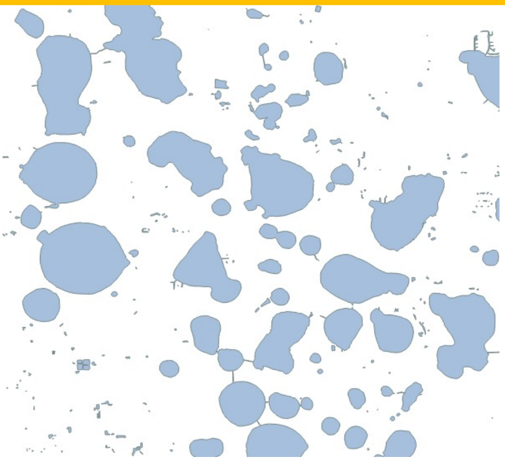






The goal of **HadoopViz** is not to propose **new visualization** techniques, instead its goal is to **scale out** existing techniques.

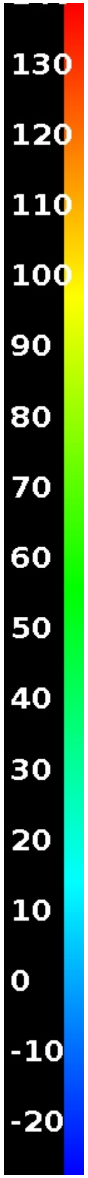
Scatter Plot

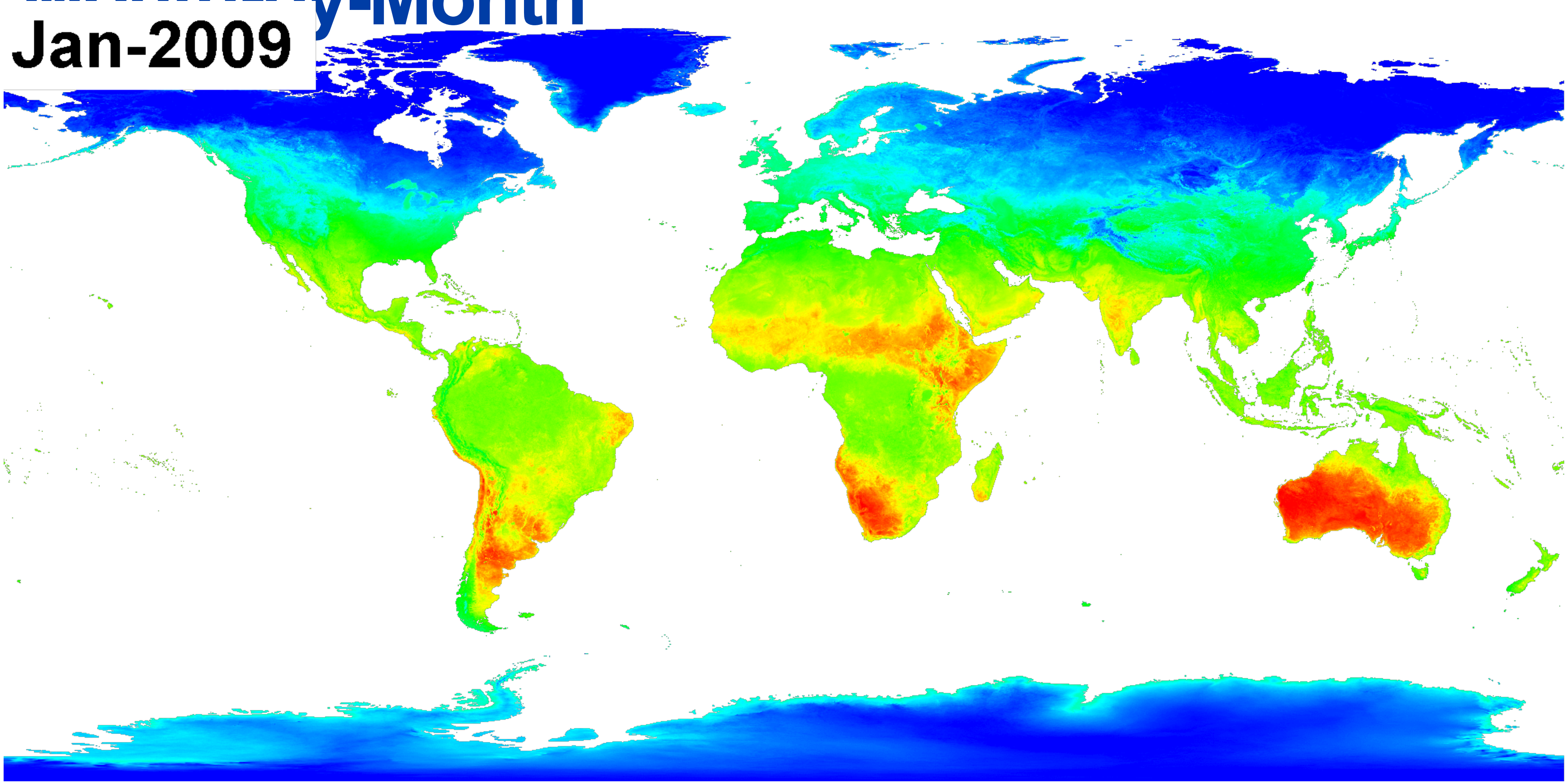


Vector Map

Admin Boundaries

Heat Map From 2009 to 2014 Month-by-Month



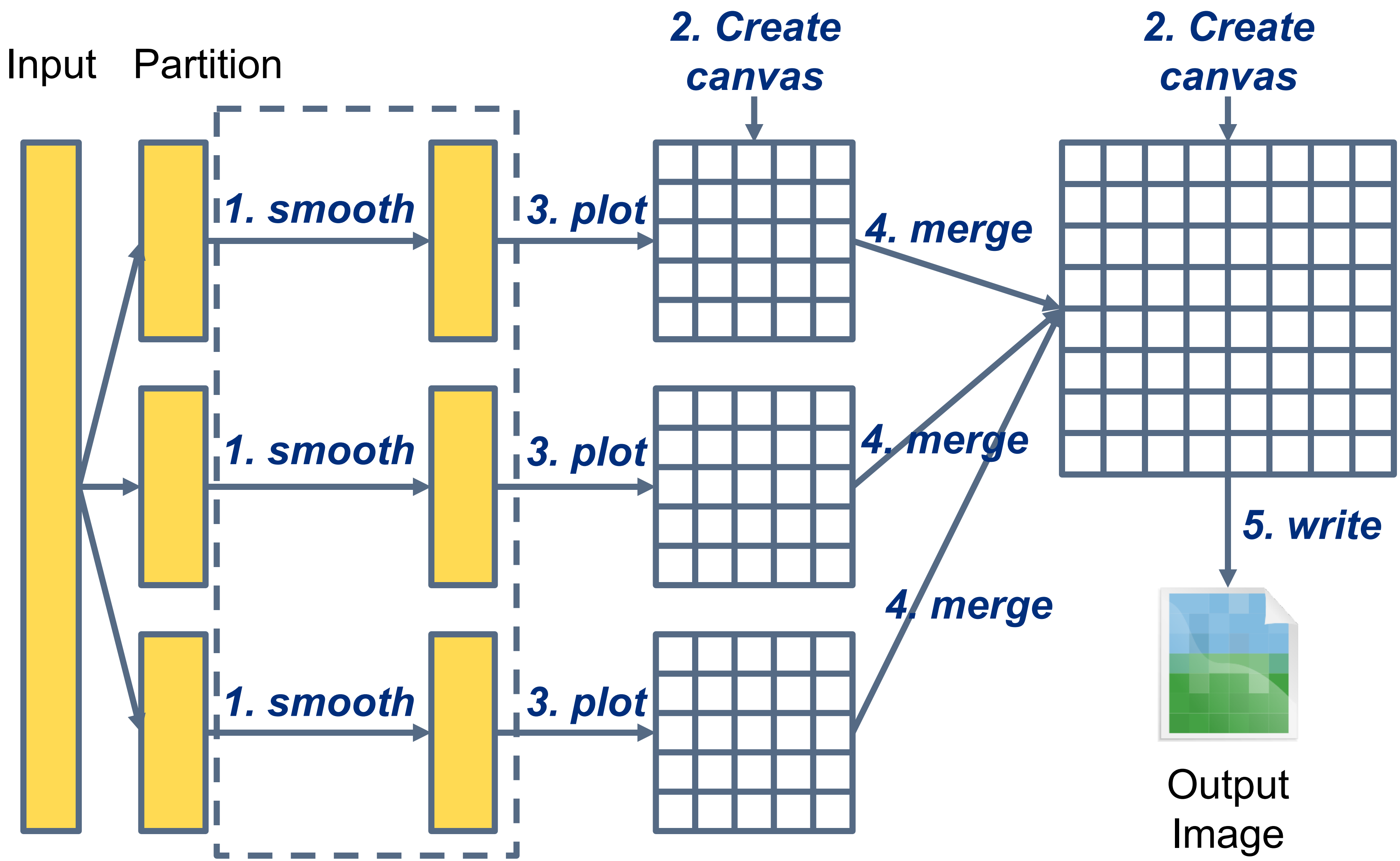


72 Frames × 14 Billion points per frame

Total = **1 Trillion points**

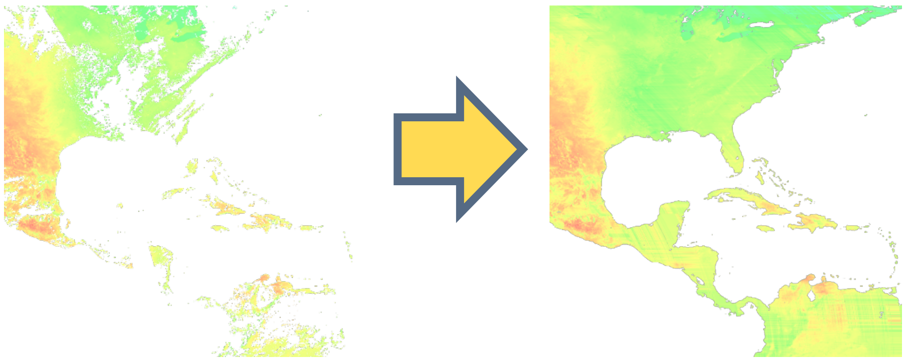
Created in **3 hours** on **10 nodes** instead of **60 hours**

Abstract Visualization



Example: Satellite Data Visualization

1. **Smooth**: Recover holes



2. **Create Canvas**: Initialize a 2D Matrix with zeros

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

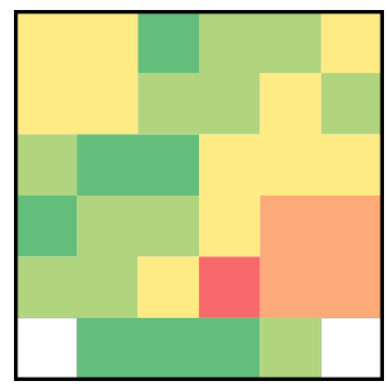
3. **Plot**:
Update the matrix

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{22} & 0 & 0 & \mathbf{7} & 0 \\ 0 & 0 & \mathbf{15} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

4. **Merge**:
Matrix addition

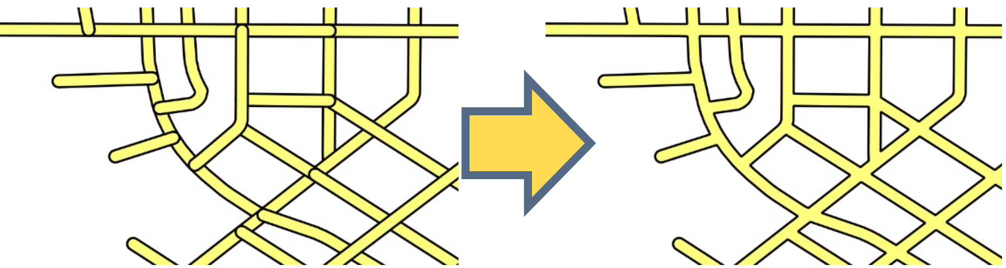
$$\begin{bmatrix} \quad \end{bmatrix} + \begin{bmatrix} \quad \end{bmatrix}$$

5. **Write**:
Generate the image

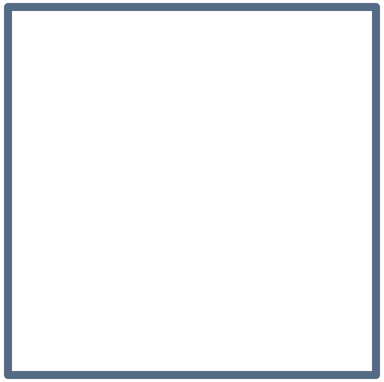


Example: Road Network Visualization

1. **Smooth**: Merge intersections



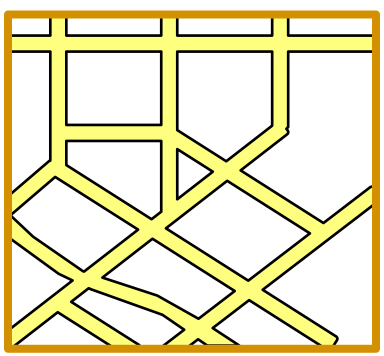
2. **Create Canvas**: Create a blank image

