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The Spatial Skyline Queries

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- Our Algorithms: VS^2 and B^2S^2
- Performance Evaluation
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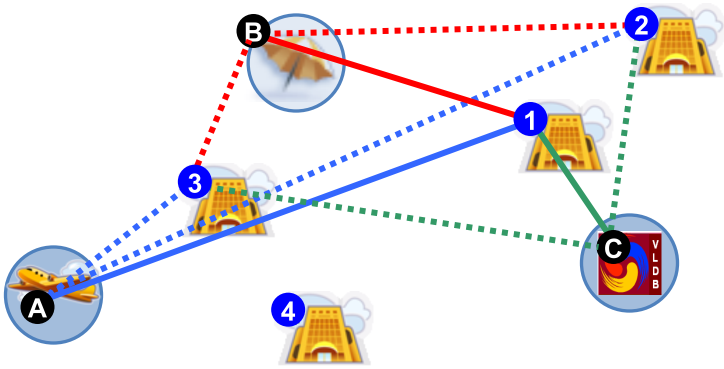
Motivation



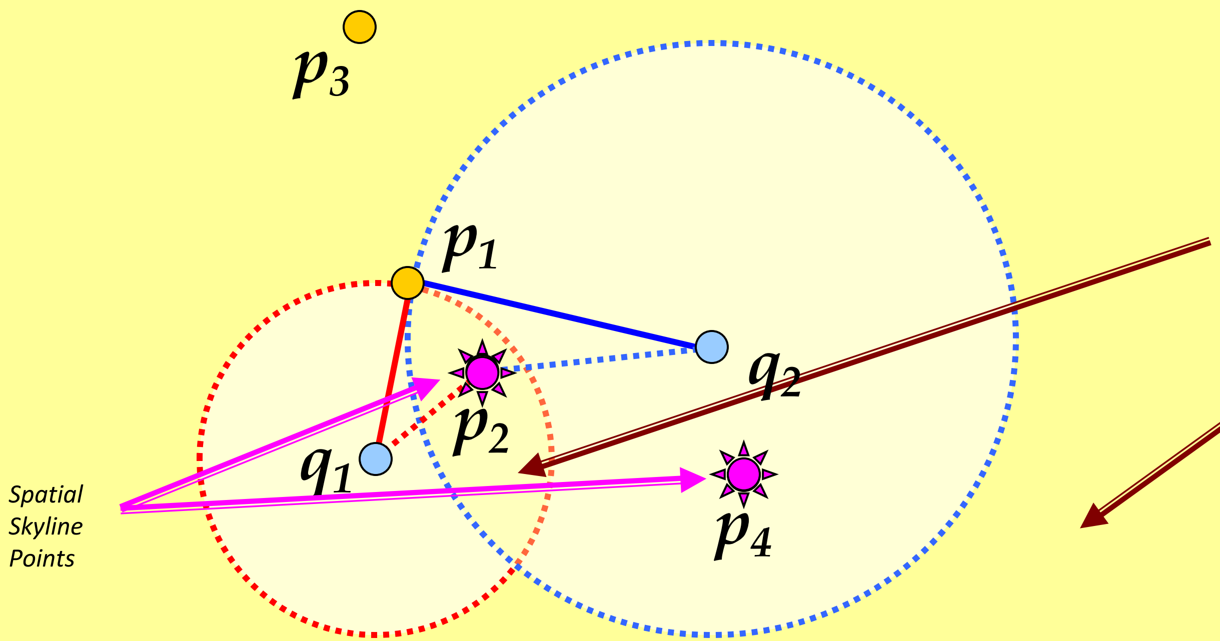
- H1 is better than H2
- H1 is closer than H3 to C but farther than H3 to A
- No hotel is better than H1 or H3 or H4

- **Problem:** Finding Hotels close to Airport, Beach, and Conference
- **Query:** What are the candidate *interesting* hotels?
  - **A skyline query with dynamic spatial attributes …**
  - **Criteria for an interesting hotel:** No hotel is *closer* than a candidate hotel to A, B, and C
    - No hotel is better than a candidate hotel in terms of all distances to A, B, and C (i.e., 3 query functions to be optimized together)

- **Applications:** Trip Planning, Crisis Management, Defense and Intelligence, Wireless Sensor Networks

Problem Definition

p_1 ***spatially dominates*** *p_2 with respect to Q iff*
$D(p_1, q_i) \leq D(p_2, q_i)$ for <u>all</u> q_i in Q and
$D(p_1, q_j) < D(p_2, q_j)$ for <u>at least one</u> q_j



- *Data P = $\{p_1, p_2, p_3, p_4\}$*
- *Query Q = $\{q_1, q_2\}$*
- *Distance D() = Euclidean*
- *p_2* ***spatially dominates*** *p_1 with respect to $\{q_1, q_2\}$*
- ***Dominator Region of*** *p_1*
- *p_1* ***spatially dominates*** *p_3*
- ***Dominance Region*** *of p_1*
- *No dominance relation between p_1 and p_4*

Spatial Skyline Query (SSQ): find the data points p_i that are **<u>not</u>** spatially dominated by any other point p_j with respect to the given query points (here, p_2 and p_4).

