# LARGE: A Length-Aggregation-based Grid Structure for Line Density Visualization

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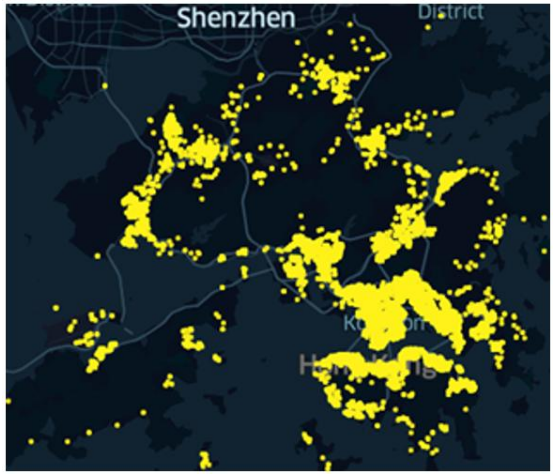
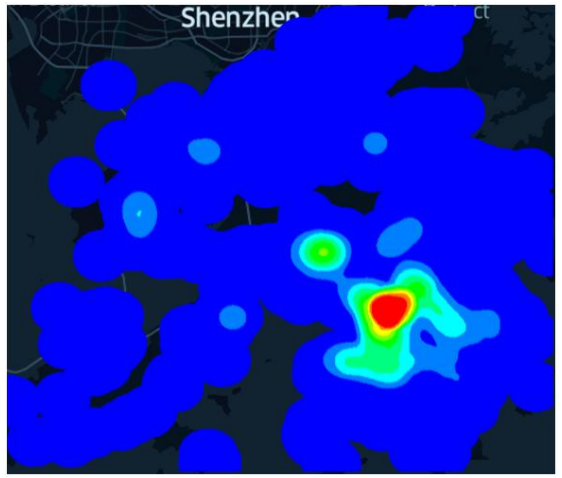
# Overview of Point Density Visualization (PDV)

- Example (Hong Kong COVID-19 dataset)
  - Each data point denotes a location of COVID-19 case.
  - Obtain the density value for each pixel based on data points.



Hong Kong COVID-19 cases



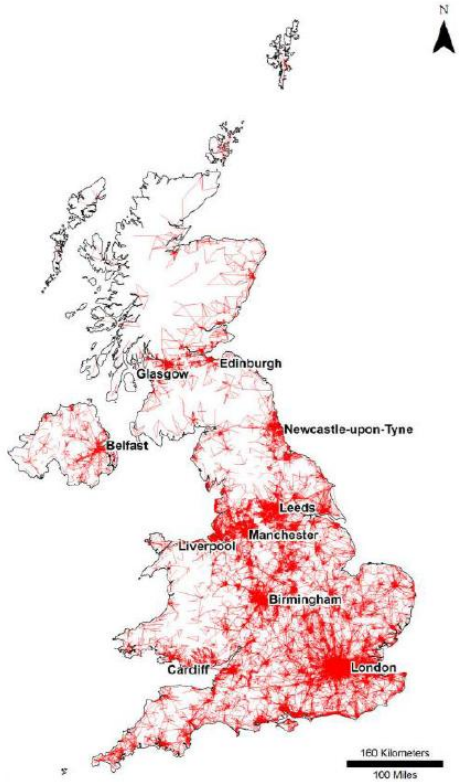
Hotspot map (based on KDV)

- Limitations ☹
  - Can only be used for supporting point datasets.
  - Domain experts need to analyze datasets with line segments (e.g., trajectories/flows).

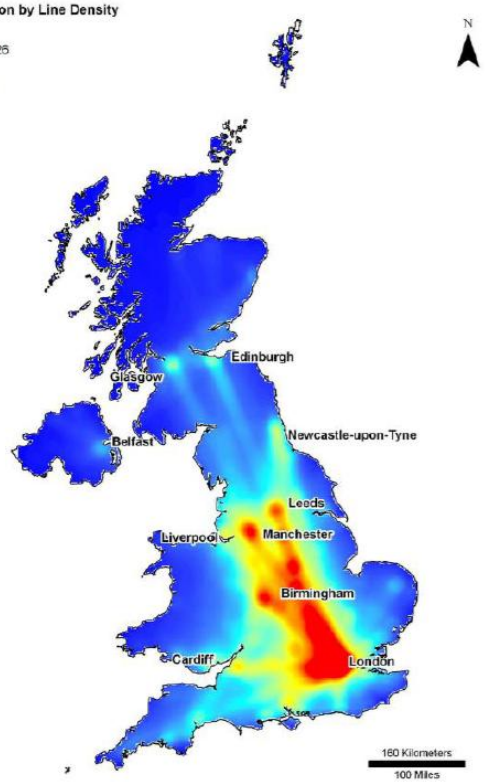
# What is Line Density Visualization (LDV)?