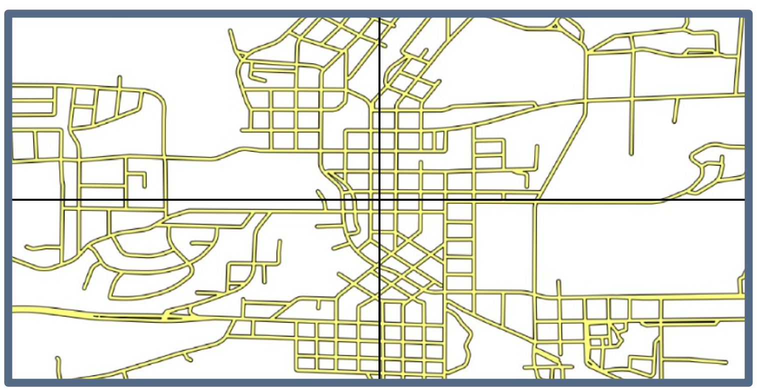


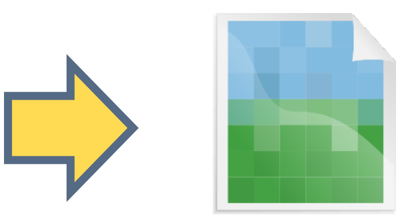
3. **Plot**: Draw roads as polygons

4. **Merge**: Plot an image on the other

5. **Write**: Encode as PNG and write to file





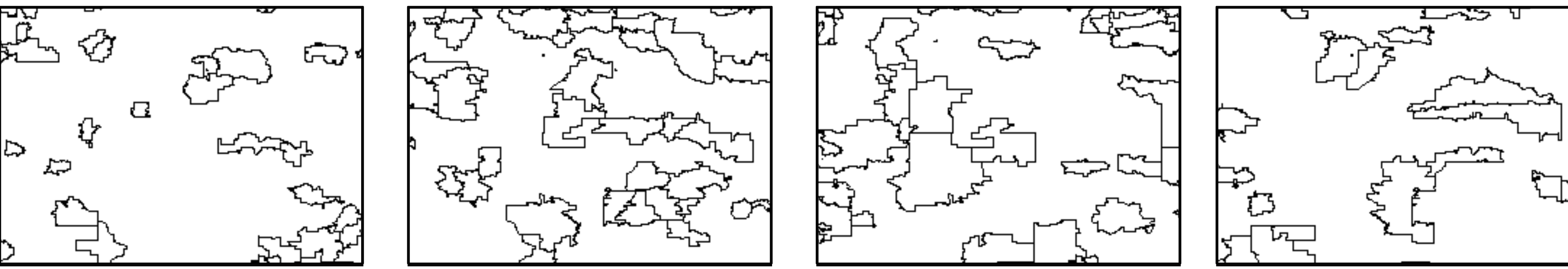


Single Level Image

Input

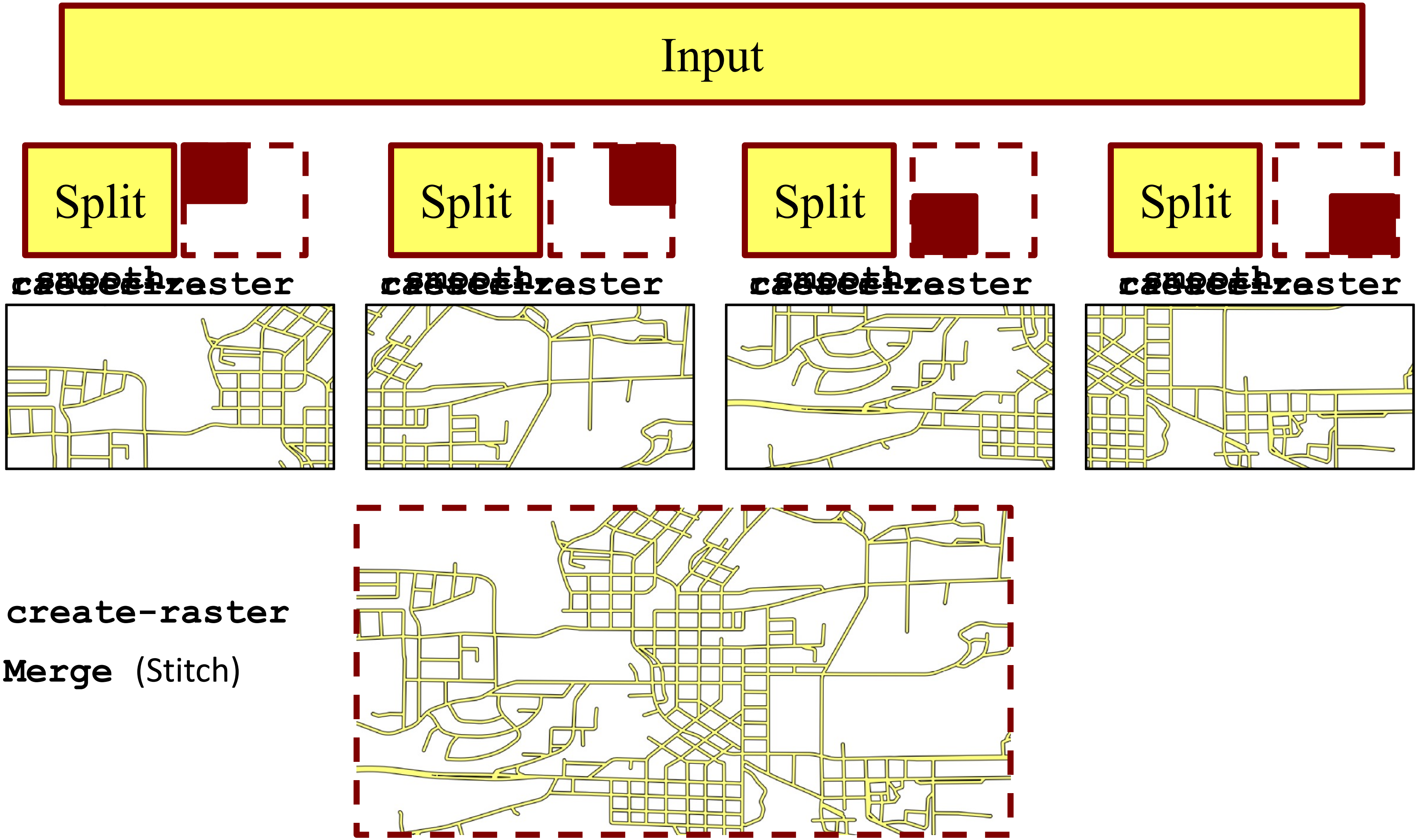
Split Split Split Split

rasterize / create raster

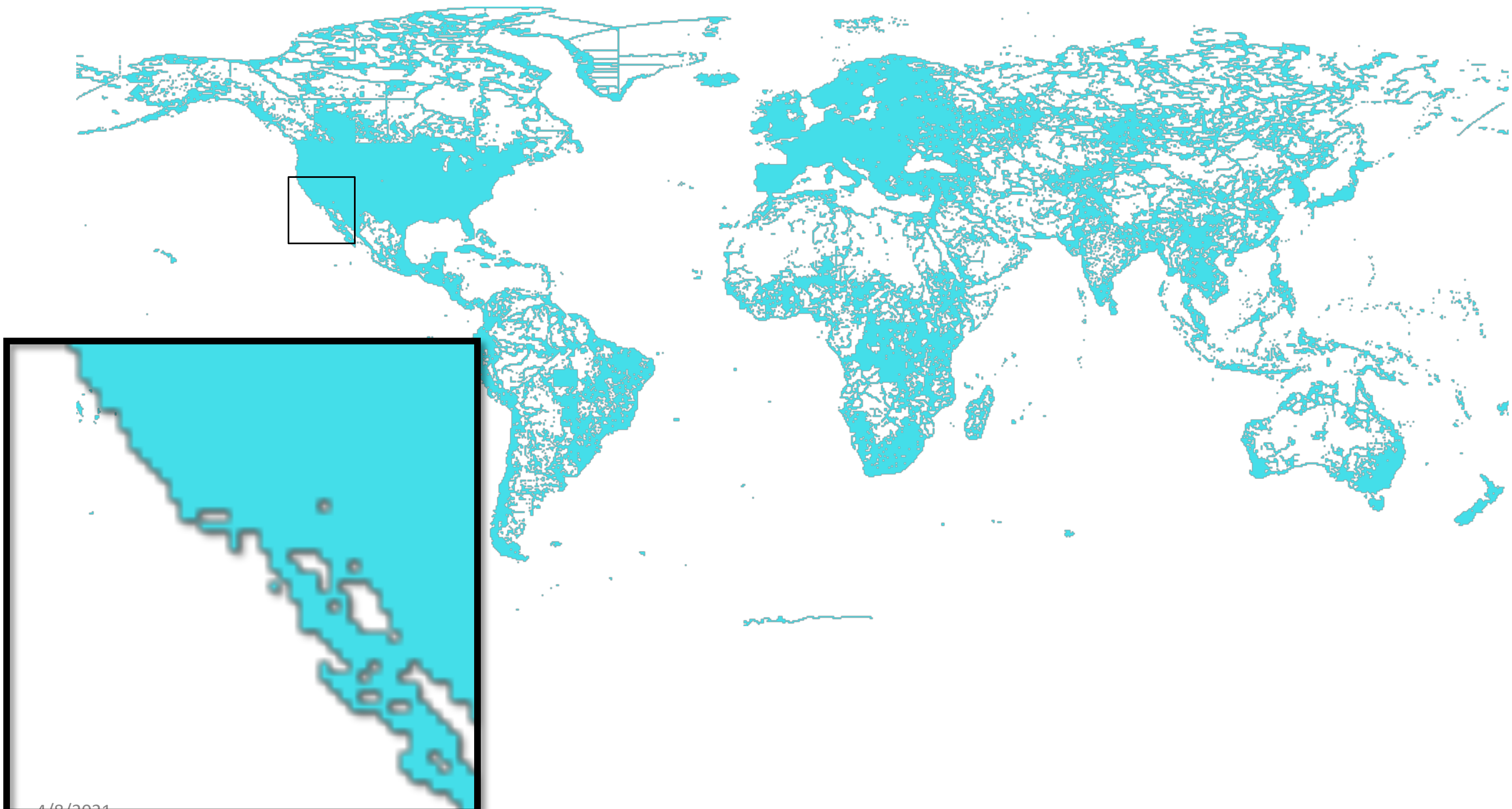


Merge
(Overlay)