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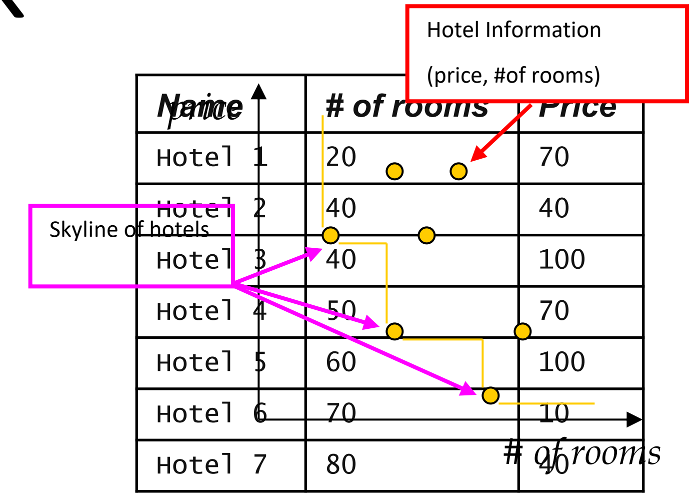
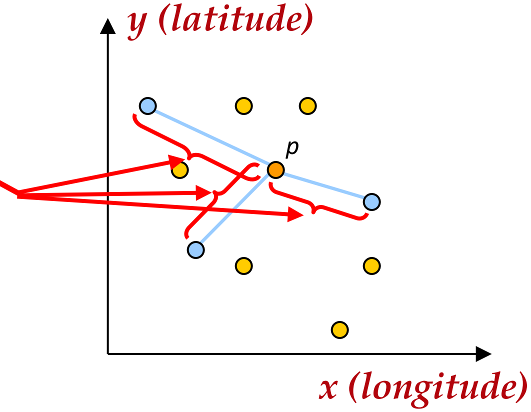
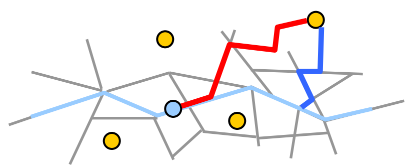
Related Work

- **General Skyline Query**
  - √ BNL and D&C, Börzsönyi et al., ICDE'01
  - Bitmap and Index, Tan et al., VLDB'01
  - √ NN, Kossmann et al., VLDB'02
  - SFS, Chomicki et al., ICDE'03
  - √ BBS, Papadias et al., SIGMOD'03
  - *Static attributes vs. dynamic spatial attributes in SSQ*
  - *SSQ is a dynamic skyline query*
- **Nearest Neighbor Search**
  - ANN, Papadias et al., TODS 2005, 30(2)
    - *Looks for subsets of spatial skyline points*
- **NN and Skyline**
  - Huang and Jensen, W2GIS'04
    - *Each point-of-interest has 2 dimensions: minimum distance to query point and minimum detour to pre-defined route ➔ dynamic skyline*
    - *Limited setting*
    - *Uses naïve in-memory skyline computation*

Name	# of rooms	Price
Hotel 1	20	70
Hotel 2	40	40
Hotel 3	40	100
Hotel 4	50	70
Hotel 5	60	100
Hotel 6	70	10
Hotel 7	80	40

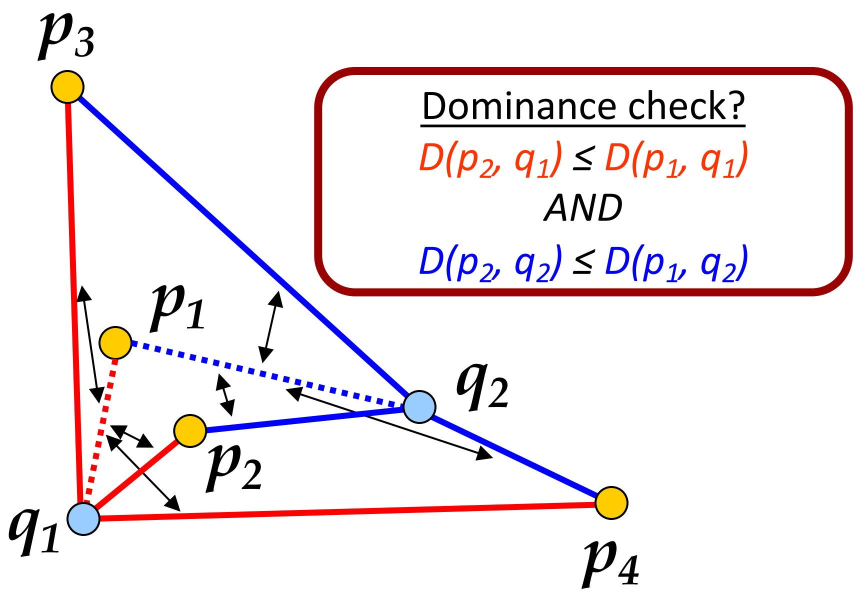






Naïve Solution

- *Data P = {p_1, p_2, p_3, p_4}*
- *Query Q = {q_1, q_2}*
- *Distance D() = Euclidean*




```
For each point pi
  iterate over points pj
  if no point spatially
dominates pi then add pi to
spatial skyline
```

Time Complexity: $O(|P|^2 |Q|)$

$|P|$: number of data points, $|Q|$: number of query points

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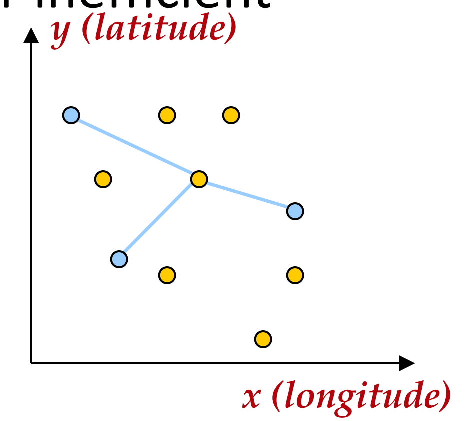
Problem Definition

- **Naïve approach**
  - **Complexity:** $O(|P|^2\ |Q|\ )$

    $|P|$: number of data points, $|Q|$: number of query points
- **Why a new algorithm is needed:**
  - Complexity of Naïve approach is high
    - Each dominance check involves $2|Q|$ distance computation operations: increases with more query points
  - General skyline algorithms are either inapplicable or inefficient
    - Due to dynamic spatial attributes
  - Optimization opportunity
    - The geometric properties of space can be exploited



Geometric Properties

- **Complexity of Naïve approach:** $O(|P|^2 \, |Q|)$
  - $|P|$: number of data points
  - $|Q|$: number of query points
- We identify geometric properties to reduce this complexity by <u>reducing</u> the number of :
  - data points to be investigated
  - query points that has no effect on the result
- Less and cheaper dominance checks
- We identify three properties …

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'.