- Example (UK mobility dataset)
  - A line segment denotes the mobility from one place to another place.
  - LDV reports the density of those line segments for each region.

- Other applications:
  - Crime pattern analysis
  - Traffic flow/trajectories analysis




Line segment (flow) dataset




LDV

Alasdair Rae. From spatial interaction data to spatial interaction information? Geovisualisation and spatial structures of migration from the 2001 UK census. Computers, Environment and Urban Systems 2009.

# Many Software Packages Support LDV

QGIS Documentation

3.40

## 24.1.6.3. Line Density

Calculates for each raster cell, the density measure of linear features within a circular neighbourhood. This measure is obtained by summing all the line segments intersecting the circular neighbourhood and dividing this sum by the area of such neighbourhood. A weighting factor can be applied to the line segments.

QGIS

ArcGIS Pro | Overview | Features | Resources | Free Trial | Extensions | Pricing

Home | Get Started | Help | Tool Reference | Python | SDK

- An overview of the Density toolset
- Calculate Kernel Density Ratio
- Kernel Density
- Line Density
- Point Density
- Space Time Kernel Density

## How Line Density works

ArcGIS Pro 3.5 | Other versions | Help archive

Available with Spatial Analyst license.

The Line Density tool calculates the density of linear features in the neighborhood of each output raster cell. Density is calculated in units of length per unit of area.

In this topic

- Units
- References

ArcGIS

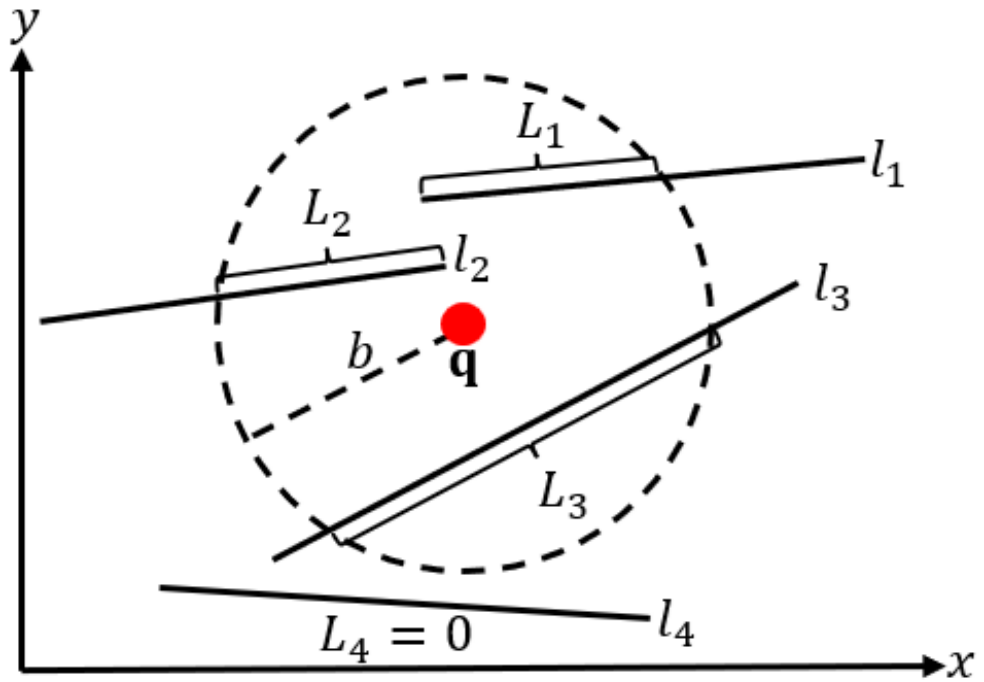
# Formal Definition of LDV

- Consider a set of line segments $\{l_1, l_2, \ldots, l_n\}$ with size $n$.

