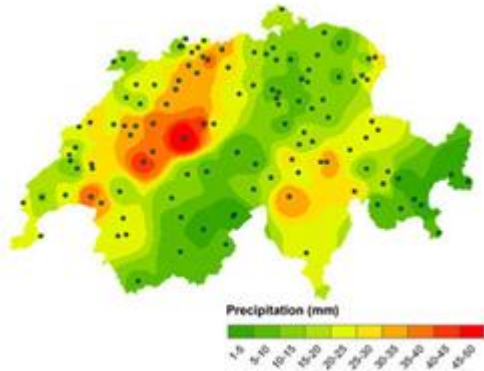


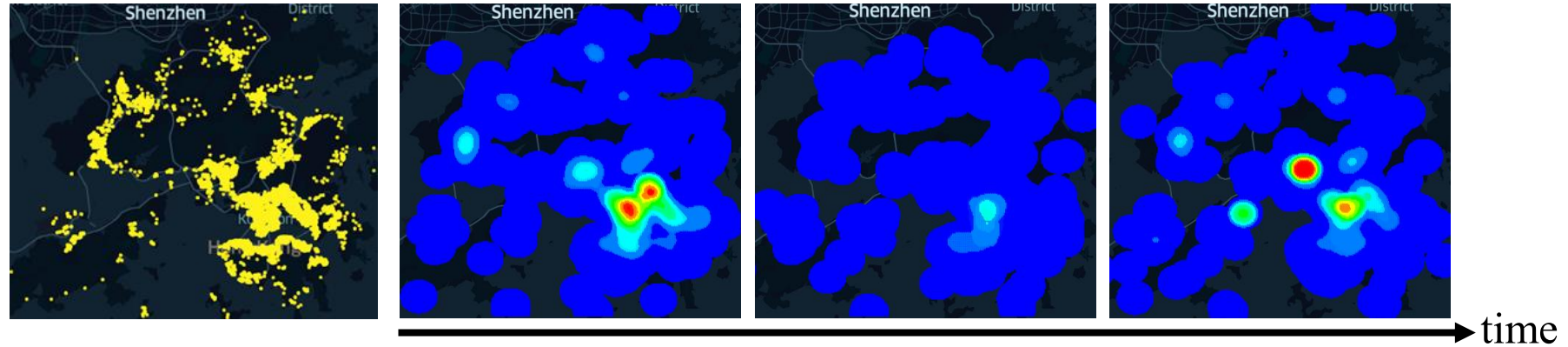
Complexity-Reduced Algorithms and Software Packages for Spatiotemporal Analysis

(Edison) Tsz Nam Chan
Shenzhen University

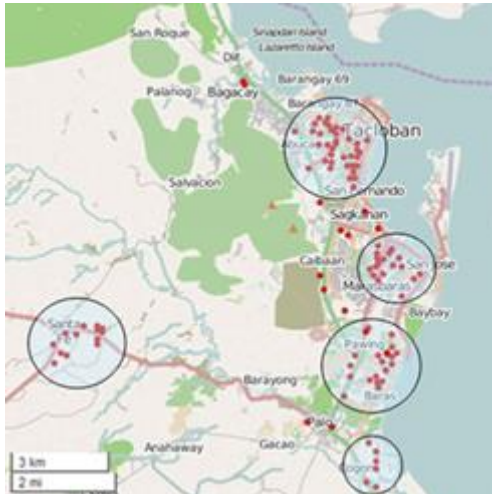
What is Spatiotemporal Analysis?