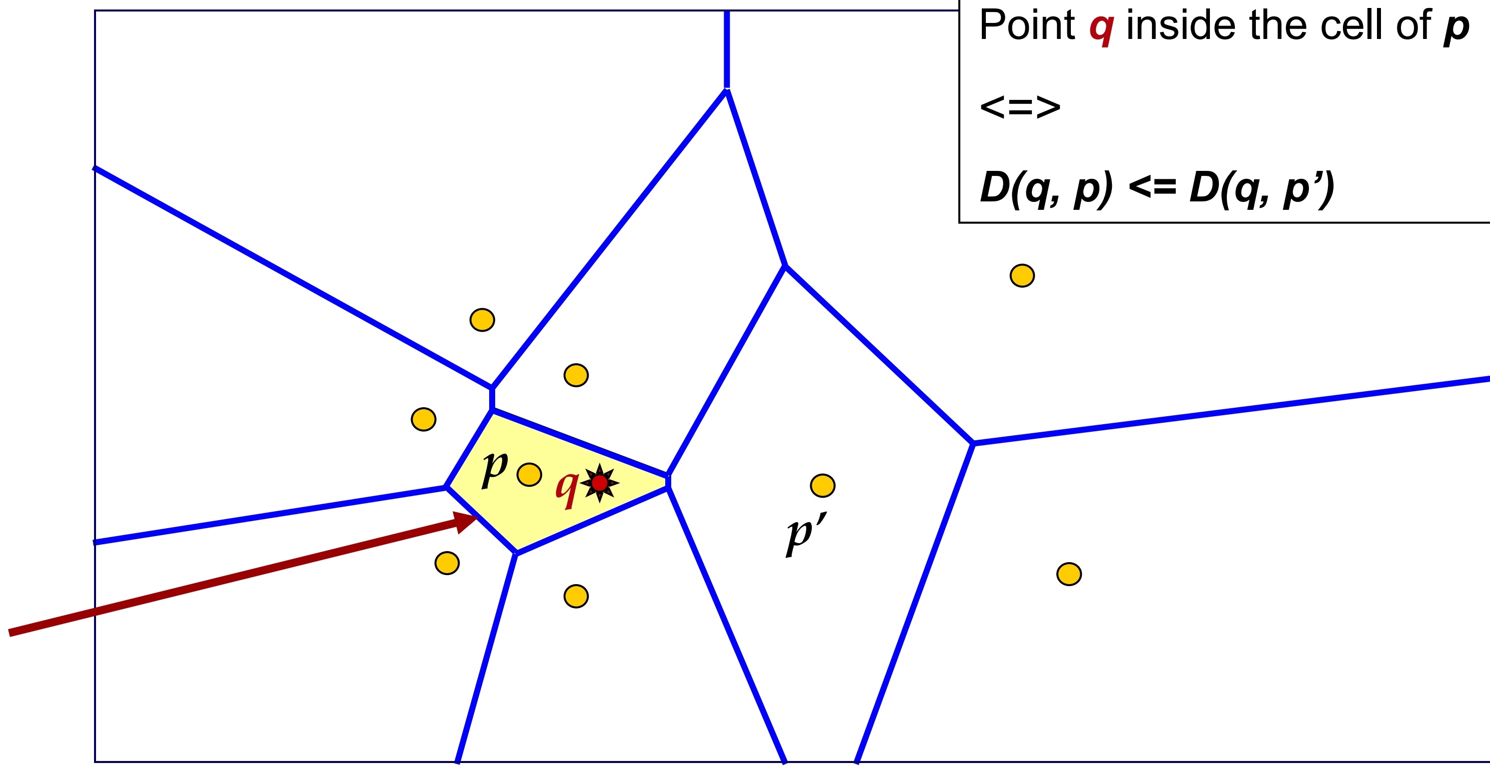
<u>Ordinary Voronoi Diagram</u>

Dataset:

Points

Distance *D(.,.)*:

Euclidean (L_2)



