Voronoi and Delaunay Analysis of Citi Bike Stations in New York City

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1. Model

The spatial distribution of bike-sharing stations can be modeled using **geometric proximity structures**. Two powerful models were applied:

- **Voronoi Diagram:** divides the city into regions where each point belongs to the nearest station. It models *service areas* and accessibility.
- **Delaunay Triangulation:** connects neighboring stations such that no point lies inside any triangle's circumcircle. It reveals the *adjacency network* between stations.

These dual models help understand both coverage and connectivity of public transportation infrastructure.

2. Approach

- **Data Collection:** Station coordinates were fetched from the *Citi Bike GBFS API*, which provides real-time station information.
- **Data Processing:** Longitude and latitude were extracted for all active, installed, and renting stations.
- **Computation:** Using the `scipy.spatial` library:
  - The `Voronoi()` function generated Voronoi regions.
  - The `Delaunay()` function produced the triangulation.
  - A custom `circumcircle()` function calculated circumcenters and radii for each triangle.
- **Visualization:** Three plots were created side by side:
  1. Voronoi diagram (coverage zones).
  2. Delaunay triangulation (neighboring links).
  3. Circumcircles (largest empty regions showing potential gaps).

3. Experiment

The Python experiment combined live geographic data and geometric modeling to map service coverage in New York City.

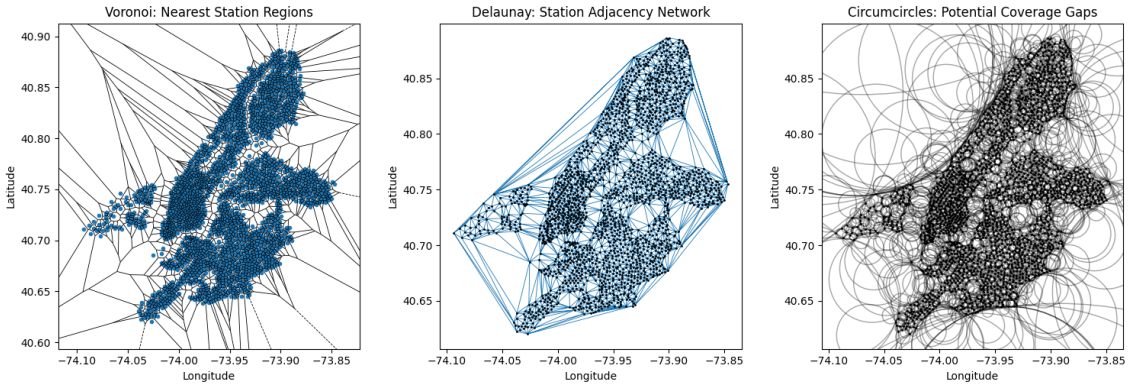

Figure 1: Output diagrams: Voronoi (left), Delaunay (middle), and Circumcircles (right).

Each black point represents a Citi Bike station. The Voronoi diagram outlines the territory of each station. The Delaunay network connects stations that share boundaries. Circumcircles highlight large unserved areas — possible candidates for new stations.

4. Conclusions

The experiment demonstrated how Voronoi and Delaunay structures can serve as analytic tools for **urban mobility planning**. From the generated plots:

- **Dense clusters** (small Voronoi cells) indicate high service redundancy.
- **Sparse areas** (large cells or large circumcircles) mark low coverage and potential for expansion.
- The Delaunay network can support optimization of bike redistribution routes.

In conclusion, geometric proximity models provide valuable insights into spatial service design. The method can easily be extended to other domains, such as airport catchments, emergency response zones, or delivery routing.

Keywords: Voronoi diagram, Delaunay triangulation, Citi Bike, spatial analysis, geometric modeling.