Space Partitioning



Level of Details

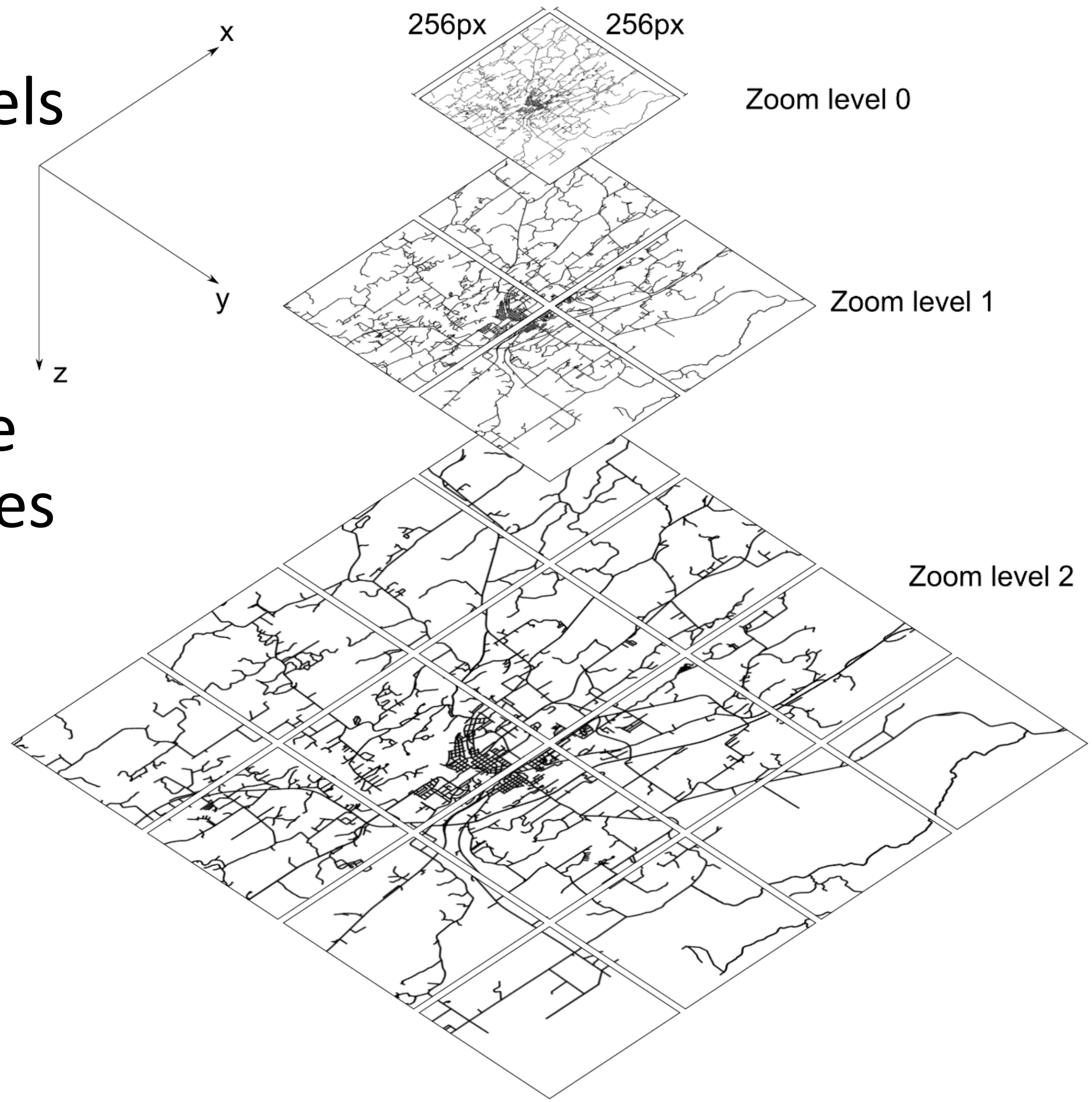


Map of California – 2GB

Generated in 2 minutes on 10-node cluster instead of one hour

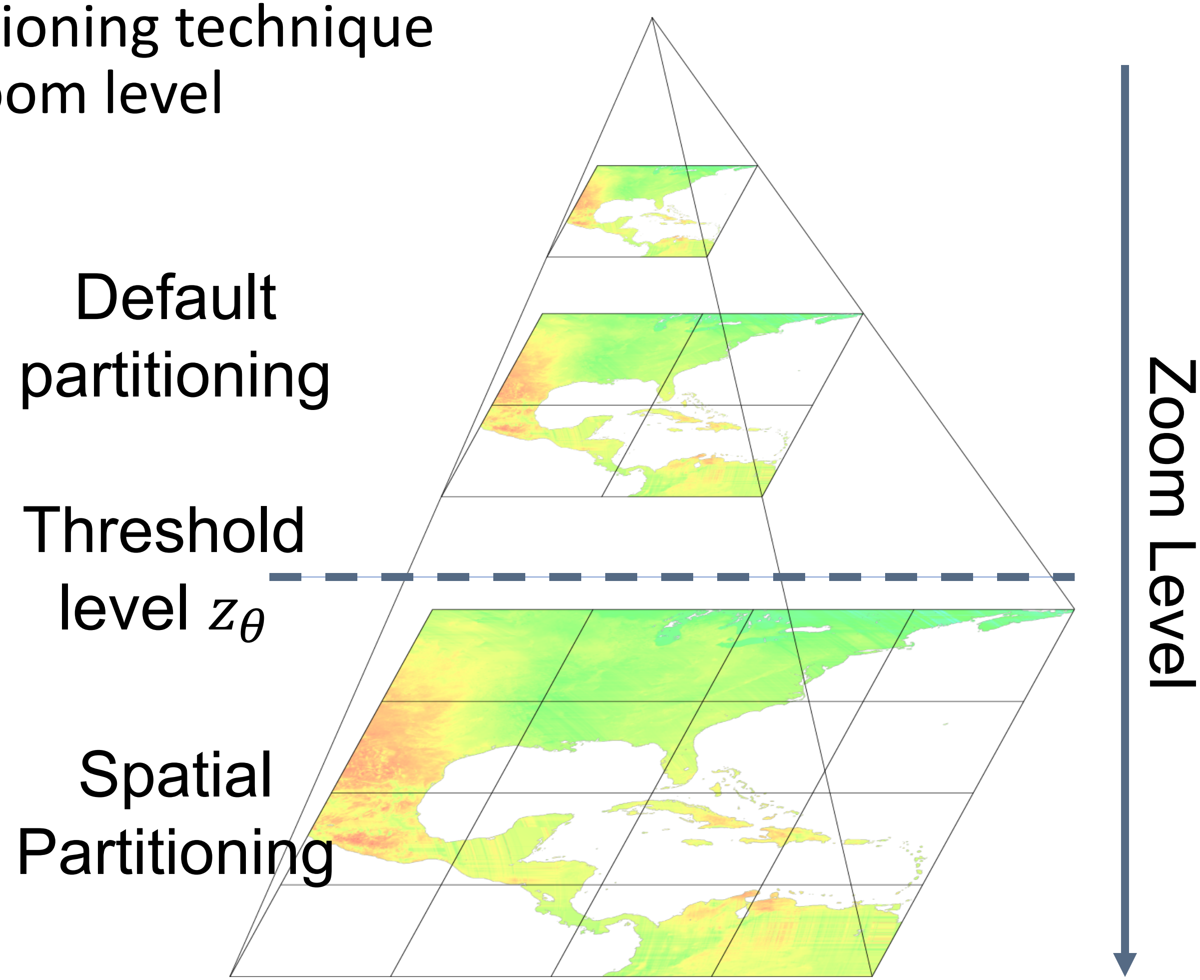
Multi-level Image

- Many images at different zoom levels
  - Pan
  - Zoom in/out
  - Fly to
- More details as the zoom level increases
- Number of tiles increases exponentially



Multi-level Visualization

- Abstract multi-level visualization algorithm
- The choice of partitioning technique changes for each zoom level



Beast Architecture

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BEAST

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In-situ Spark Loaders/Writers

Spatial Data Types

Thank You

Questions?

A Unified Big Data Interface

Unified Big Data Abstraction

Cost Model

Query Optimizer

Query Executor

Spatial Hadoop

mahout

HIVE

hadoop

SparkSQL

GraphX

MLLib

Spark

Sphinx

Impala

...

YARN – Resource Manager

HDFS – File System

Language

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

Spatial Hadoop
VLDB'13◇
ICDE'15

Language
Pigeon [ICDE'14◇]

Visualization
[VLDB'15◇, ICDE'16]

Operations
Basic operations – CG_Hadoop
[SIGSPATIAL'13, TSAS★]

MapReduce
Spatial File Splitter
Spatial Record Reader

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

ST-Hadoop [TODS★]

★ Under review

◇Demo paper

Language (Pigeon)

- Hides the complexity of the system with a high level language
- OGC standard used by Oracle Spatial and PostGIS
- Extends Pig Latin with OGC-compliant primitives
  - Spatial data types (e.g., Polygon)
  - Basic operations (e.g., Area)
  - Spatial predicates (e.g., Touches)
  - Spatial analysis (e.g., Union)
  - Spatial aggregate functions (e.g., Convex Hull)

A. Eldawy and M. F. Mokbel, "Pigeon: A Spatial MapReduce Language", Demo at **IEEE ICDE'14**

Spatial Data Types

Data Loading

```
lakes = LOAD 'lakes' AS (id:int, area:polygon);
```

Range Query

```
houses_in_range =
 Filter houses BY
 Overlap(house_loc, range);
```

KNN

```
nearest_houses =
 KNN houses WITH_K=100
 USING DistanceTo(house_loc,
  query_loc);
```

Spatial Join

```
lakes_states = Join lakes BY lakes_boundary
  states BY states_boundary Predicate = Overlap
```

Spatio-temporal Indexing

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

Spatial Hadoop
VLDB'13◇
ICDE'15

Language
Pigeon [ICDE'14◇]

Visualization
HadoopViz[VLDB'15◇]