Voronoi Cell of p

Point ***q*** inside the cell of ***p***

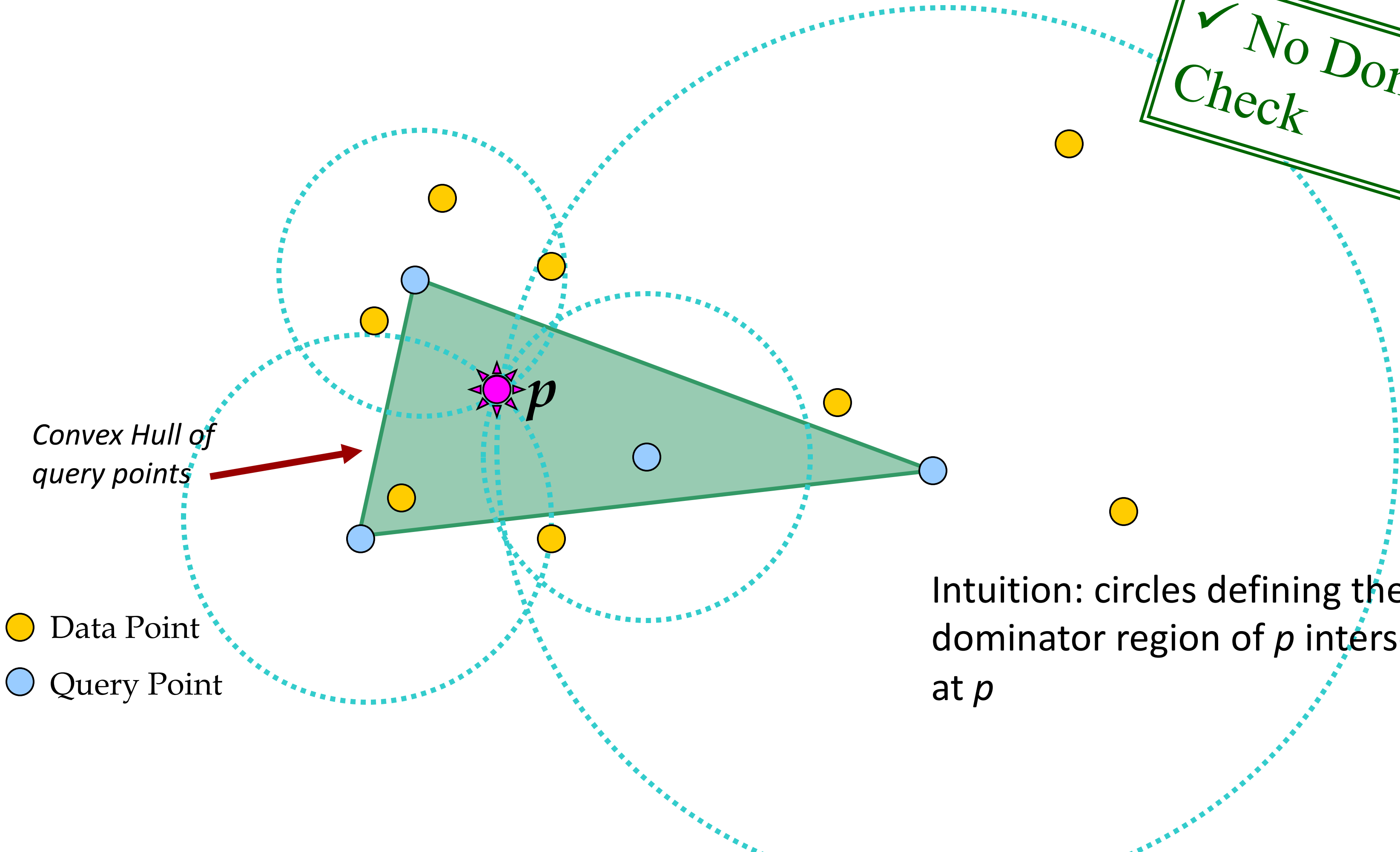
<=>

D(q, p) <= D(q, p')

Geometric Properties

GP$_1$: Any point *p* inside the **convex hull** of query points *Q* is a spatial skyline point.

✓ No Dominance Check

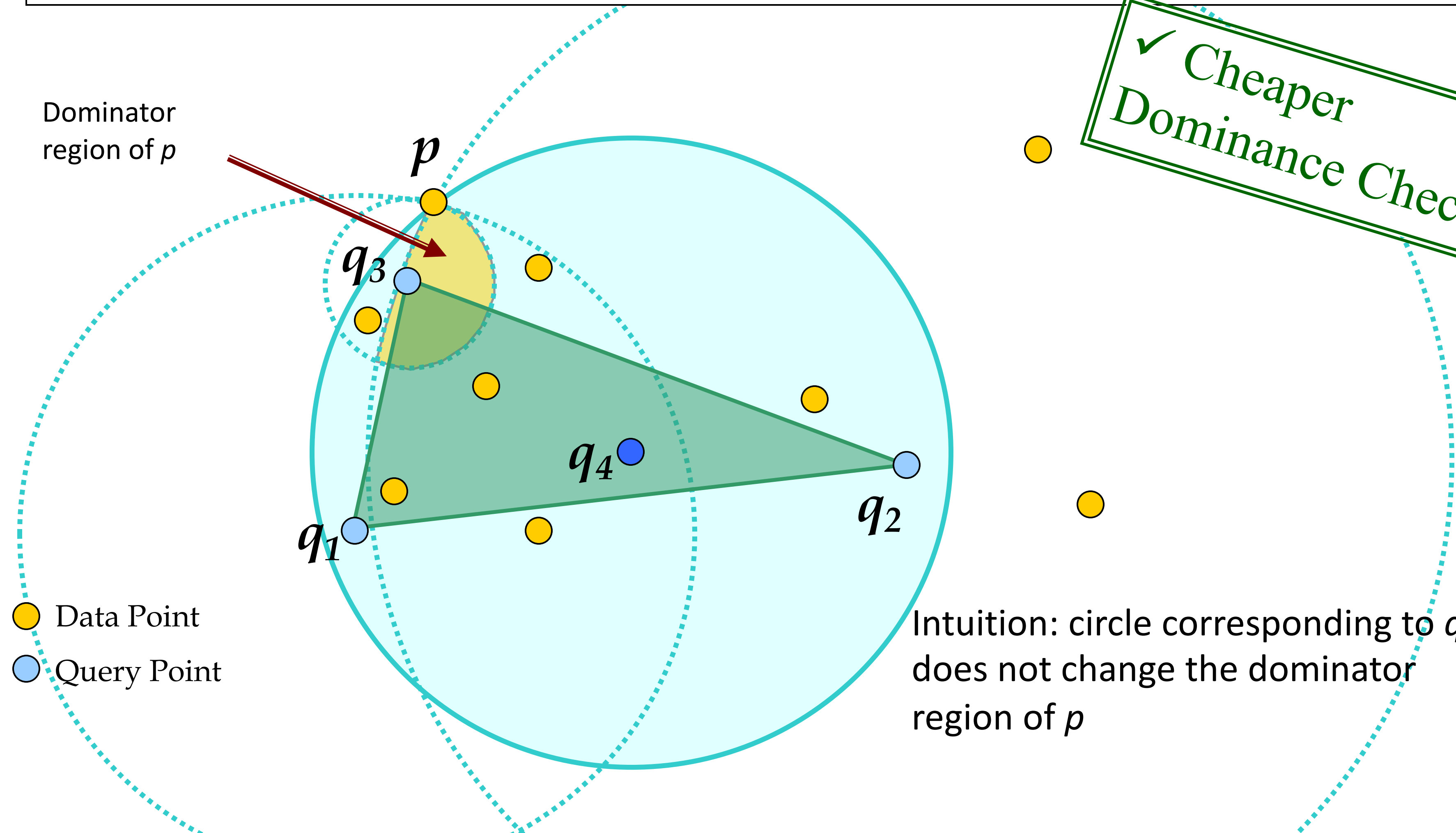


Intuition: circles defining the dominator region of *p* intersect only at *p*

Geometric Properties

GP$_2$: The set of skyline points does not depend on any query point *q* inside the convex hull of query points *Q*.