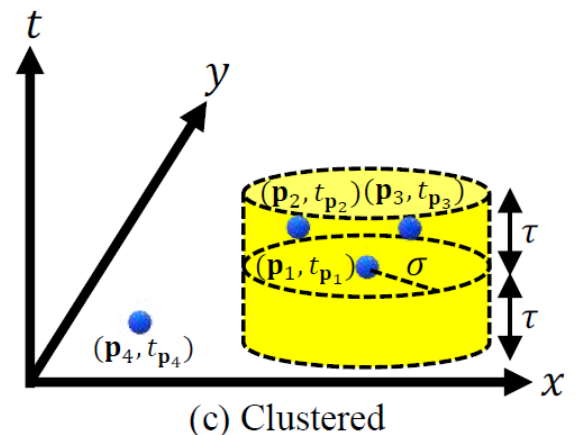
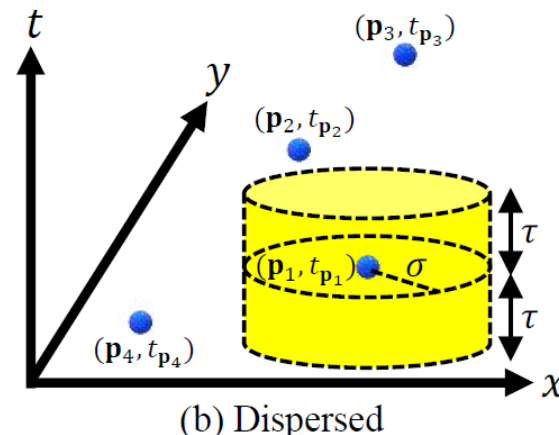
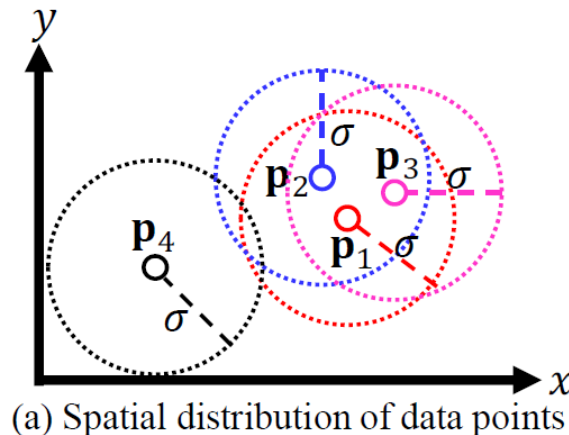
Spatial interpolation



Spatiotemporal hotspot detection



Point clustering



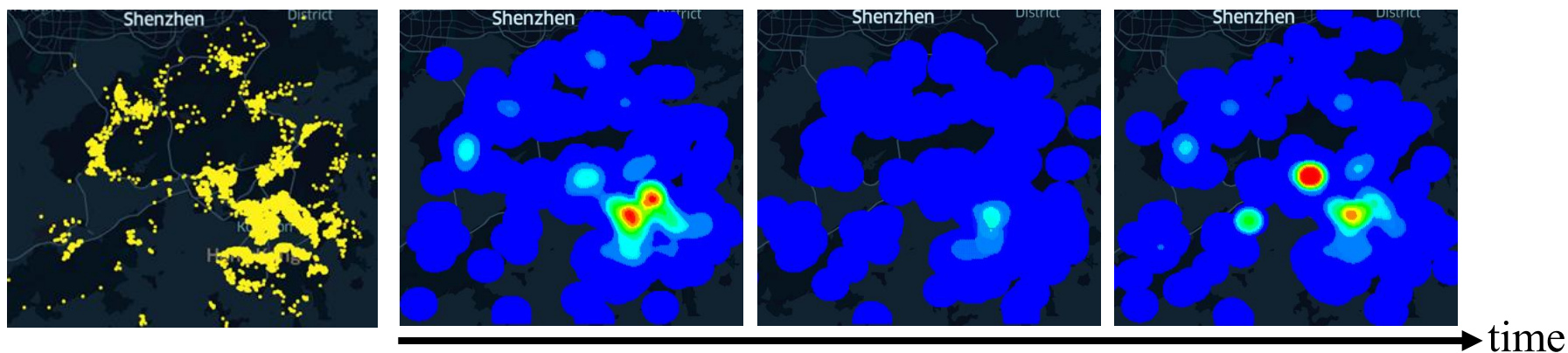
Spatiotemporal K-function

Why Spatiotemporal Analysis?

- Discover some meaningful hidden patterns from a location dataset.
- Fundamental tools for GIS domain experts/users.
- Never expire in the AI age. 😊
 - Cannot explain the results by many deep learning models. 😞
 - High explainability with spatiotemporal analysis tools. 😊
- This is a foundation. AI can assist for choosing the correct tools for analysis.

Spatiotemporal Analysis is Slow!