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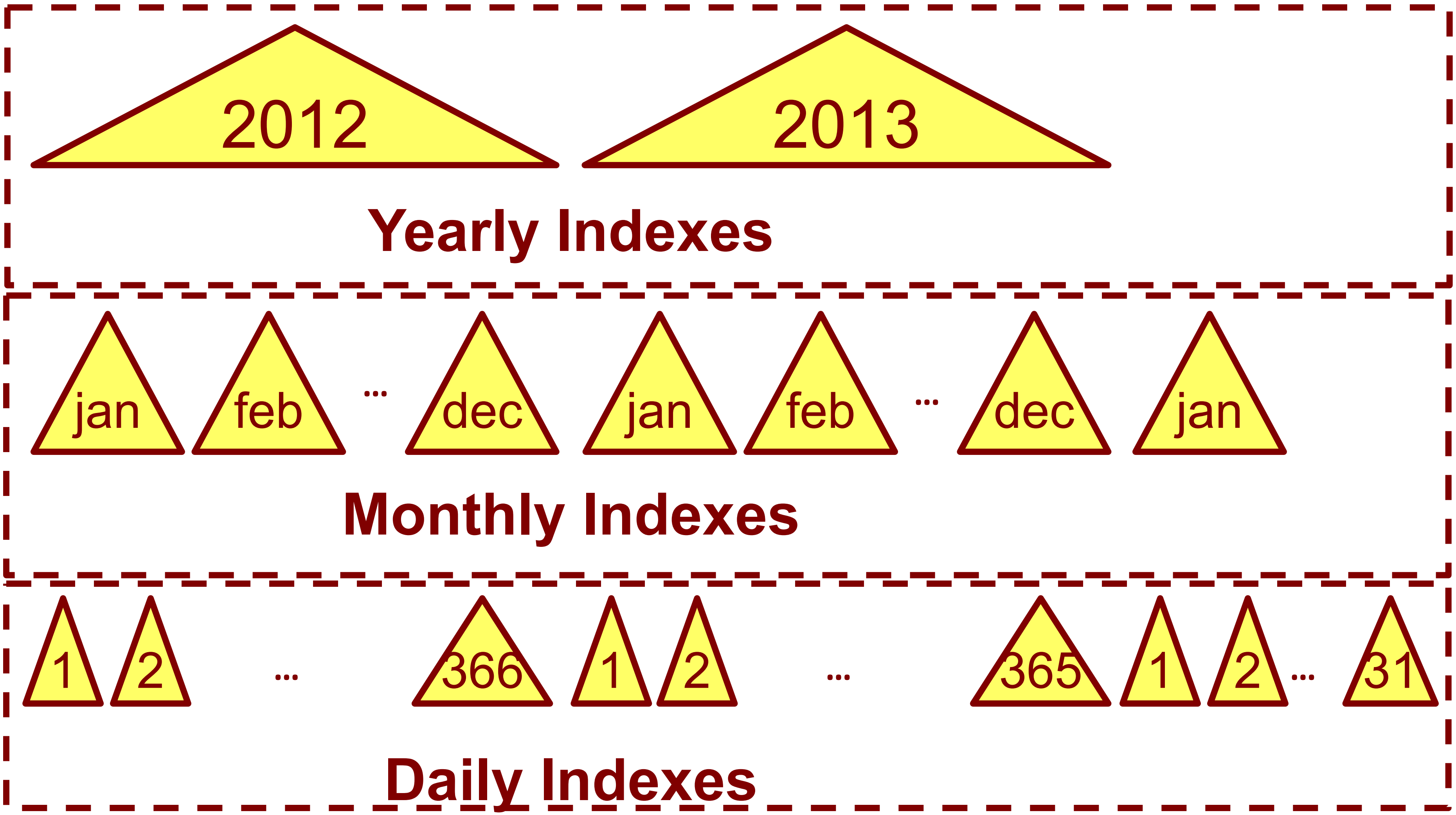
ST-Hadoop [TODS★]

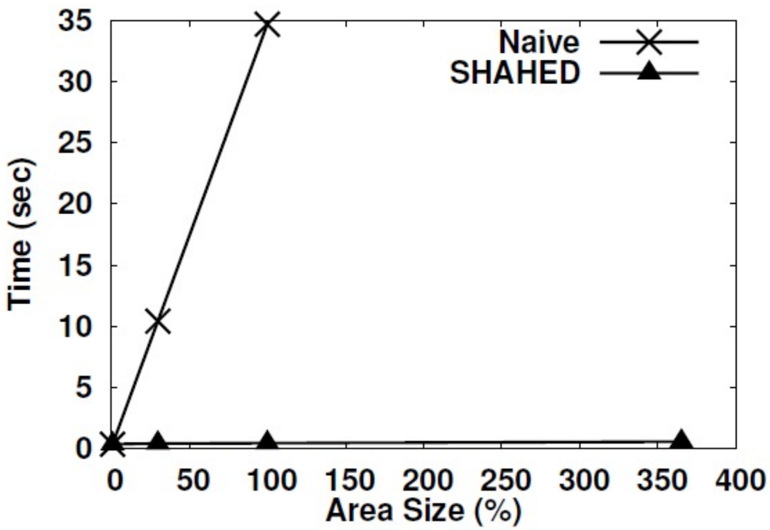
A. Eldawy, L. Alarabi, M. F. Mokbel. "ST-Hadoop: A MapReduce Framework for Spatial and Spatio-temporal Data" Submitted to **ACM TODS**

Multiresolution Spatio-temporal Index

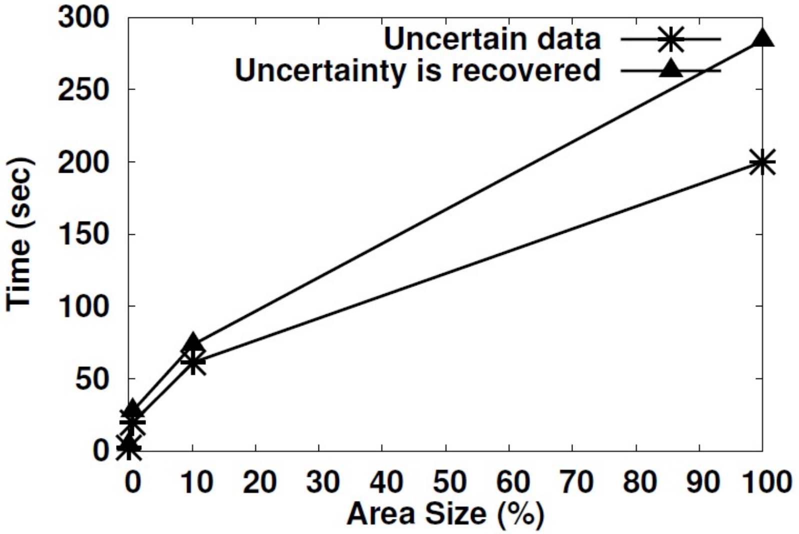


A. Eldawy, L. Alarabi, M. F. Mokbel. "ST-Hadoop: A MapReduce Framework for Spatial and Spatio-temporal Data" Submitted to **ACM TODS**