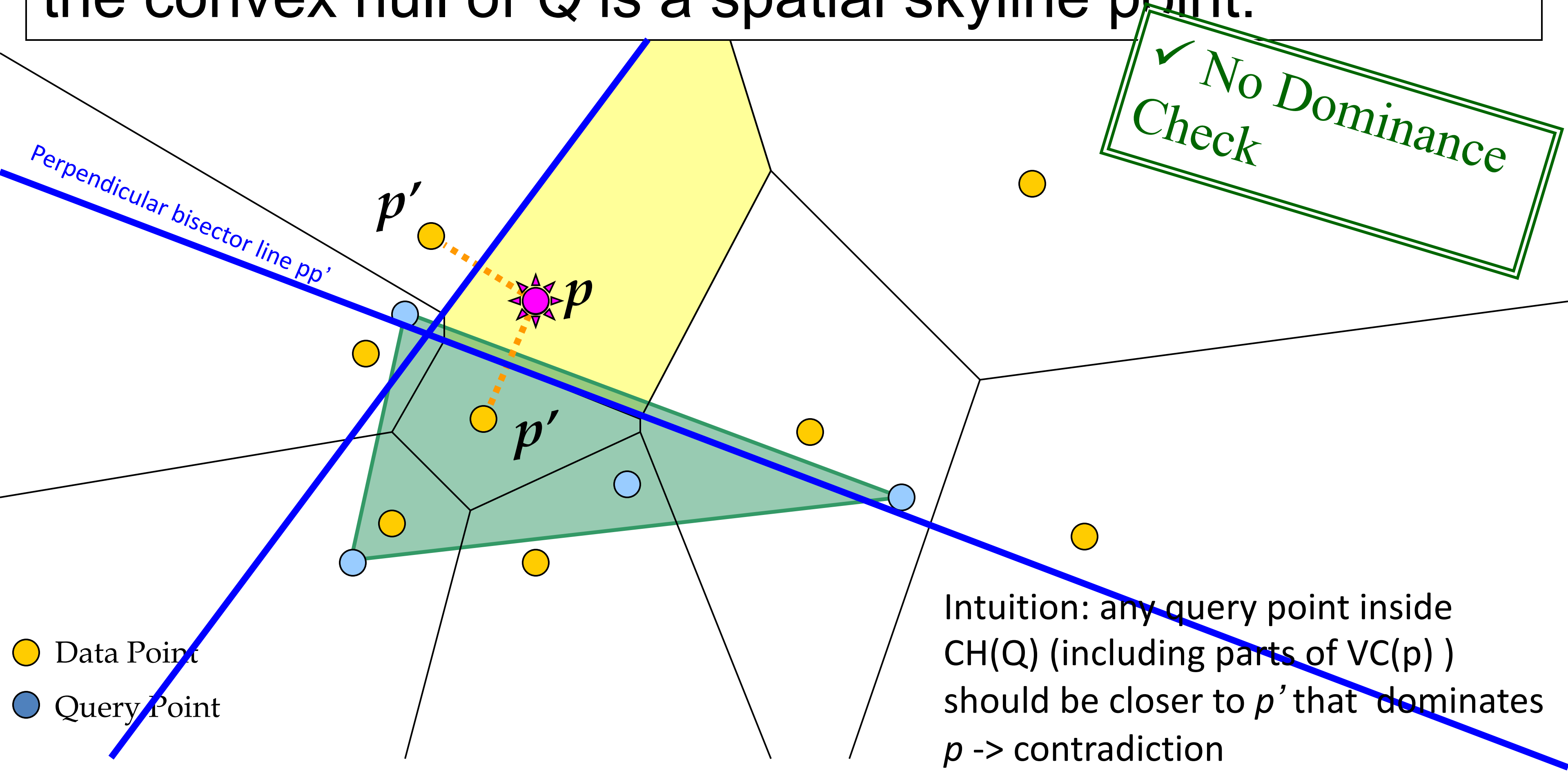
✓ Cheaper Dominance Checks



Intuition: circle corresponding to q_4 does not change the dominator region of *p*

Geometric Properties

GP$_3$: Any point *p* whose Voronoi cell **intersects** with the convex hull of *Q* is a spatial skyline point.



Intuition: any query point inside CH(Q) (including parts of VC(p)) should be closer to *p'* that dominates *p* -> contradiction

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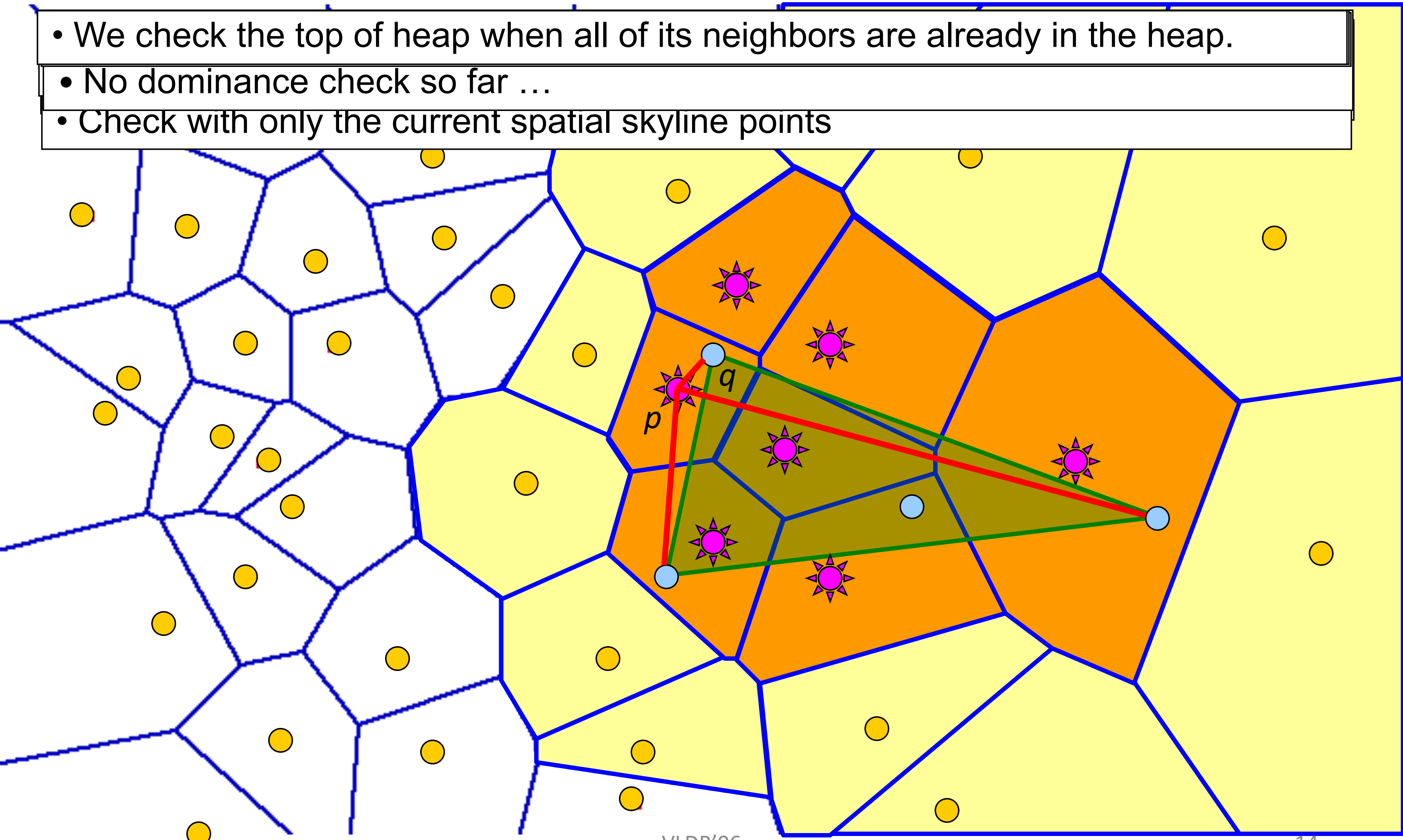
Algorithm: VS^2