- Many spatiotemporal analysis tools take at least quadratic time complexities.
- Example (Hotspot detection based on spatiotemporal kernel density visualization)
 - Resolution $X \times Y = 1280 \times 960$
 - Timestamps $T = 32$
 - Number of data points $n = 1000000$
 - Time cost is $XYTn = 39.3216$ trillion ☹️



Spatiotemporal Analysis is Slow!

- Many software packages are based on naïve solutions.
 - Cannot be scalable to million-scale datasets.
 - Cannot feasibly support real-time applications (even for small-scale datasets).



ArcGIS



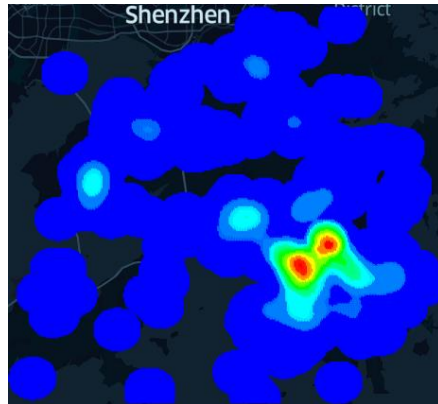
MapGIS

Fast solution and software are needed for each spatiotemporal analysis tool.

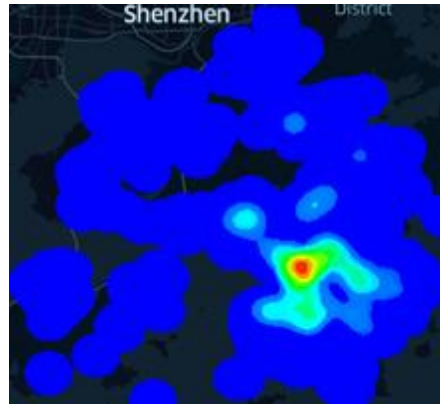
How to Improve the Efficiency of Spatiotemporal Analysis Tools?

1. Formulate each spatiotemporal analysis tool as a query processing (computational) problem.
2. Understand some mathematical properties of this problem.
3. Design data structures and algorithms for this problem and implement them.
4. Establish the software plugin and the webpage function for these implementations.

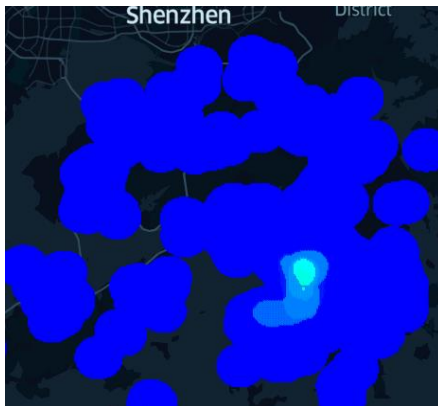
Spatiotemporal Kernel Density Visualization (STKDV)



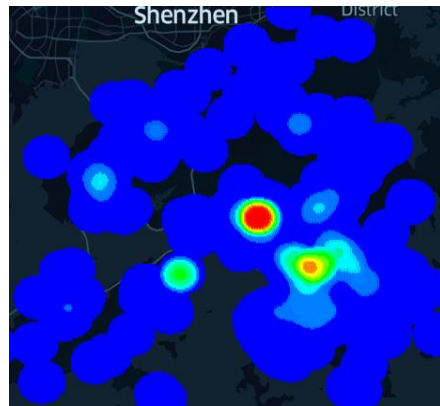
2nd August 2020



6th December 2020



28th February 2021



28th January 2022

- Consider a location dataset $\hat{P} = \{(\mathbf{p}_1, t_{\mathbf{p}_1}), (\mathbf{p}_2, t_{\mathbf{p}_2}), \dots, (\mathbf{p}_n, t_{\mathbf{p}_n})\}$ with size n .
- Color each pixel \mathbf{q} with the timestamp t_i based on the spatiotemporal kernel density function $\mathcal{F}_{\hat{P}}(\mathbf{q}, t_i)$.

$$\mathcal{F}_{\hat{P}}(\mathbf{q}, t_i) = \sum_{(\mathbf{p}, t_{\mathbf{p}}) \in \hat{P}} w \cdot K_{\text{space}}^{(b_{\sigma})}(\mathbf{q}, \mathbf{p}) \cdot K_{\text{time}}^{(b_{\tau})}(t_i, t_{\mathbf{p}})$$

