Voronoi-based Geospatial Query Processing with MapReduce

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Outline

- Motivation
- Related Work
- Preliminaries
- Voronoi Diagram (Index) Creation
- Query Types
- Performance Evaluation
- Conclusion and Future Work

Motivation

- **Geospatial queries**
  - Nearest Neighbor: Given a query point and a set of objects, find the nearest object to the query point.

Show me the Nearest McDonalds

Motivation

- **Applications of geospatial queries:**
  - GIS, Decision support systems, Bioinformatics, etc.
- **Total revenue of GIS**
  - $5 billion in 2002, $30 billion in 2005.
- **Geospatial queries on Cloud…**
  - Geospatial queries are intrinsically parallelizable
  - Advances in location-based services + large dataset

Related Work

- Centralized Systems
  - M. Sharifzadeh and C. Shahabi. VoRTree: Rtrees with Voronoi Diagrams for Efficient Processing of Spatial Nearest Neighbor Queries. VLDB, 2010.
  - K. Zheng, P.C. Fung, X. Zhou. K-Nearest Neighbor Search for Fuzzy Objects. SIGMOD, 2010.

- Parallel and Distributed Systems
  - Parallel Databases
    - J.M. Patel. Building a Scalable Geospatial Database System. SIGMOD, 1997.
  - Distributed Systems
    - C. Mouza, W. Litwin and P. Rigaux. SD-Rtree: A Scalable Distributed Rtree. ICDE, 2007.
  - Cloud Platforms
    - A. Cary, Z. Sun, V. Hristidis and N. Rishe. Experiences on Processing Spatial Data with MapReduce. SSDBM, 2009.

Our Approach

- MapReduce-based. Points are in 2D Euclidean space.
- Data are indexed with Voronoi diagrams.
- Both Index creation and query processing are done with MapReduce.
- 3 types of queries:
  - Reverse Nearest Neighbor.
  - Maximizing Reverse Nearest Neighbor (First implementation on a non-centralized system).
  - K-Nearest Neighbor Query.

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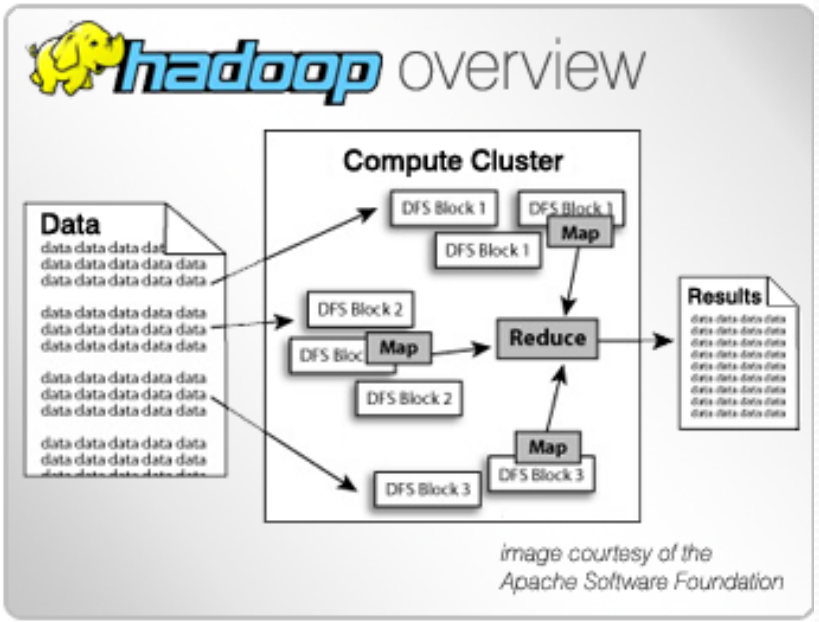
Preliminaries: MapReduce

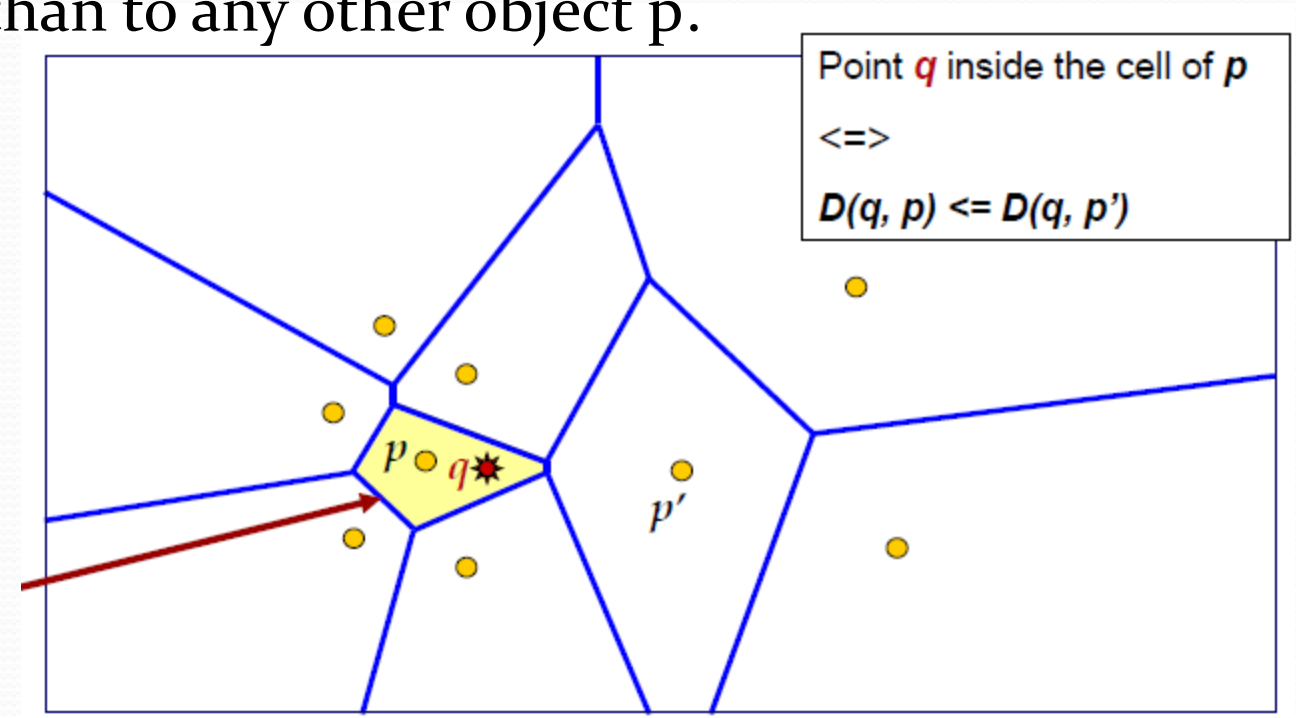
- Map(k1,v1) -> list(k2,v2)
- Reduce(k2, list (v2)) -> list(v3)