- **VS^2**: Voronoi-based Spatial Skyline Algorithm
- Utilizes the geometric interpretation of the skyline
  - GP_1 GP_3 – With **no dominance check**, adds any data point *p* whose Voronoi cell intersects with the convex hull of *Q*
  - GP_2 – Performs **cheaper dominance check** **only on a small subset** of points (neighbors of skyline points ~ O(S))
- Traverses the **Voronoi Diagram*** of data points

* Delaunay Graph

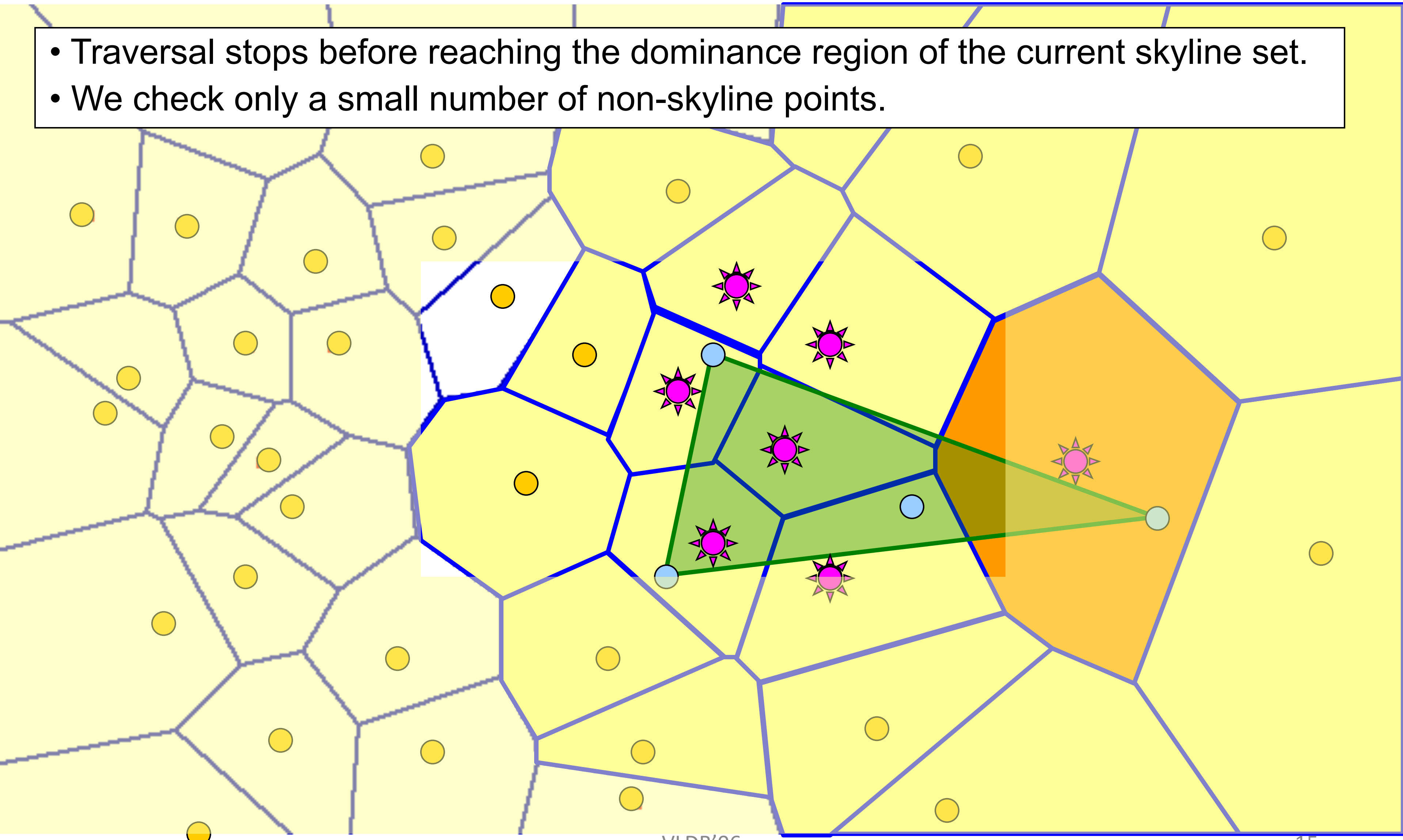
Algorithm: VS^2



- We check the top of heap when all of its neighbors are already in the heap.
- No dominance check so far …
- Check with only the current spatial skyline points

Algorithm: VS^2

- Traversal stops before reaching the dominance region of the current skyline set.
- We check only a small number of non-skyline points.