Spatiotemporal Kernel Density Visualization (STKDV)

- Some representative spatial and temporal kernel functions that are used in the spatiotemporal kernel density function $\mathcal{F}_{\hat{P}}(\mathbf{q}, t_i)$.

$$\mathcal{F}_{\hat{P}}(\mathbf{q}, t_i) = \sum_{(\mathbf{p}, t_{\mathbf{p}}) \in \hat{P}} w \cdot K_{\text{space}}^{(b_{\sigma})}(\mathbf{q}, \mathbf{p}) \cdot K_{\text{time}}^{(b_{\tau})}(t_i, t_{\mathbf{p}})$$

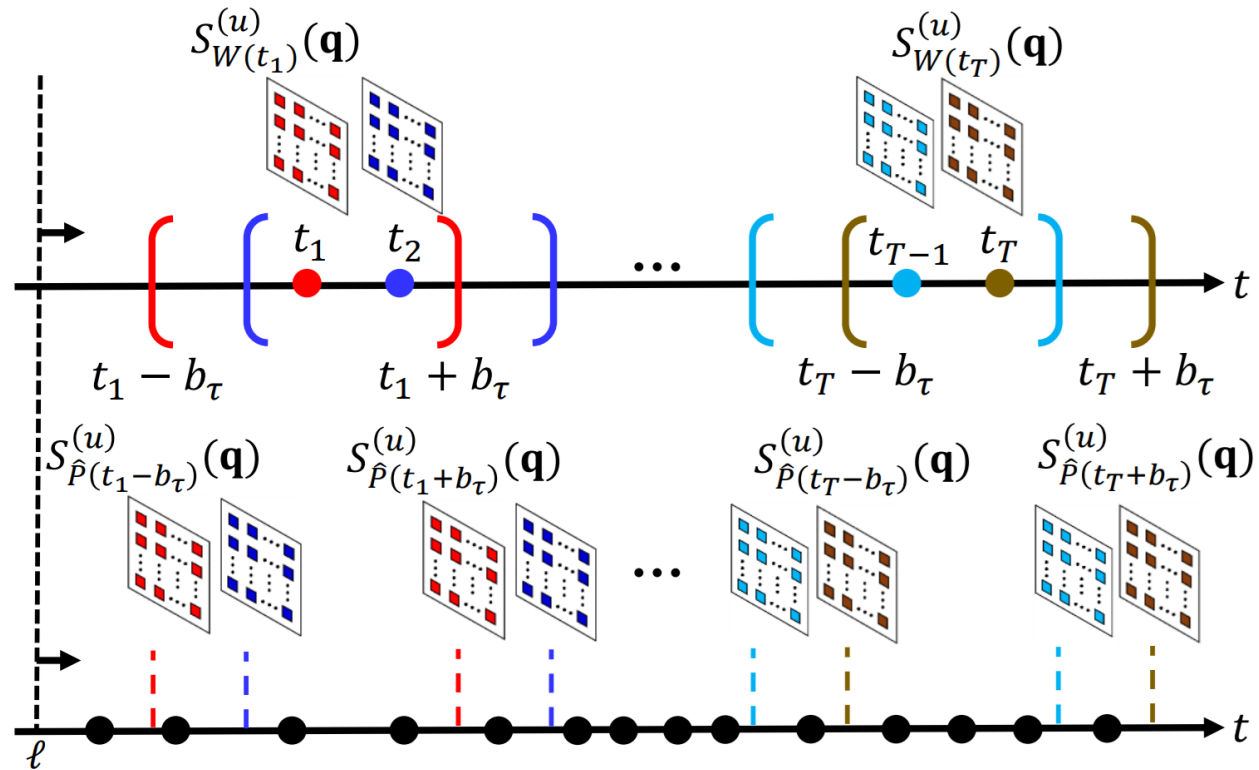
Kernel	$K_{\text{space}}^{(b_{\sigma})}(\mathbf{q}, \mathbf{p})$	$K_{\text{time}}^{(b_{\tau})}(t_i, t_{\mathbf{p}})$
Uniform	$\begin{cases} \frac{1}{b_{\sigma}} & \text{if } \text{dist}(\mathbf{q}, \mathbf{p}) \leq b_{\sigma} \\ 0 & \text{otherwise} \end{cases}$	$\begin{cases} \frac{1}{b_{\tau}} & \text{if } \text{dist}(t_i, t_{\mathbf{p}}) \leq b_{\tau} \\ 0 & \text{otherwise} \end{cases}$
Epanechnikov	$\begin{cases} 1 - \frac{1}{b_{\sigma}^2} \text{dist}(\mathbf{q}, \mathbf{p})^2 & \text{if } \text{dist}(\mathbf{q}, \mathbf{p}) \leq b_{\sigma} \\ 0 & \text{otherwise} \end{cases}$	$\begin{cases} 1 - \frac{1}{b_{\tau}^2} \text{dist}(t_i, t_{\mathbf{p}})^2 & \text{if } \text{dist}(t_i, t_{\mathbf{p}}) \leq b_{\tau} \\ 0 & \text{otherwise} \end{cases}$
Quartic	$\begin{cases} (1 - \frac{1}{b_{\sigma}^2} \text{dist}(\mathbf{q}, \mathbf{p})^2)^2 & \text{if } \text{dist}(\mathbf{q}, \mathbf{p}) \leq b_{\sigma} \\ 0 & \text{otherwise} \end{cases}$	$\begin{cases} (1 - \frac{1}{b_{\tau}^2} \text{dist}(t_i, t_{\mathbf{p}})^2)^2 & \text{if } \text{dist}(t_i, t_{\mathbf{p}}) \leq b_{\tau} \\ 0 & \text{otherwise} \end{cases}$