Performance of SHAHED

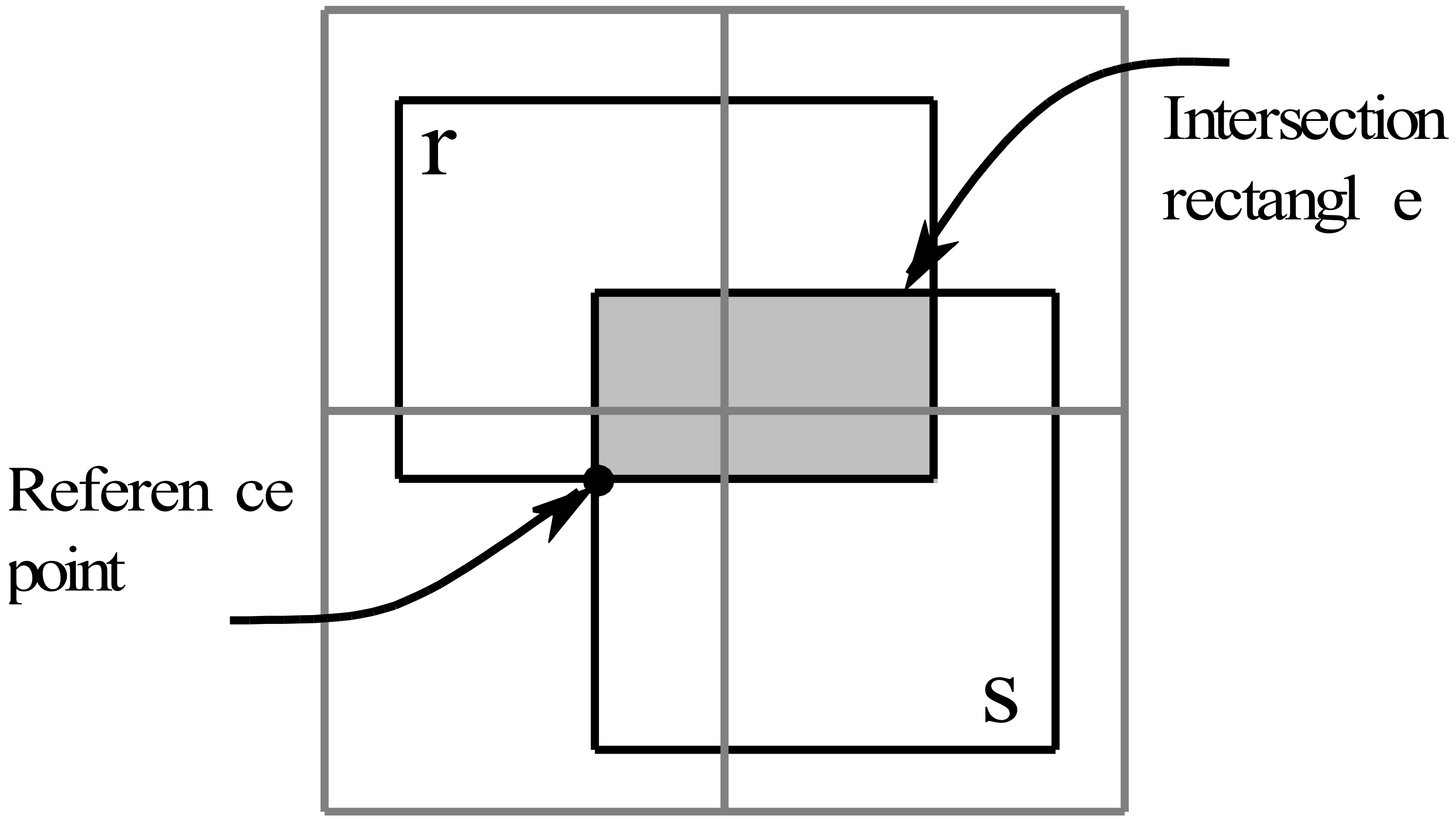


(c) Selection Query

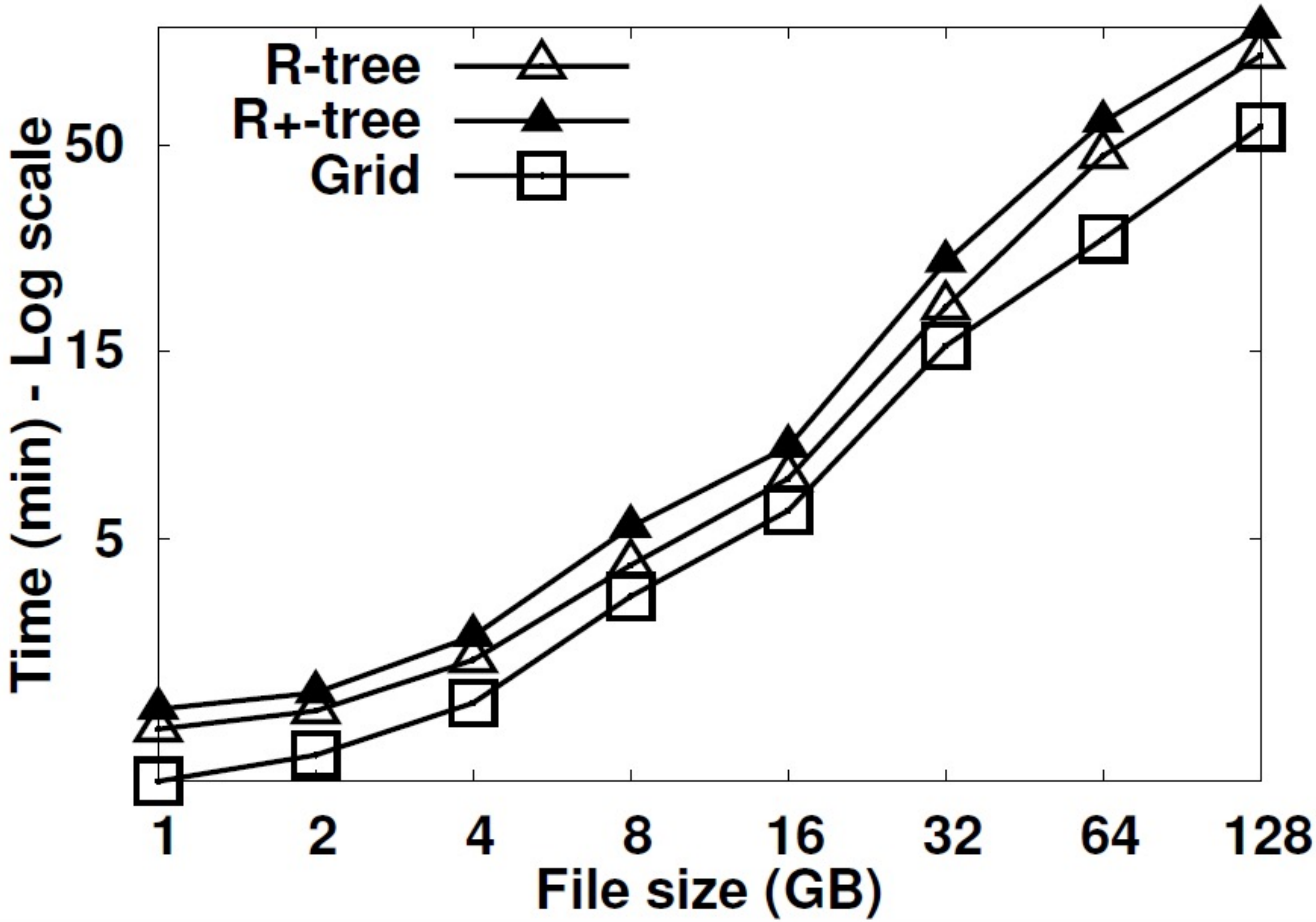


(d) Visualization

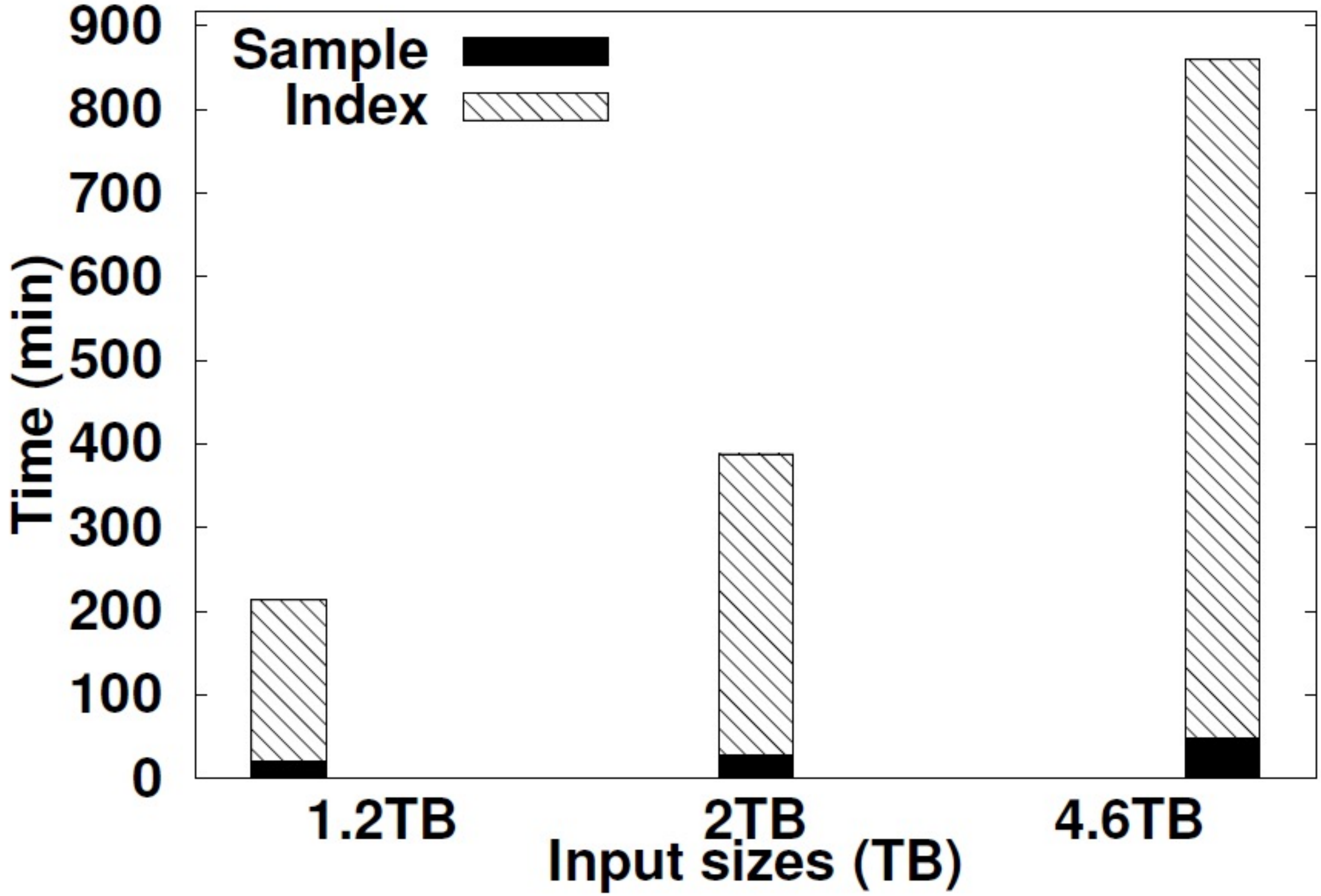
Reference Point



Index building



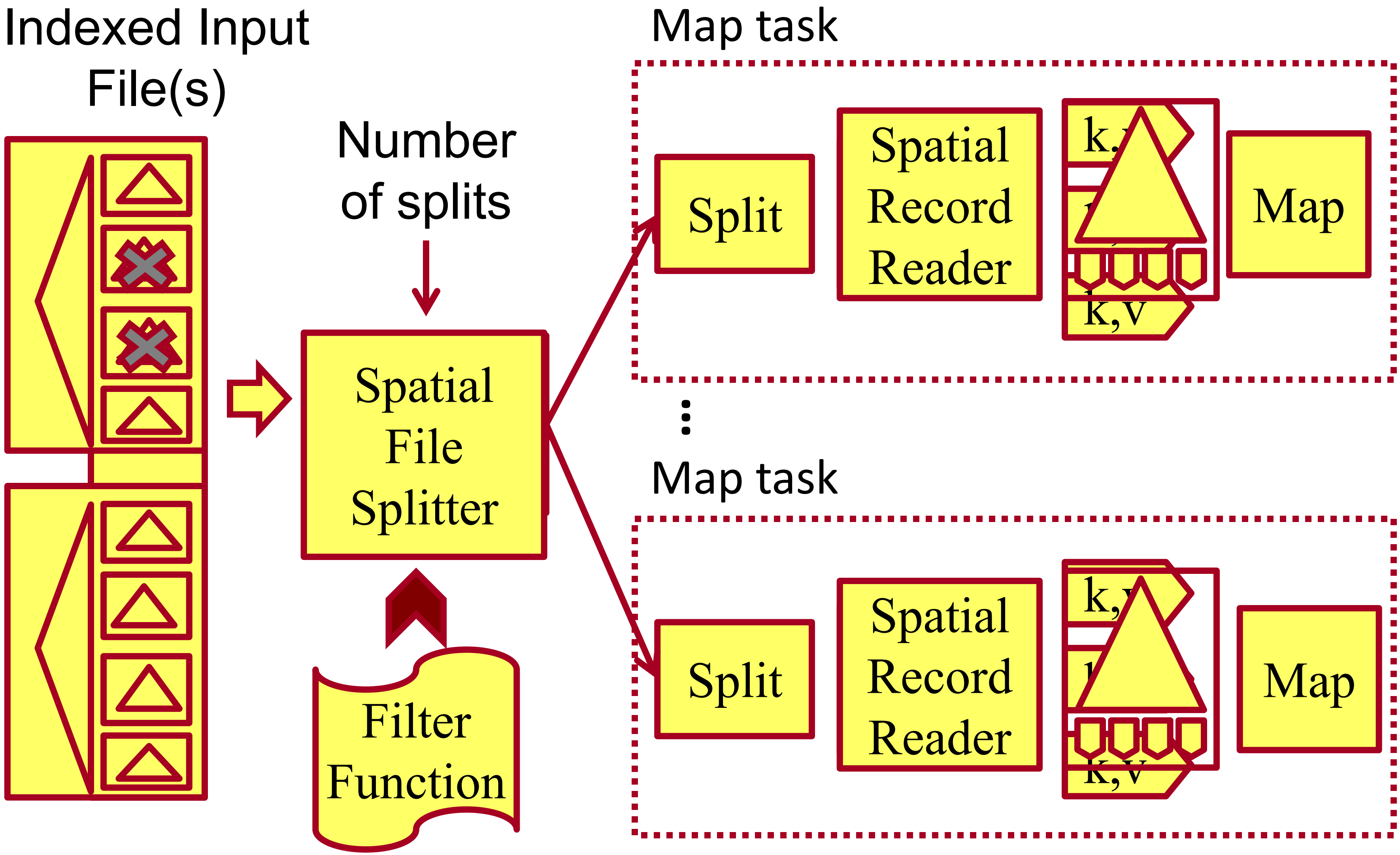
Index Building for NASA Data



Related Work

- Most techniques for spatial data processing in Hadoop use Hadoop as a blackbox
  - RQ, KNN and SJMR [Zhang et al'09]
  - R-tree construction [Cary et al'09]
  - KNN Join [Lu et al'12, Zhang et al'12]
  - RNN [Akdogan et al'10]
  - ANN [Wang et al'10]
- MD-HBase [Nishimura et al'11]
  - Framework for multi-dimensional data processing
  - Based on HBase, a key-value store on HDFS
  - Does not support MapReduce programming