Preliminaries: Voronoi Diagrams

- Given a set of spatial objects, a Voronoi diagram *uniquely partitions the space into disjoint regions (cells).*
- The region including object p includes all locations which are closer to p than to any other object p'.

<u>Ordinary Voronoi diagram</u>
Dataset:
Points
Distance D(.,.):
Euclidean

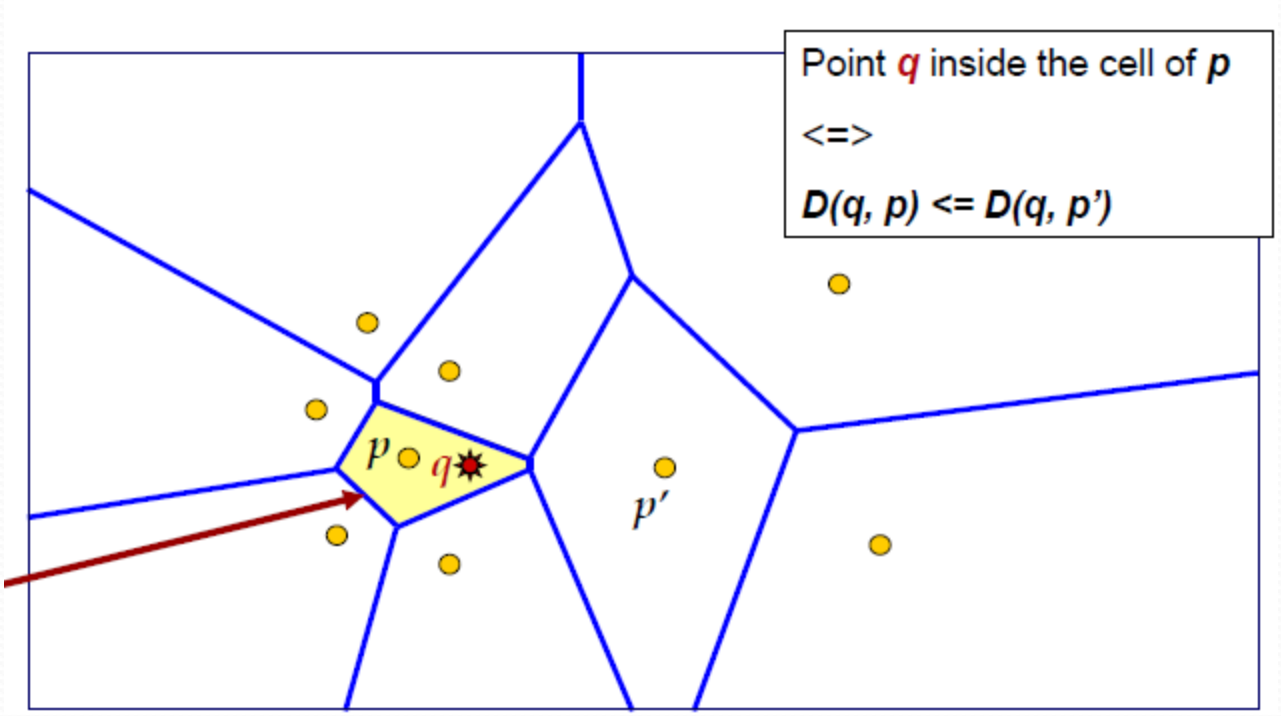


Voronoi Cell of p

Preliminaries: Voronoi Diagrams

- A point cannot have more than 6 Voronoi neighbors on average. Limited search space!