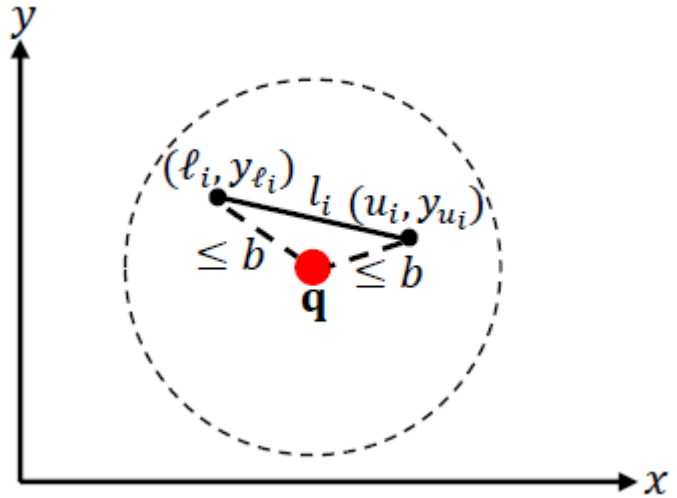
- Color each pixel $\mathbf{q}$ based on the line density function $\mathcal{L}(\mathbf{q})$.

$$\mathcal{L}(\mathbf{q}) = \frac{1}{\pi b^2} \sum_{i=1}^{n} L_i$$

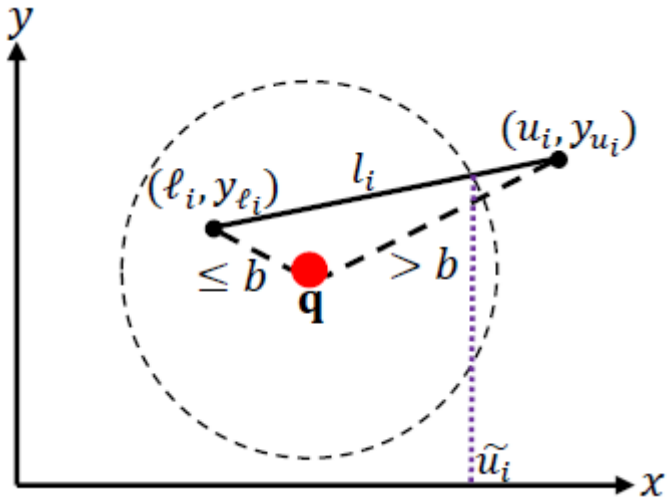
where $L_i$ denotes the length of the line segment $l_i$ that is within the search range $b$.