Map plan – SpatialHadoop



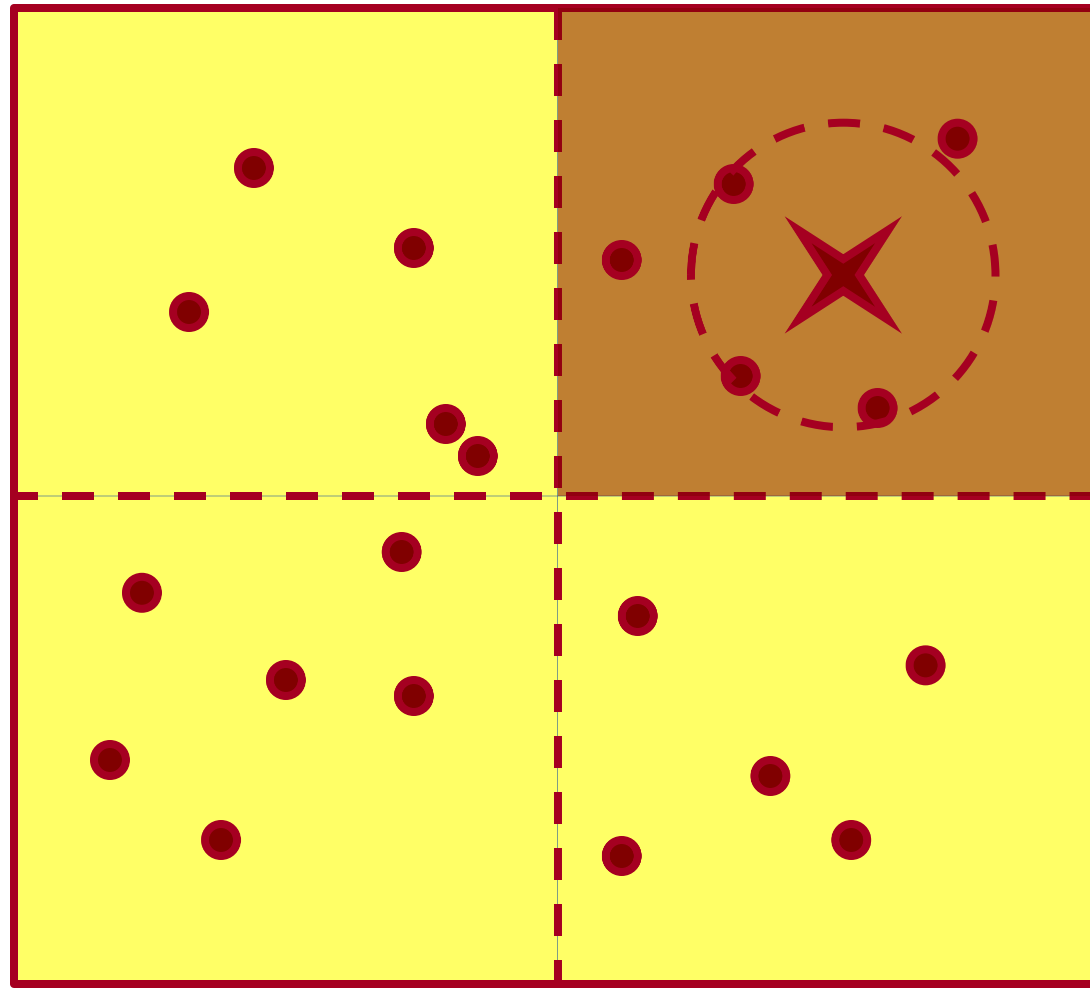
KNN

SpatialFileSplitter selects the block that contains the query point

Map function performs kNN in the selected block

Answer is tested for correctness

✓ Answer is correct



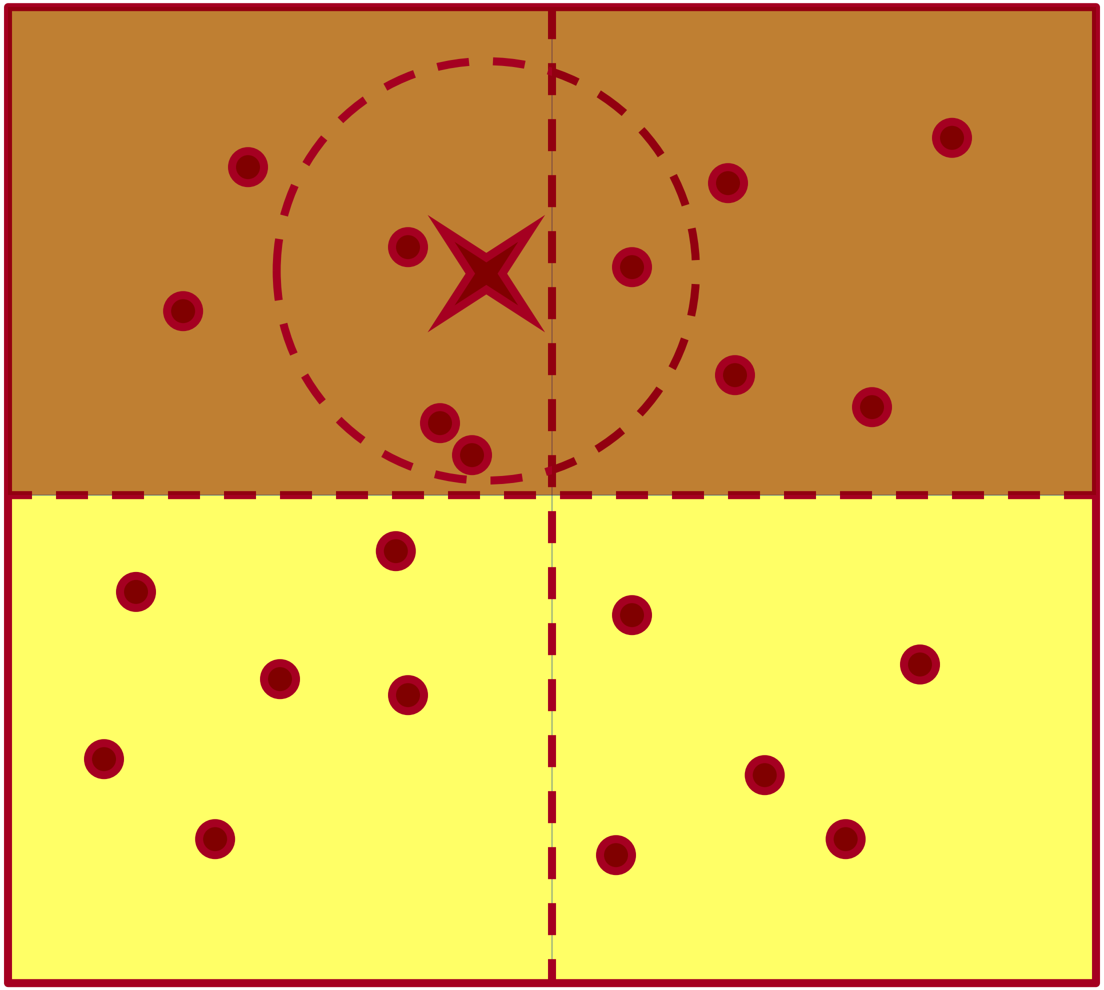
k=3

KNN

First iteration runs as before and result is tested for correctness

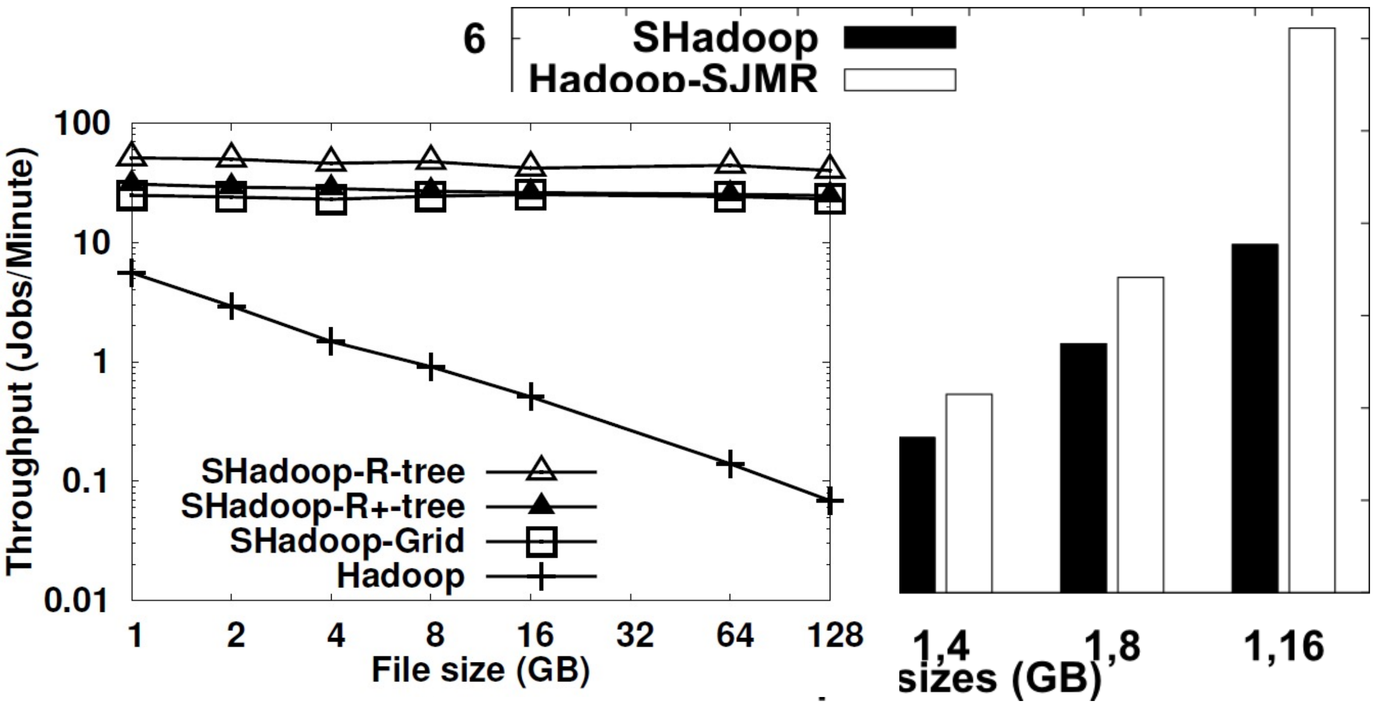