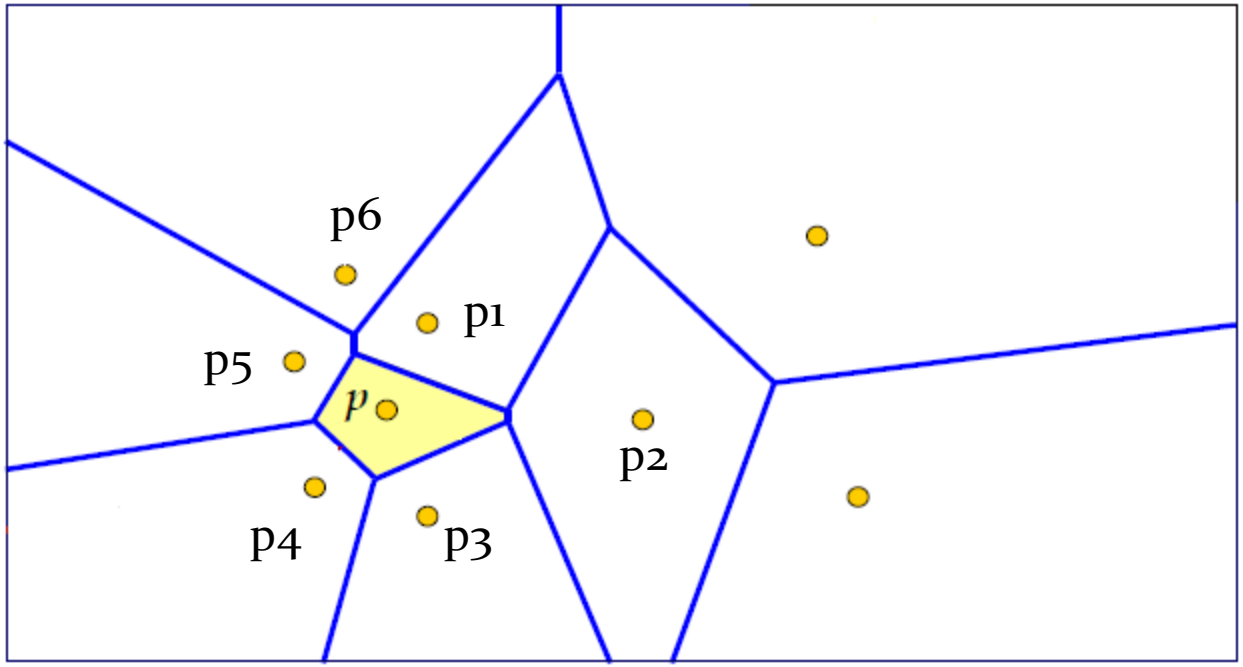
<u>Ordinary Voronoi diagram</u>
Dataset:
Points
Distance D(.,.):
Euclidean



Voronoi
Cell of p

Preliminaries: Voronoi Diagrams

- Nearest Neighbor of p is among its Voronoi neighbors (VN). VN(p) = $\{p_1, p_2, p_3, p_4, p_5, p_6\}$



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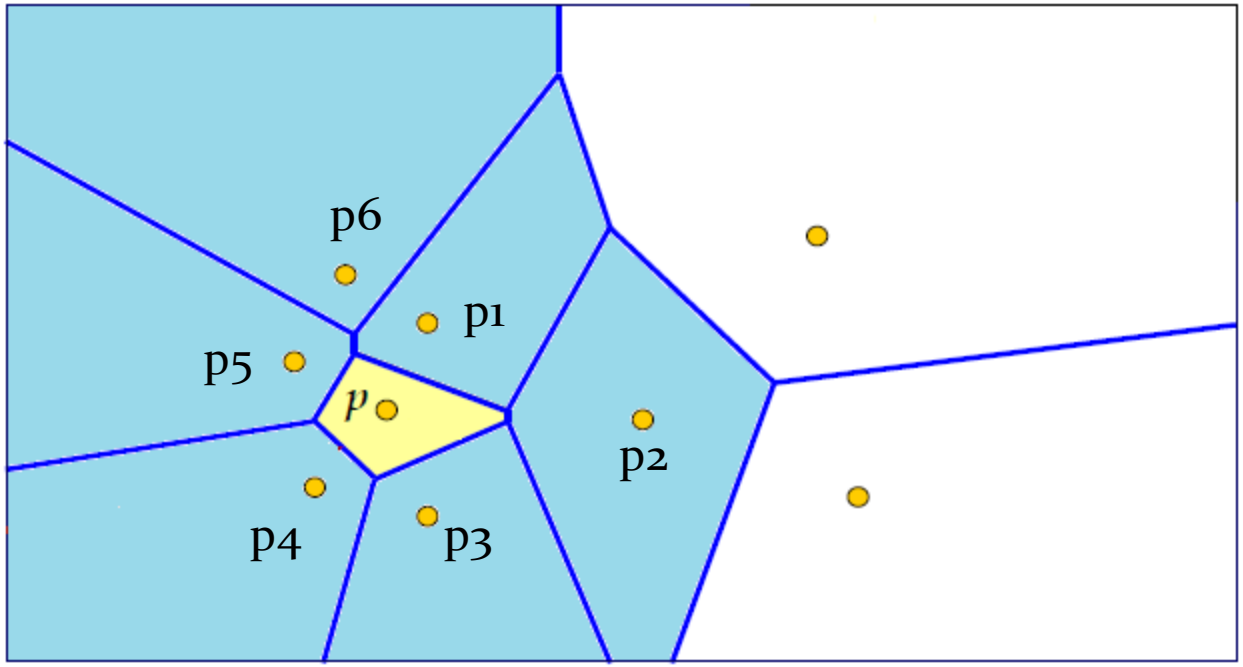