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Algorithm: VS²

- **Time Complexity:** $O(|S|^2\ |CH_v(Q)| + \Phi(|P|)\ )$
  - Naïve: $O(|P|^2\ |Q|\ )$
- $|S|$: number of skyline points
- $|CH_v(Q)|$: number of vertices of the convex hull of Q $(<= |Q|)$
- $\Phi(|P|)$: complexity of finding the data point from which VS² starts traversing inside the convex hull of Q *(O(log(|P|)) with point location or O(|P|^{1/2}))*
- **Space Complexity:** $O(|P|)$
  - *Space required for ordinary Voronoi Diagram is O(|P|)*

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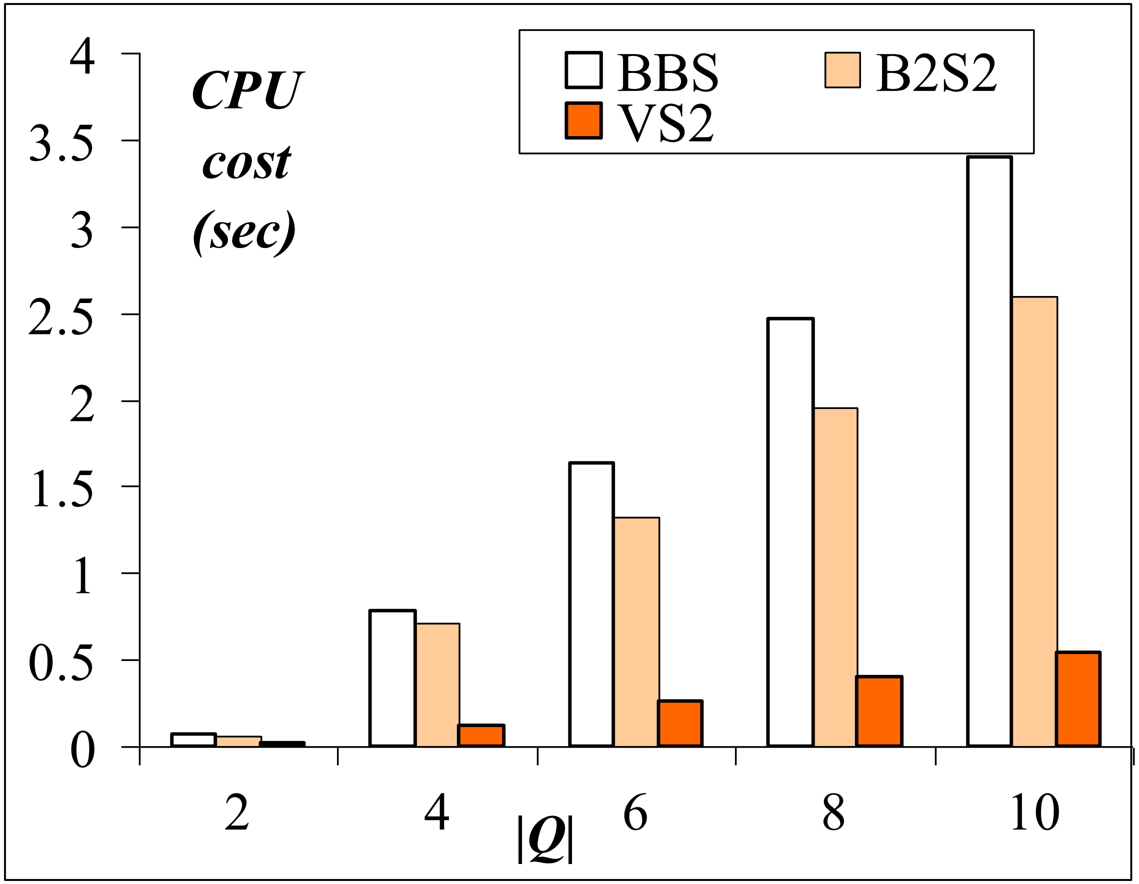
Algorithms: B^2S^2

- **B^2S^2:** Branch-and-Bound Spatial Skyline Algorithm
- Customization of BBS [Papadias et al.] for SSQs
- Uses **some** of the geometric properties of the skyline (GP_1 and GP_2)
- Similar to BBS traverses an R-tree on data points
- **Traversal order:** specified by any monotone function (e.g., $mindist(p, CH_v(Q))$)

Performance Evaluation

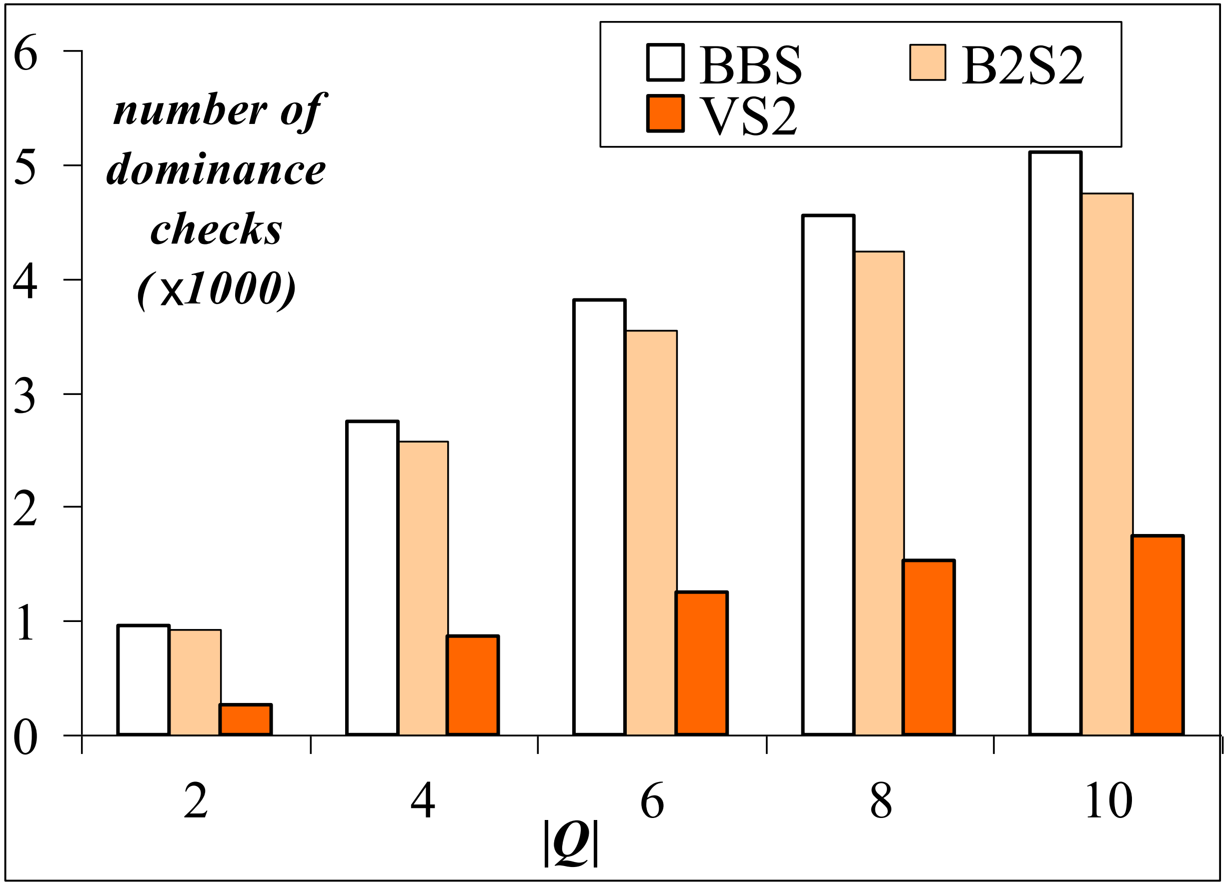
- **Dataset:** USGS including one million locations
- R*-tree on data points for BBS and B^2S^2
- Pre-built Delaunay graph of data points for VS^2