Spatiotemporal Kernel Density Visualization (STKDV)

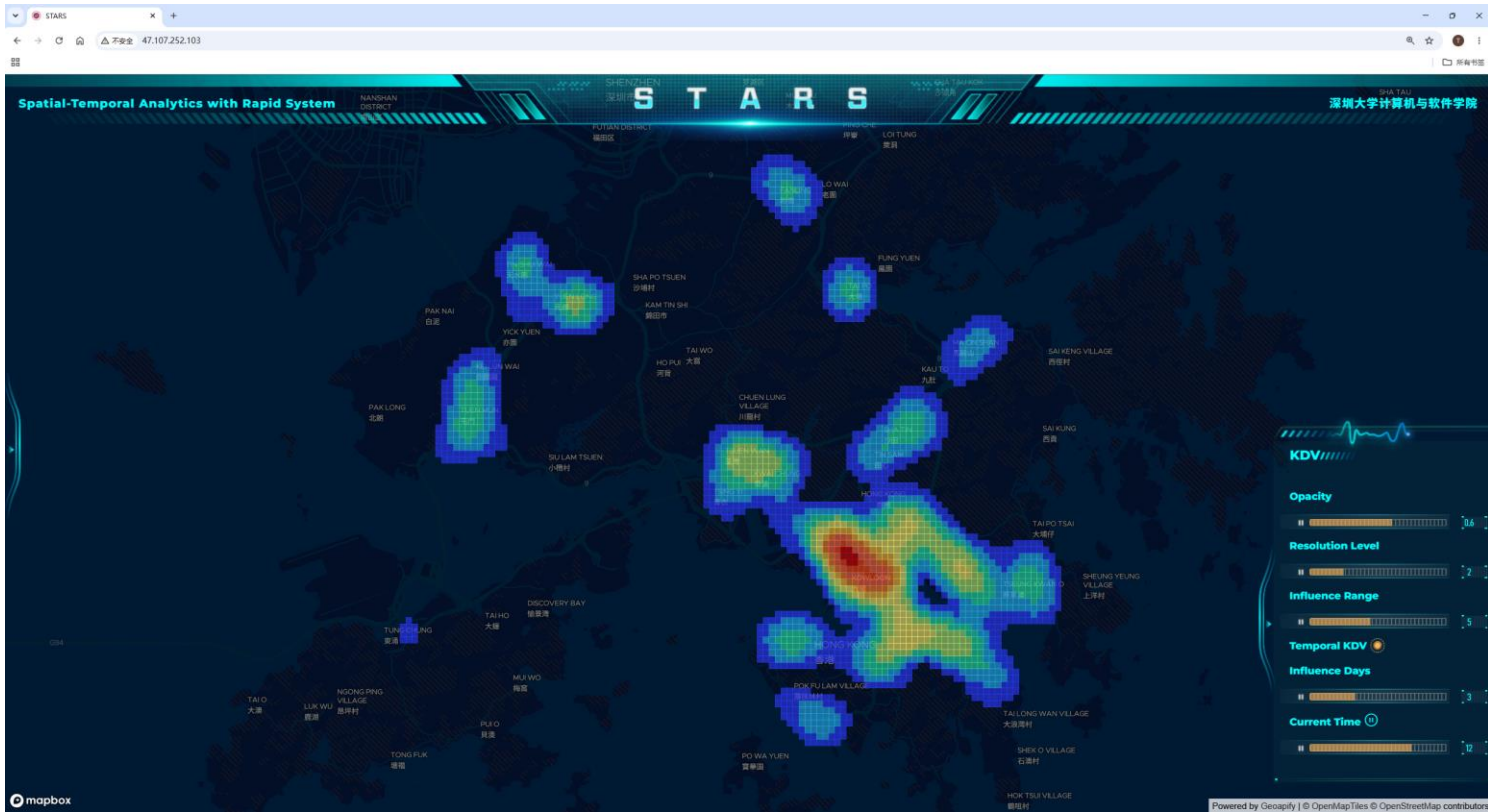
- Decompose $\mathcal{F}_{\hat{p}}(\mathbf{q}, t_i)$ based on linear algebra operations, which represents it based on $S_{W(t_i)}^{(u)}(\mathbf{q})$, where