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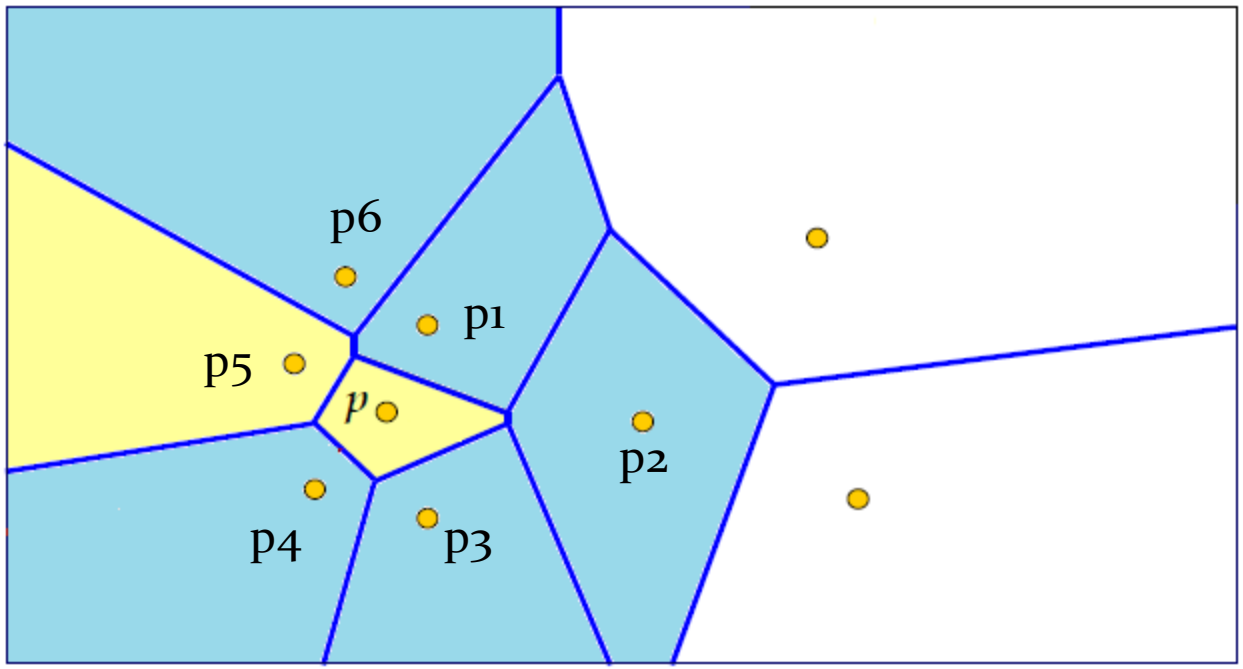
p_5 is p's nearest neighbor.



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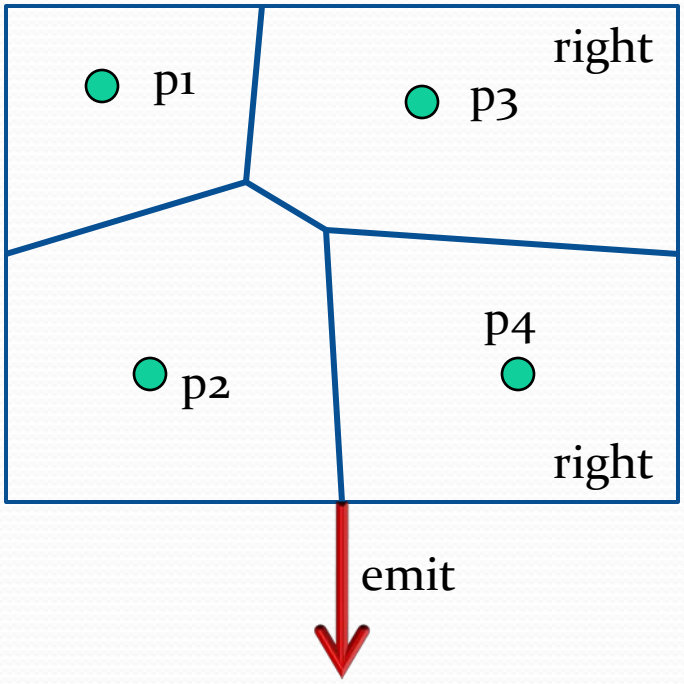
Voronoi Generation: Map phase

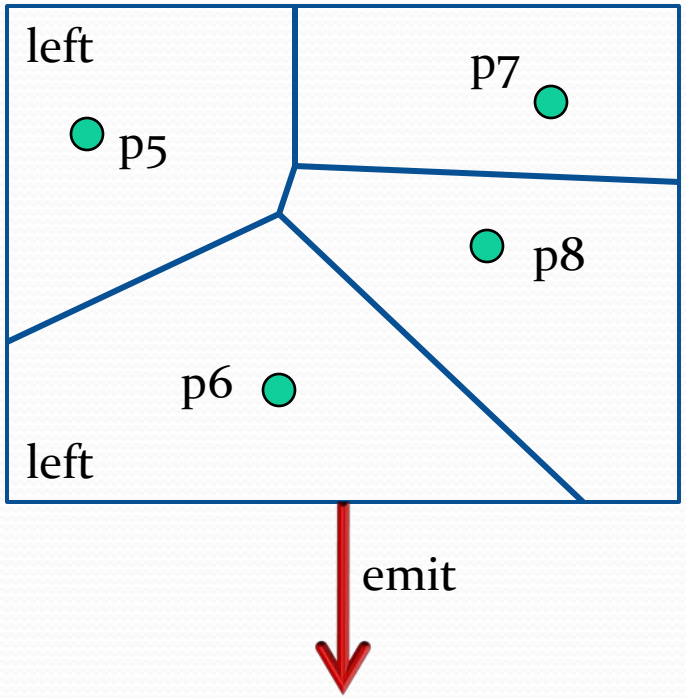
Generate Partial Voronoi Diagrams (PVD)