Performance Evaluation



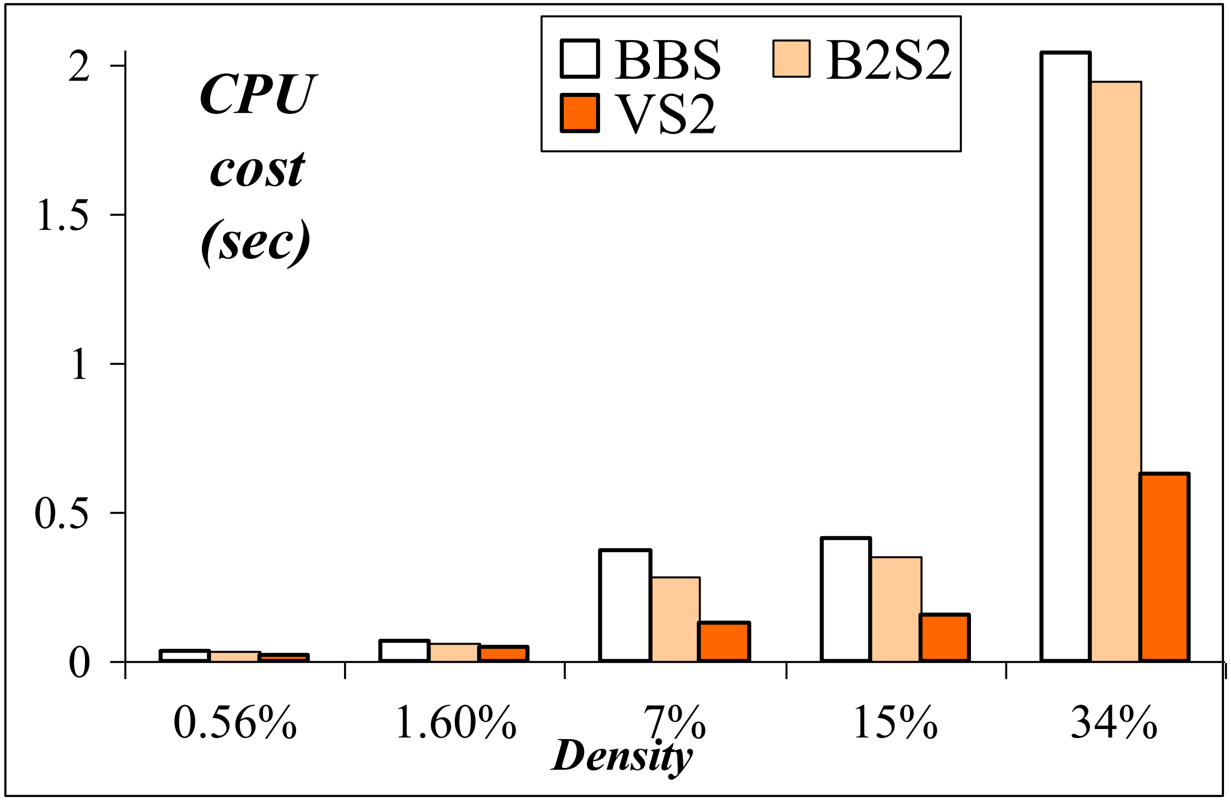
- *Max MBR(Q)=0.3%*
- The difference in improvement of VS² over BBS increases for larger query sets.

Performance Evaluation



- Variations of B^2S^2 require less dominance checks than BBS.
- Note that each dominance check is cheaper in our VS^2 and B^2S^2 algorithms.

Performance Evaluation



- *Max |MBR(Q)| = 0.5%, |Q| = 6*
- VS² is also scalable with respect to the density of data (i.e., number of skyline points)

Conclusion and Future Work

- We introduced the spatial skyline queries.
- We exploited the geometric properties of its solution space.
- We proposed two algorithms:
  - B^2S^2 that uses our properties to customize BBS for SSQs
  - VS^2 that utilizes a Voronoi diagram to minimize the number of dominance checks
- We proposed two variations of VS^2 for:
  - continuous spatial skyline query
  - handling non-spatial attributes
- VS^2 significantly outperforms its competitor approach BBS.

Future Work

- Addressing SSQ in other spaces
- Studying variations of SSQ

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References

- Mehdi Sharifzadeh and Cyrus Shahabi, The Spatial Skyline Queries, VLDB 2006, Seoul, Korea, September 2006.