$$S_{W(t_i)}^{(u)}(\mathbf{q}) = \sum_{(\mathbf{p}, t_p) \in W(t_i)} t_p^u \cdot K_{\text{space}}^{(b_\sigma)}(\mathbf{q}, \mathbf{p})$$

- The time complexity is reduced to $O(XY(T + n))$. 😊

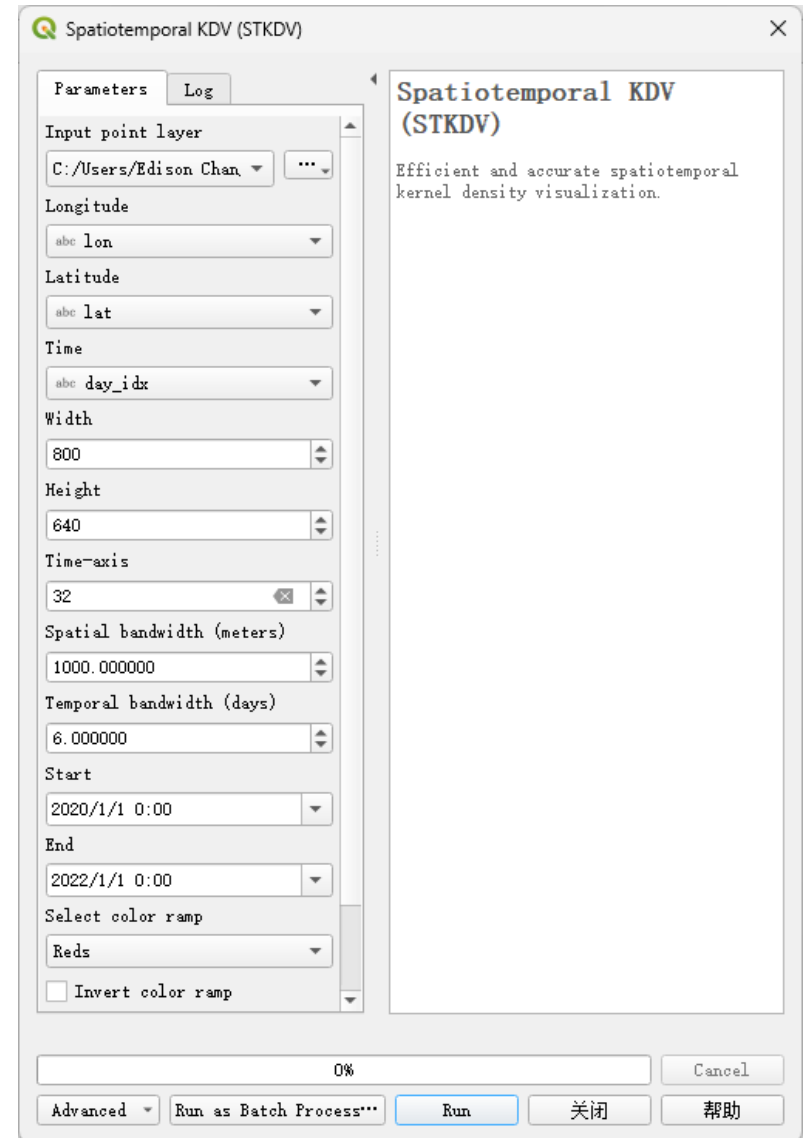


Spatiotemporal Kernel Density Visualization (STKDV)



Spatiotemporal Analysis with Rapid System (STARS)

<http://47.107.252.103/>



QGIS plugin: Fast Density Analysis

Our Software Package: Fast Density Analysis



Fast Density Analysis

Plugin ID: 3025

A fast kernel density visualization plugin for geospatial analytics

★★★★★ (134) votes

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Version		QGIS >=	QGIS <=			Date
2.1	-	3.0.0	3.99.0	808	bojianzhu	2026年5月11日 GMT+8 00:48
2.0	-	3.0.0	3.99.0	2663	bojianzhu	2025年12月14日 GMT+8 01:47
1.7	-	3.0.0	3.99.0	4477	bojianzhu	2025年5月30日 GMT+8 11:42
1.6	-	3.0.0	3.99.0	13273	bojianzhu	2023年7月12日 GMT+8 15:55
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1.0	-	3.0.0	3.99.0	626	bojianzhu	2023年6月28日 GMT+8 02:24

Our Software Package: Fast Line Density Analysis



Fast Line Density Analysis

Plugin ID: 3396

A fast line density visualization plugin for geospatial analytics

★★★★★ (112) votes

Download latest

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1.2	-	3.0.0	3.99.0	1694	bojianzhu	2024年6月21日 GMT+8 14:10
1.1	-	3.0.0	3.99.0	564	bojianzhu	2024年6月20日 GMT+8 01:35
1.0	-	3.0.0	3.99.0	755	bojianzhu	2024年6月17日 GMT+8 12:14

Future Work

- Develop complexity-reduced algorithms for other spatiotemporal analysis tools.
 - Inverse distance weighting (IDW)
 - Kriging
 - DBSCAN clustering
- Integrate all these algorithms into a unified QGIS/ArcGIS plugin and the web-based system STARS.
- Advertise this plugin and STARS.
- Write a book (in Springer Nature) about this topic.

Our New Book

Tsz Nam Chan · Dingming Wu
Mastering the Academic Writing Mindset
A Guide to Crafting Computer Science Papers