Split 1



<key, value>: <1, PVD(Split 1)>

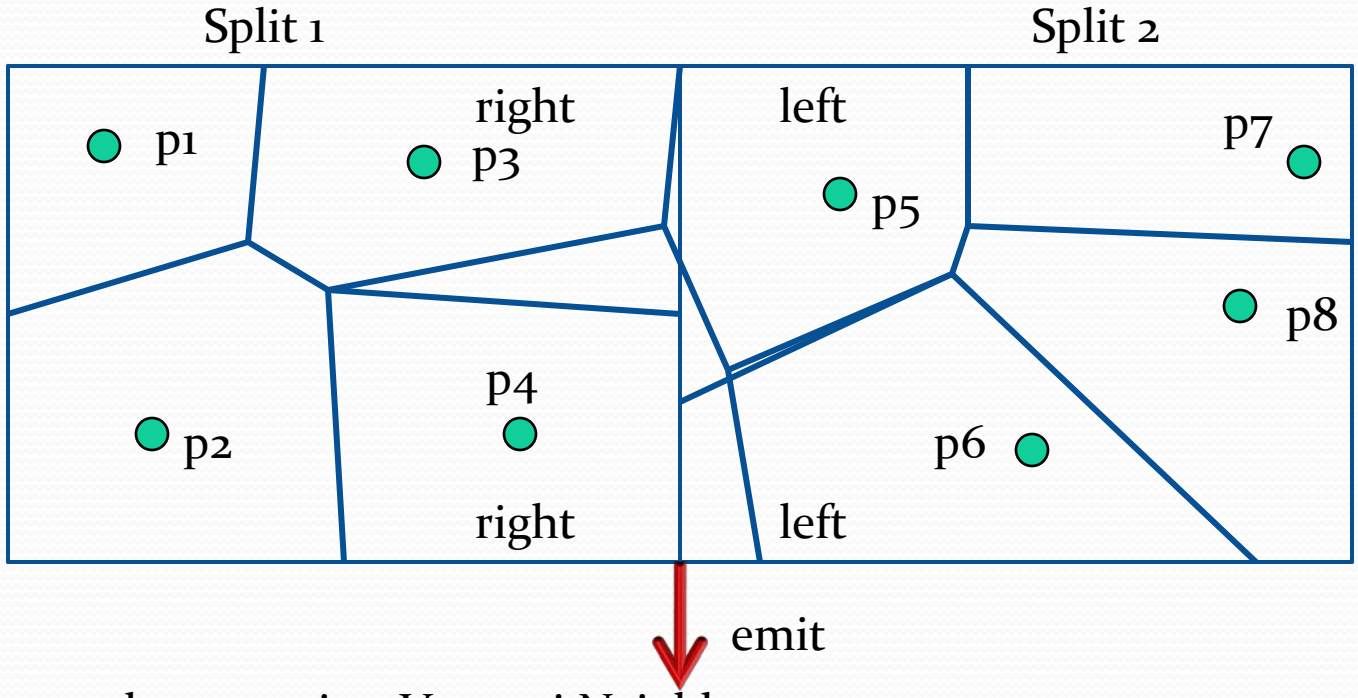
Split 2



<key, value>: <1, PVD(Split 2)>

Voronoi Generation: Reduce phase

Remove superfluous edges and generate new edges.



<key, value>: <point, Voronoi Neighbors>

<p1, {p2, p3}>

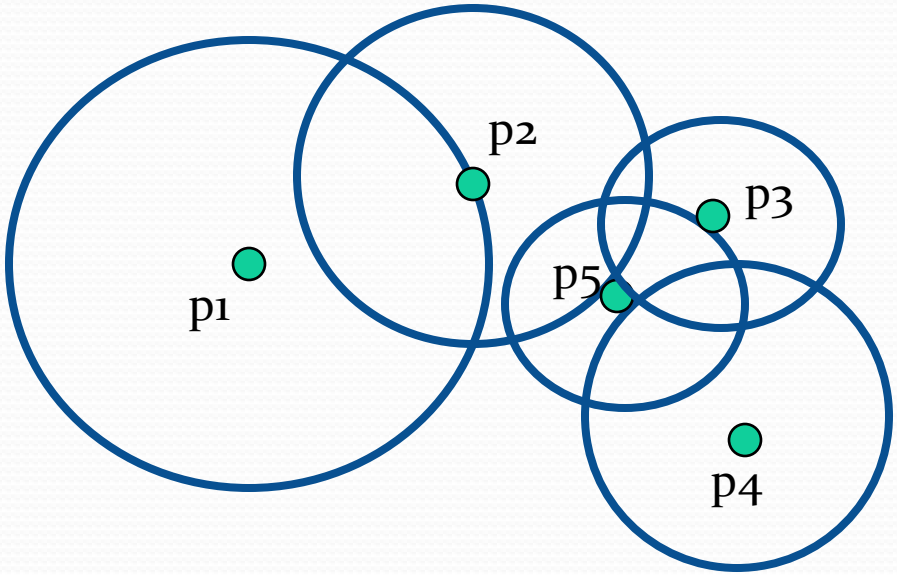
<p2, {p1, p3, p4}>

<p3, {p1, p2, p4, p5}>

.....