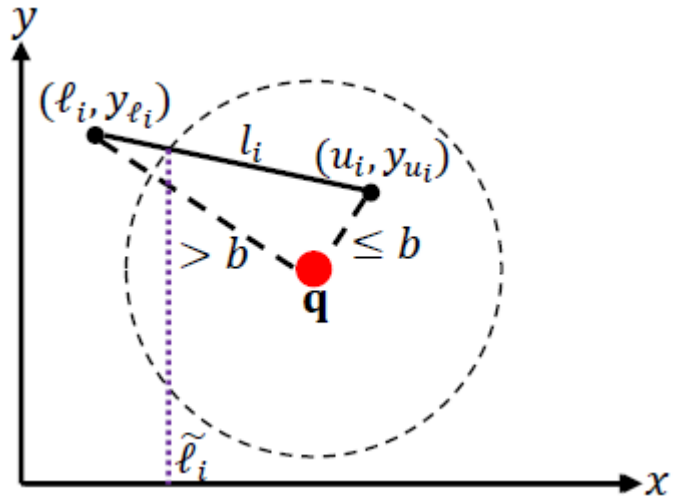
# SCAN: A Basic Method



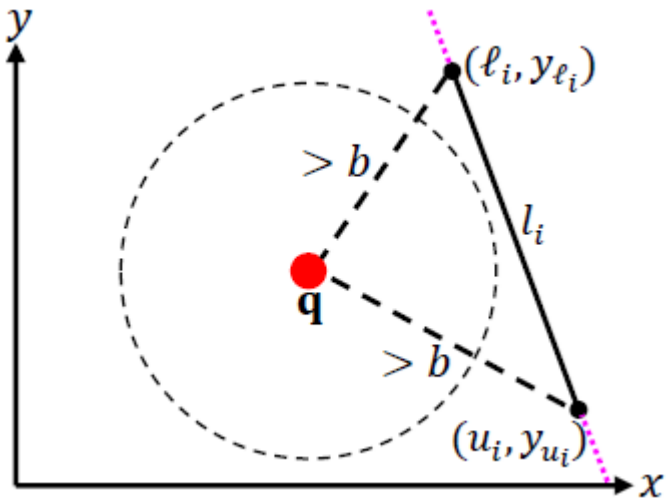

Case 1



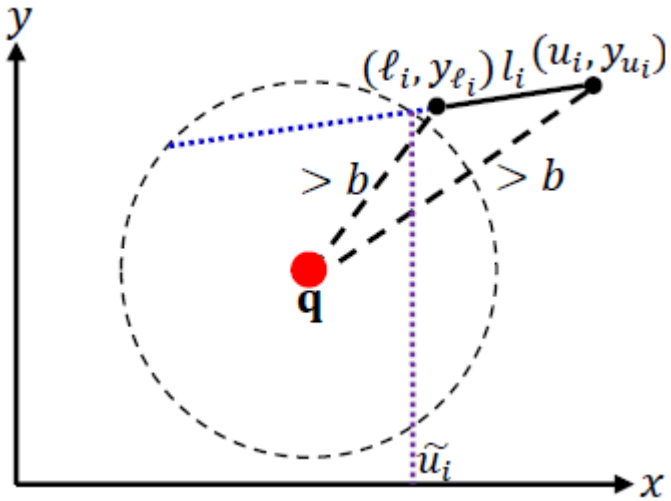

Case 2



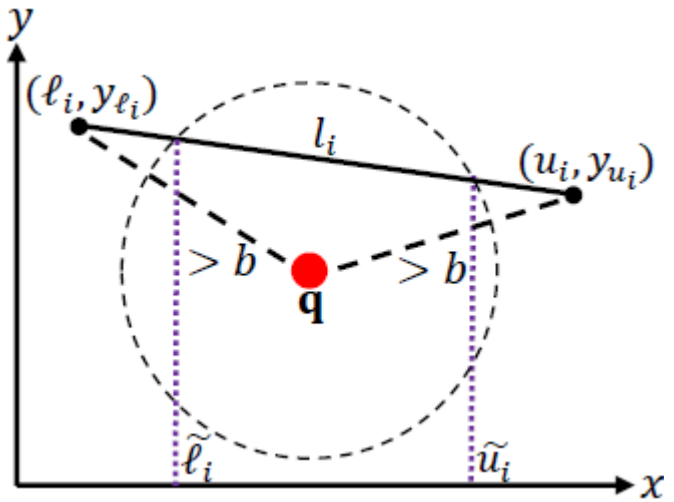

Case 3




Case 4a




Case 4b



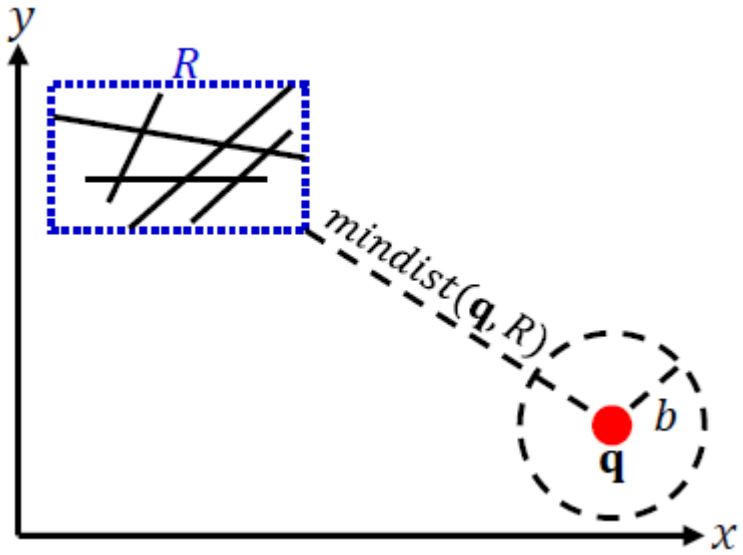

Case 4c

# Weakness of SCAN

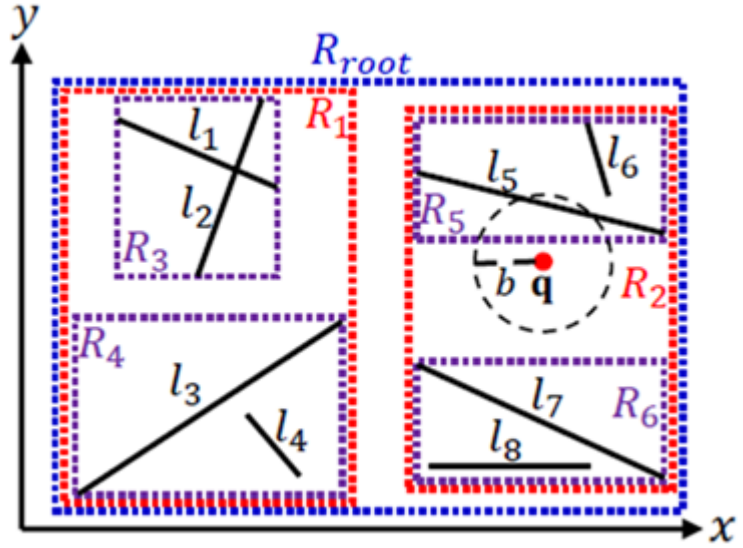
- Needs to process all line segments for each pixel. ☹
- Time complexity: $O(XYn)$ time. ☹

# R-tree: An Advanced Method

- Idea: Those line segments that are too far away from the pixel **q** can be filtered.