In the undergraduate study of computer science, a lecturer only teaches some things that are in the literature (most likely in an open access textbook). Those knowledges may have been discovered before in several decades ago. A student is deemed to be good if they have perfectly finished assignments and have prepared well for their examinations. As an example, those students can easily get high grades for all fundamental courses (e.g., programming courses, linear algebra, probability and statistics, data structures, and design and analysis of algorithms) if they have worked extremely hard for the exercises that are provided in those open access textbooks or in class. Therefore, the undergraduate students do not need to have creativity (e.g., establish new knowledges) for obtaining an undergraduate degree. All they need to do is to consolidate their foundation. However, the most critical transition from undergraduate study to postgraduate study is to create new knowledges, which advance the state of the art in the computer science field. Moreover, postgraduate students need to write papers in a logical way (by telling a great story) so that other reviewers can accept them. In order to accomplish these two tasks, students need to change their mindsets for adapting to this new environment. In this book, we discuss this main theme in detail for analyzing the common mistakes that are easily made by new students and show the correct methodology for reading/writing papers. With this methodology, we believe that those students who are dedicated to computer science research can be very productive for publishing top-tier papers.

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Mastering the Academic Writing Mindset

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Mastering the Academic Writing Mindset

A Guide to Crafting Computer Science Papers

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