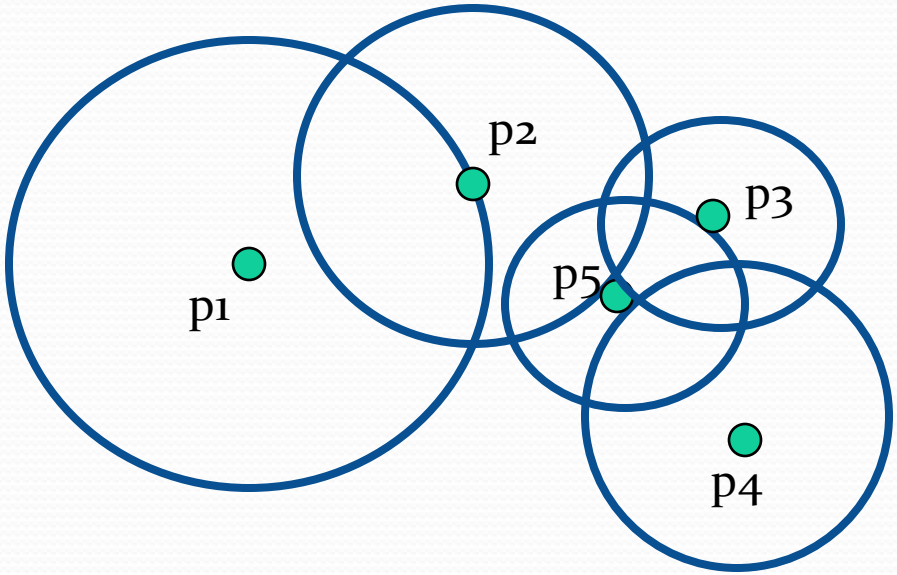
Query Type 1: Reverse Nearest Neighbor

- Given a query point q, Reverse Nearest Neighbor Query finds all points that have q as their nearest neighbors.
- NN(p1) = p2
- NN(p2) = p5
- NN(p3) = p5
- NN(p4) = p5
- NN(p5) = p3
- Reverse Nearest Neighbors of p5: {p2, p3, p4}



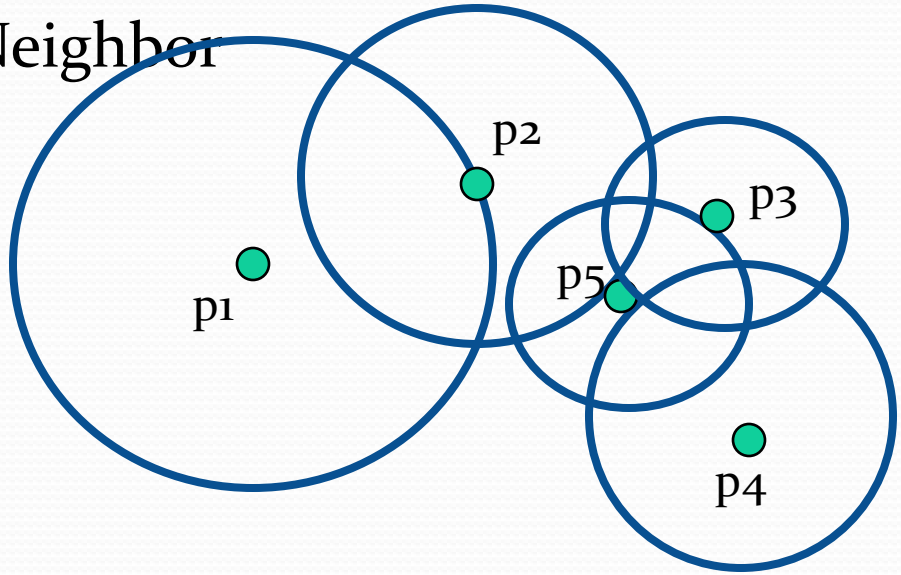
Query Type 1: Reverse Nearest Neighbor

- How does Voronoi Diagram help?
- Find Nearest Neighbor of a point p Without Voronoi Diagrams:
  - Calculate a distance value from p to every other point in the map step and find the minimum in the reduce step.
    - Large intermediate result.



Query Type 1: Reverse Nearest Neighbor

- Map Phase:
  - Input: <point, Voronoi Neighbors>
  - Each point p finds its Nearest Neighbor
  - Emit: <NN(p_n), p_n>
  - Ex: <p5, p2>
    <p5, p3>
    <p5, p4>
- Reduce Phase:
  - <point, Reverse Nearest Neighbors>
  - Ex: <p5, {p2, p3, p4}>