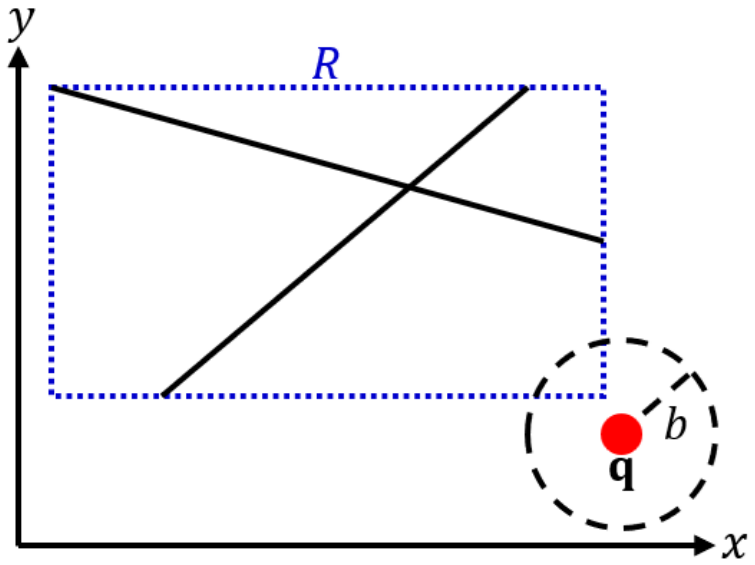



- Use the R-tree structure for pruning those groups of segments that are far away from **q**.

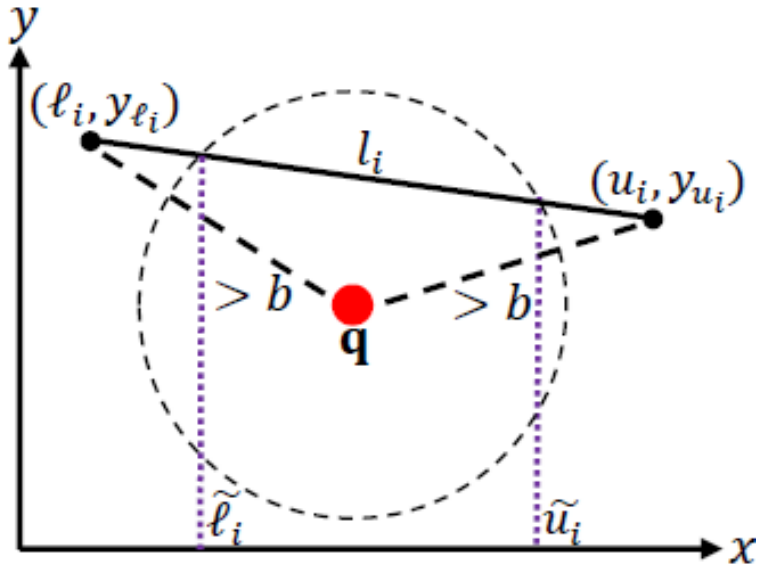


# Weakness of R-tree

- The efficiency performance of R-tree can be significantly degraded if those line segments are long. ☹




- Cannot efficiently process those line segments that are close to the pixel **q** (Can only handle **easy cases**). ☹