- ✗ Answer is incorrect

Second iteration processes other blocks that might contain an answer

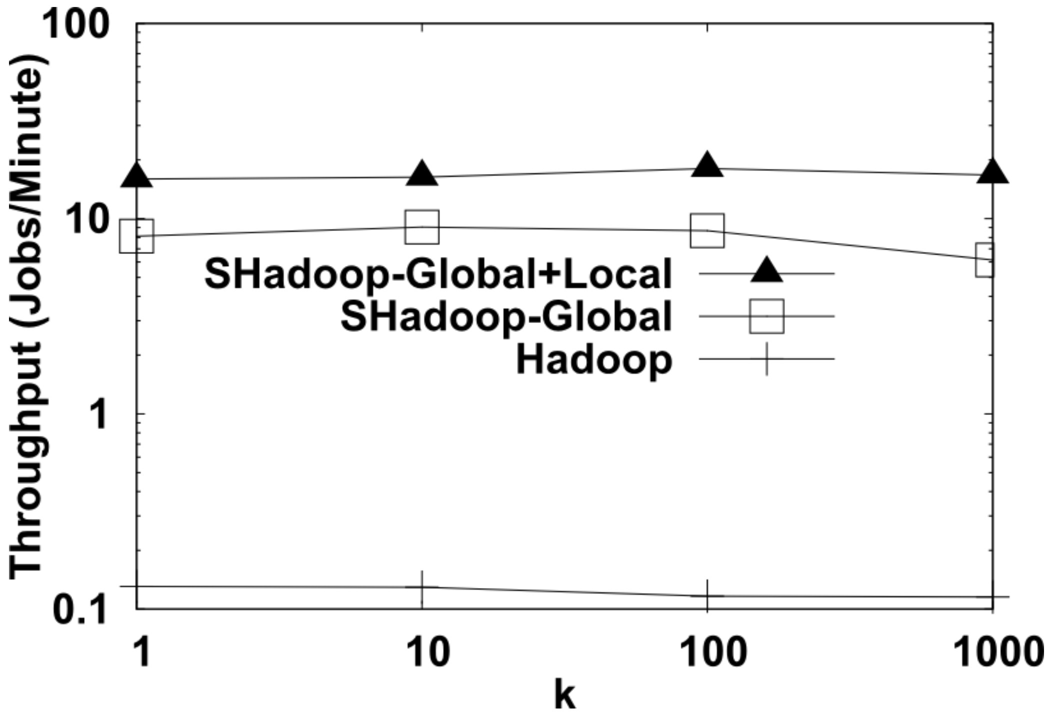


k=3

Range query


6
SHadoop
Hadoop-SJMR
100
10
1
0.1
0.01
Throughput (Jobs/Minute)
SHadoop-R-tree
SHadoop-R+-tree
SHadoop-Grid
Hadoop
1
2
4
8
16
32
64
128
File size (GB)
1,4
1,8
1,16
sizes (GB)

K Nearest Neighbor



Preliminary Results