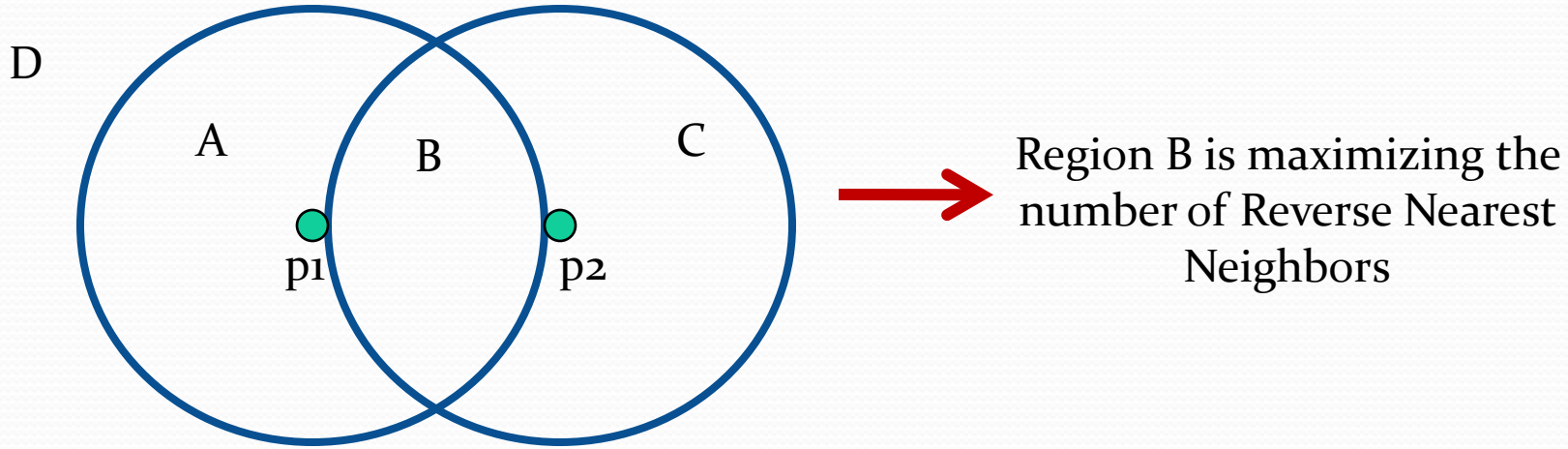


Query Type 2: MaxRNN

- Motivation behind parallelization:
- It requires to process a large dataset in its entirety that may result in an unreasonable response time.
- In a recent study, it has been showed that the computation of MaxRNN takes several hours for large datasets.

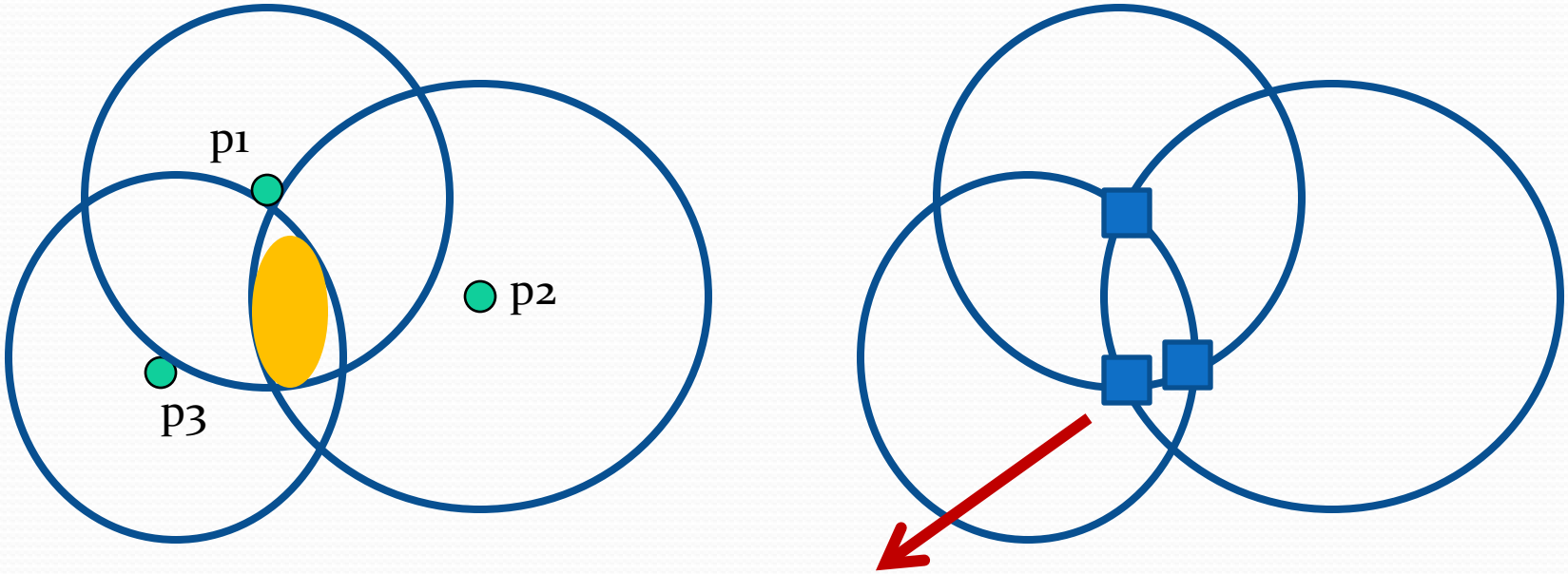
Query Type 2: MaxRNN

- Locates the optimal region A such that when a new point p is inserted in A, the number of Reverse Nearest Neighbors for p is maximized. Known as the optimal location problem.



Query Type 2: MaxRNN

- The optimal region can be represented with intersection points that have been overlapped by the highest number of circles.