# Our Contributions

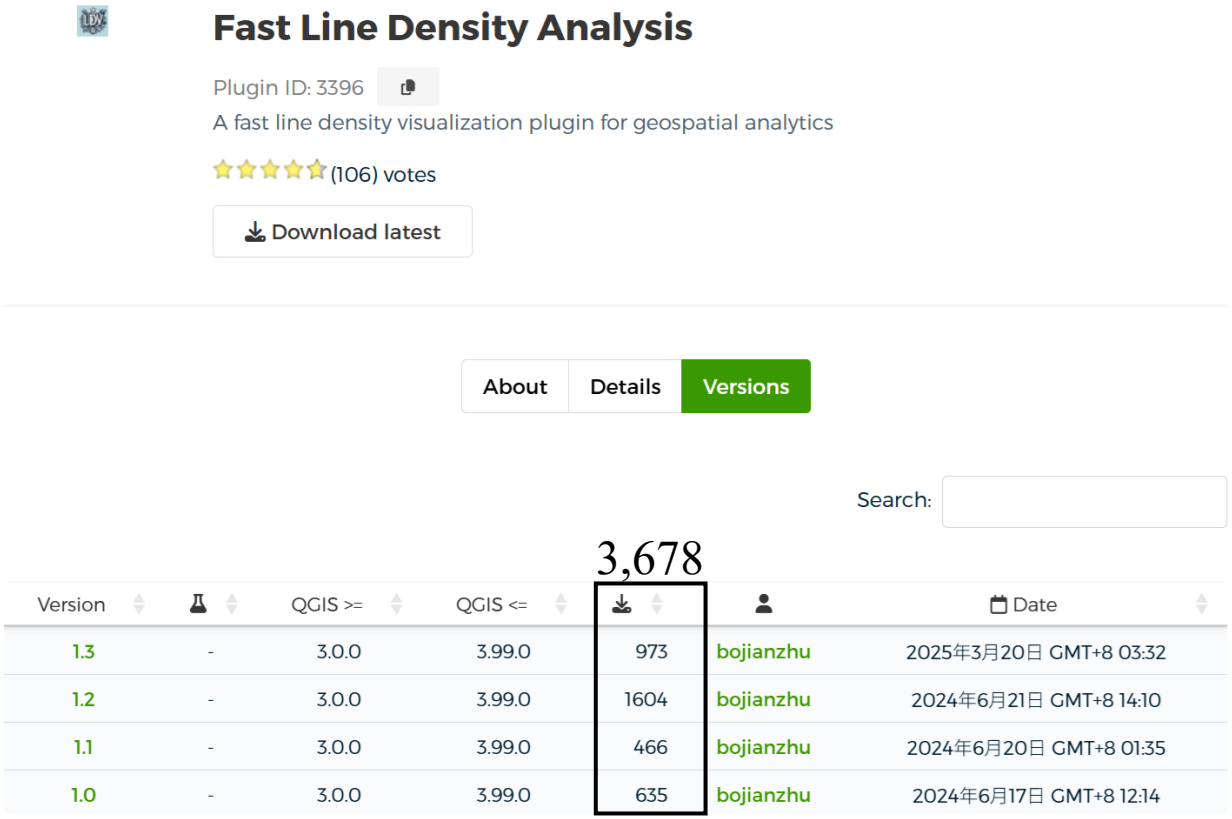
- Develop an approximate solution, called LARGE, which can efficiently handle those line segments that are close to the pixel **q** (**hard cases**), with a non-trivial relative error guarantee. ☺

- Can combine with the R-tree structure (**kill both easy and hard cases**). ☺

- Can achieve up to 291.8x speedups compared with the state-of-the-art solutions. ☺

# Our Contributions

- Develop a QGIS plugin, called Fast Line Density Analysis (based on LARGE), which is available online now.