Query Type 2: MaxRNN

- 2 step Map/Reduce Solution
  - 1. step finds the NN of every point and computes the radiuses of the circles.
  - 2. step finds the overlapping circles first. Then, it finds the intersection points that represent the optimal region.
    - Runs several times.

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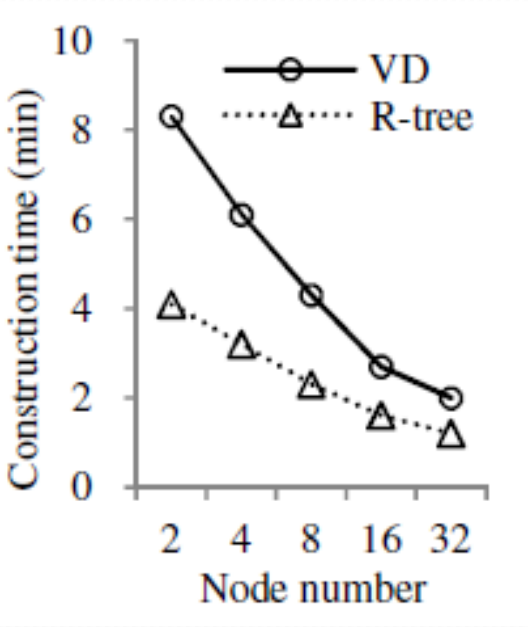
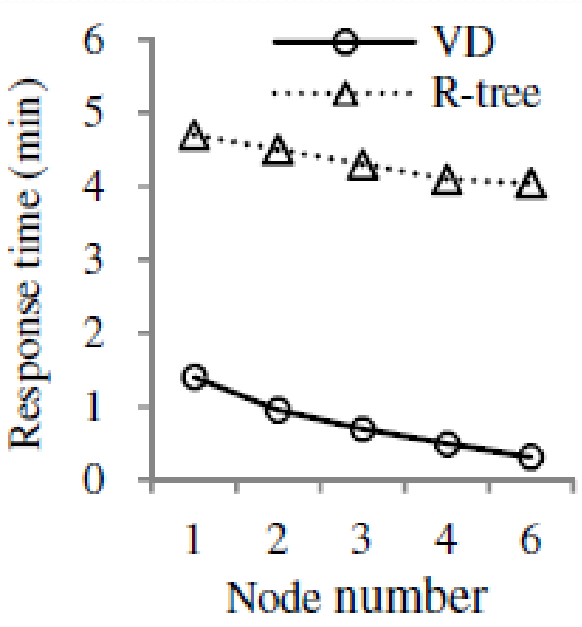
Performance Evaluation

- Real-World Navteq datasets:
  - BSN: all businesses in the entire U.S., containing approximately 1,300,000 data points.
  - RES: all restaurants in the entire U.S., containing approximately 450,000 data points.
- Experiments were done with Hadoop on Amazon EC2
- Evaluated our approach based on
  - Index Generation
  - Query Response times
- Replication factor = 1

Performance Evaluation

- **Voronoi Index**
  - Competitor approach: MapReduce based Rtree
  - RTree generation is faster than Voronoi.
  - Voronoi is better in query in Query Response times (Ex: Reverse Nearest Neighbor)

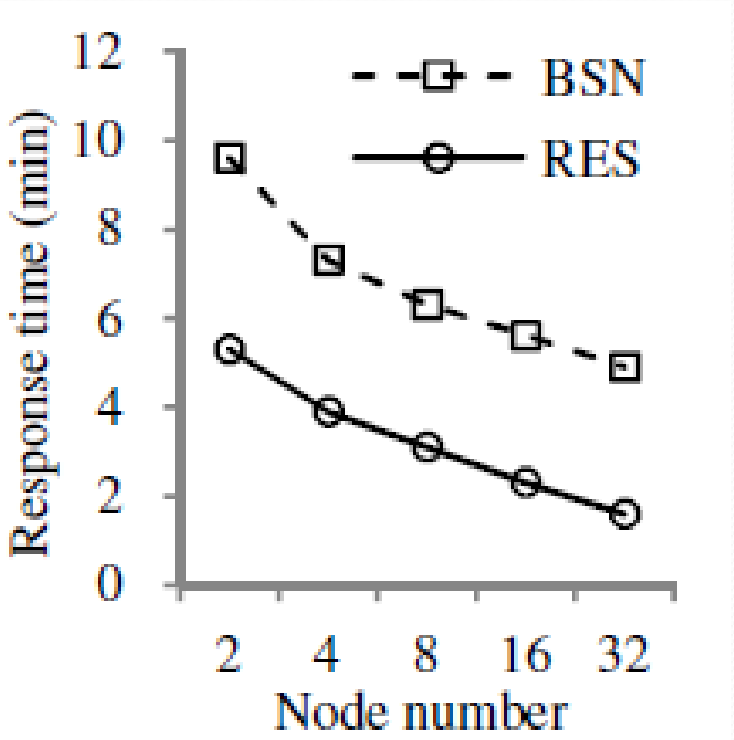




Nearest Neighbor of every point

Performance Evaluation

- **MaxRNN**
  - First implementation on a non-centralized system.
  - Evaluated the performance for 2 different datasets



Conclusion and Future Work

- **Conclusion**
  - Geospatial Queries are parallelizable.
  - Voronoi Diagram significantly improves the performance.
  - Linear scalability can be achieved.
- **Future Work**
  - Other types of queries: Skyline, Reverse k-Nearest Neighbor, etc.

Thanks!