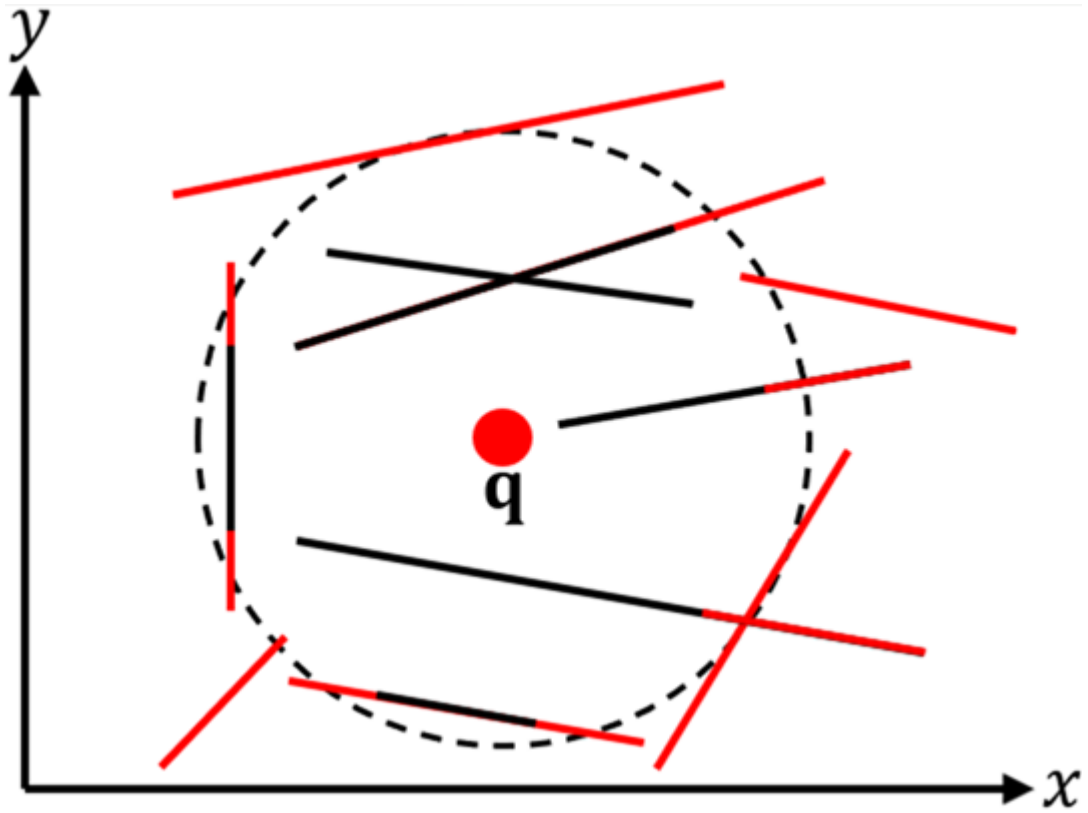



Tsz Nam Chan, Bojian Zhu, Dingming Wu, Yun Peng, Leong Hou U, Wei Tu, Ruisheng Wang: "A Fast Line Density Visualization Plugin for Geographic Information Systems" SIGMOD 2025.

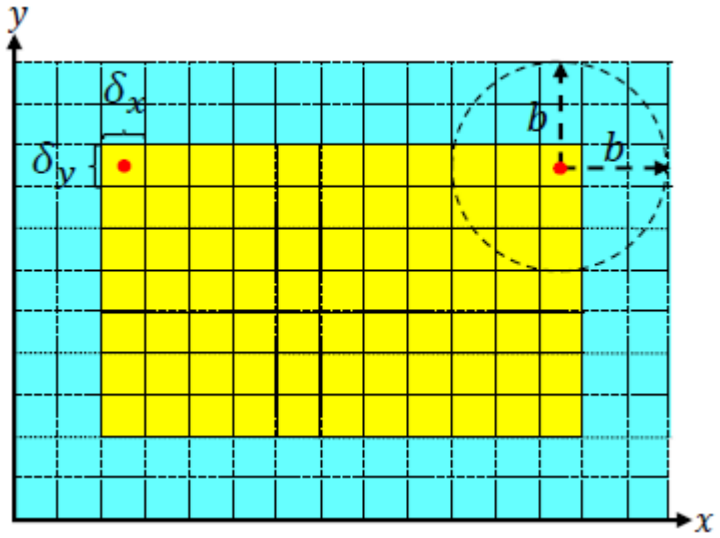
# Core Idea of Our Solution: LARGE

- Capturing the majority of density values from those line segments (with black portion) should be accurate enough.

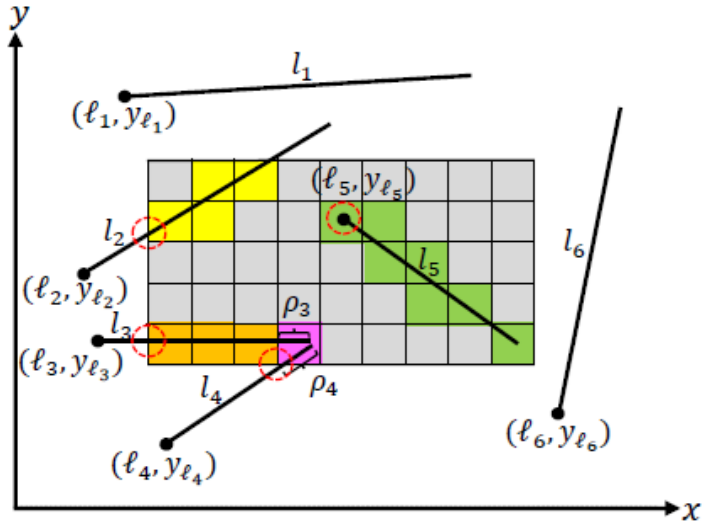
- Ignoring the red portion of each line segment should be fine.



# LARGE: Index Construction




(1) Obtain the extended region (blue + yellow) from the original (yellow) plane.




(2) Obtain the accumulated length for each grid in the extended region.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0 | 2.9 | 4.2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.5 | 0.8 | 0 | 0 | 1.6 | 0.7 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 3.1 | 3 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.6 | 5.8 | 0 |
| 5 | 5 | 5 | 9.8 | 0 | 0 | 0 | 0 | 2.7 |

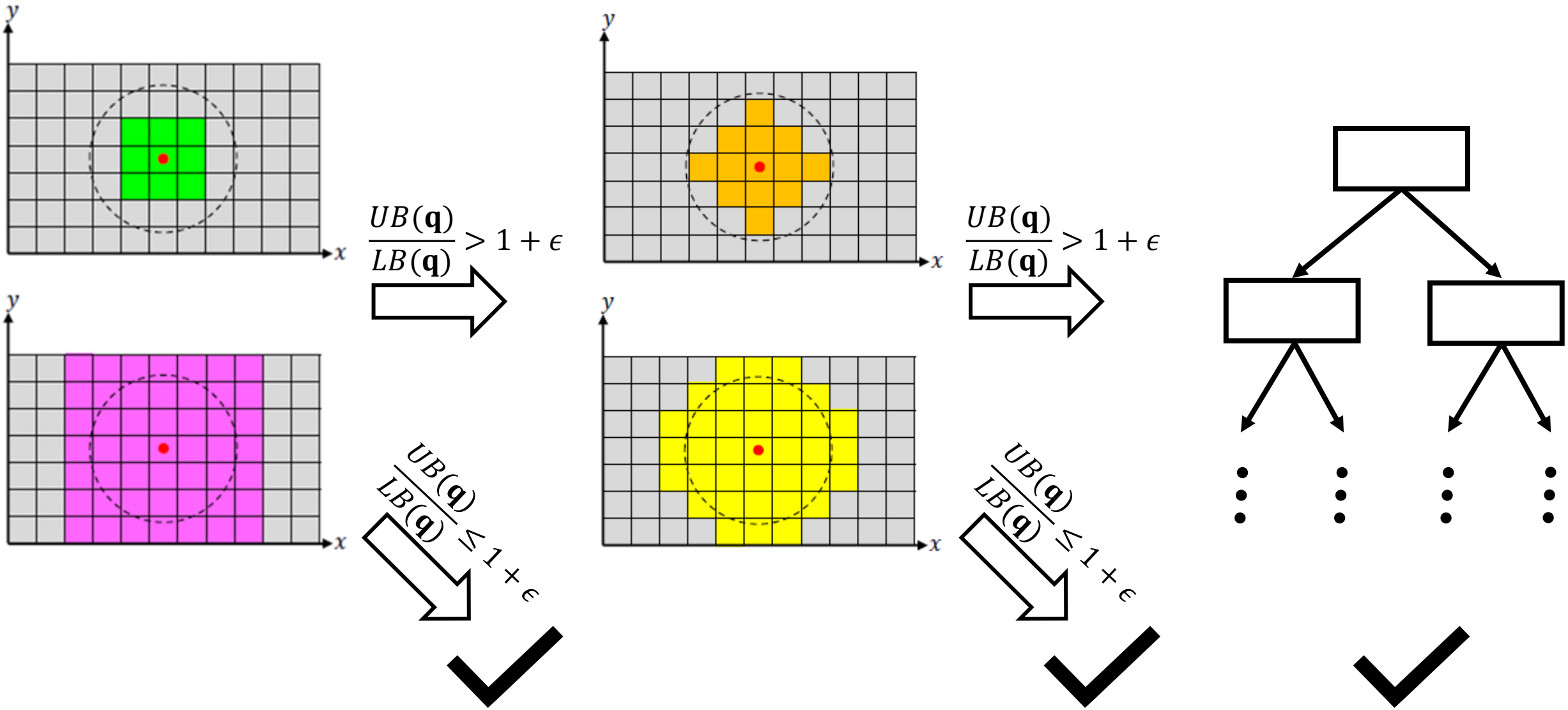
Grid structure $G$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 11.5 | 20.2 | 29.4 | 39.2 | 40.8 | 44.6 | 48.2 | 54 | 56.7 |
| 11.5 | 17.3 | 22.3 | 32.1 | 33.7 | 37.5 | 41.1 | 46.9 | 49.6 |
| 5 | 10 | 15 | 24.8 | 24.8 | 27.9 | 31.5 | 37.3 | 40 |
| 5 | 10 | 15 | 24.8 | 24.8 | 24.8 | 25.4 | 31.2 | 33.9 |
| 5 | 10 | 15 | 24.8 | 24.8 | 24.8 | 24.8 | 24.8 | 27.5 |

Prefix-sum grid structure $PG$

(3) Construct $PG$ for $G$.

# LARGE: Bound-Computation-based Solution



# Future Directions

- Can we develop tighter bound functions?
- Can we extend the idea of LARGE to support other GIS tools (e.g., K-function with flow dataset)?
- Can we support Network Line Density Visualization (NLDV)?
- Can we integrate LARGE into other GIS systems (including ArcGIS and SuperMap)?