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Revealing intra-urban spatial structure through an exploratory analysis by combining road network abstraction model and taxi trajectory data

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Associate Professor **Song Gao** (University of Wisconsin-Madison)
Assistant Professor **Wei Luo** (National University of Singapore)

Profile

About Me

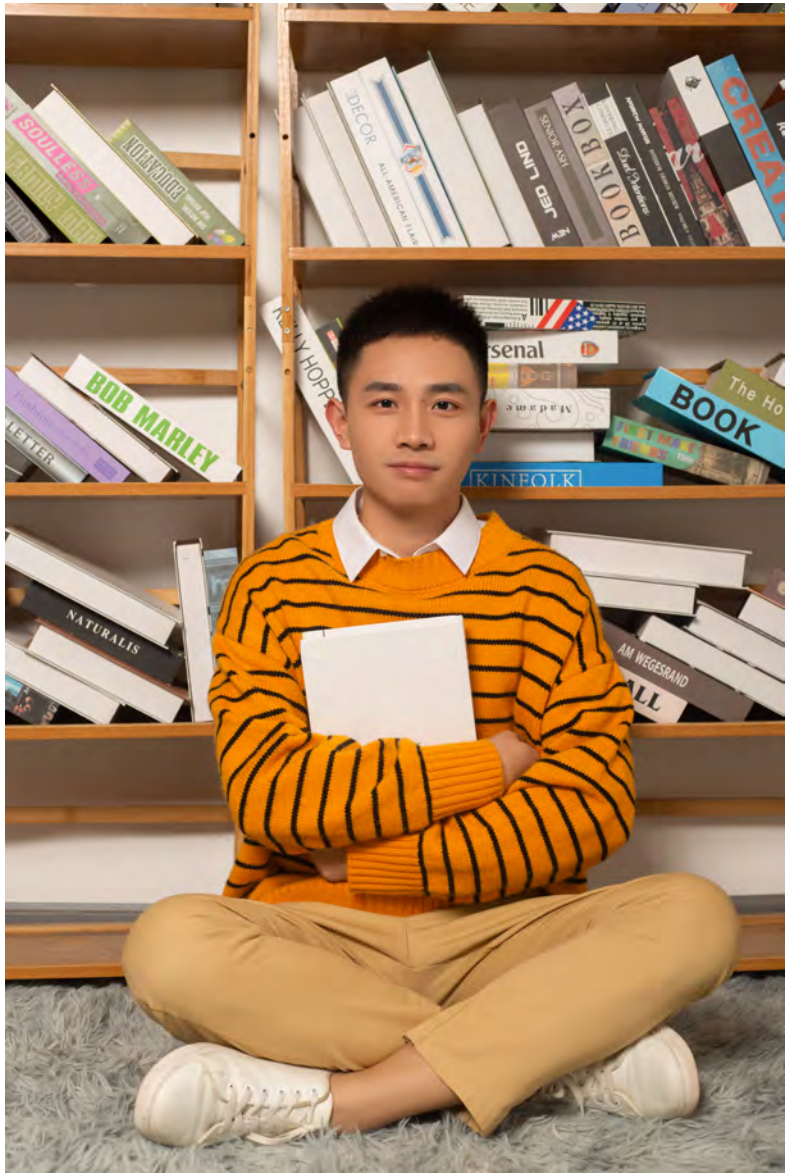
- PhD candidate at China University of Geosciences, Wuhan.
- Joint student at National University of Singapore.
- An enthusiastic GISer and AI fan🤔.

Research Interest

- The analysis of urban functional regions using multisource geographic data.
- Research issues: uncertainty of division scales, functional heterogeneity and regional interaction patterns.

Publications

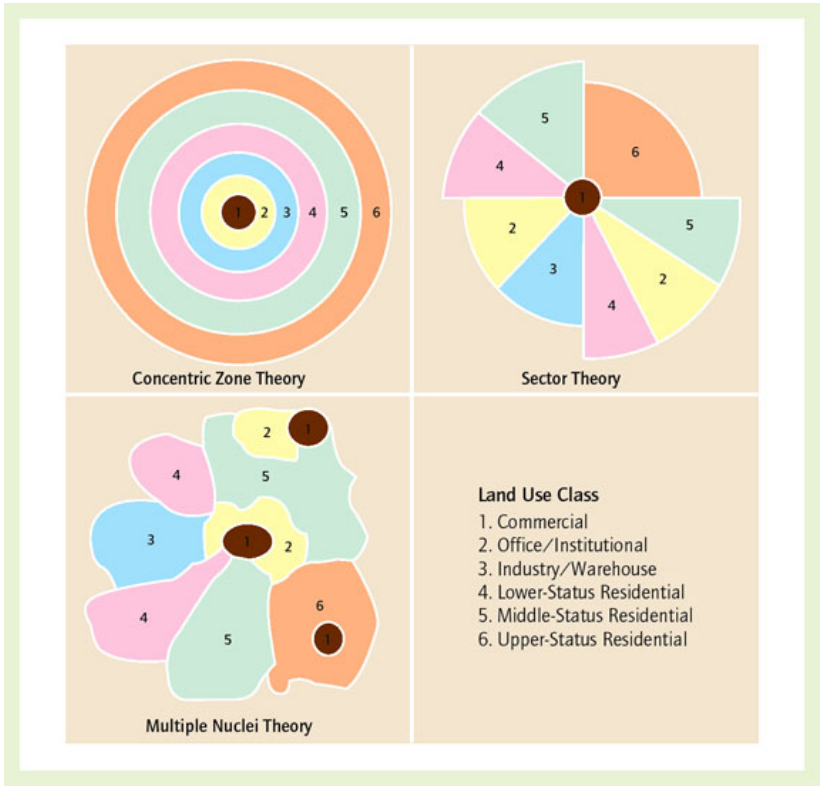
- **Hu, S.**, Gao, S., Wu, L., et al. (2021). Urban function classification at road segment level using taxi trajectory data: A graph convolutional neural network approach. Computers, Environment and Urban Systems, 87, 101619.
- **Hu, S.**, Xu, Y., Wu, L., et al. (2021). A framework to detect and understand thematic places of a city using geospatial data. Cities, 109, 103012.
- **Hu, S.**, He, Z., Wu, L., et al. (2020). A framework for extracting urban functional regions based on multiprototype word embeddings using points-of-interest data. Computers, Environment and Urban Systems, 80, 101442.



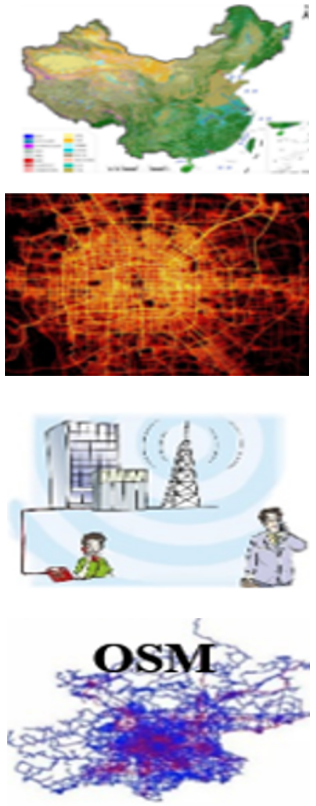
Introduction

Urban Sprawl

Inefficient use of land resources



Urban spatial structure



Geo big data

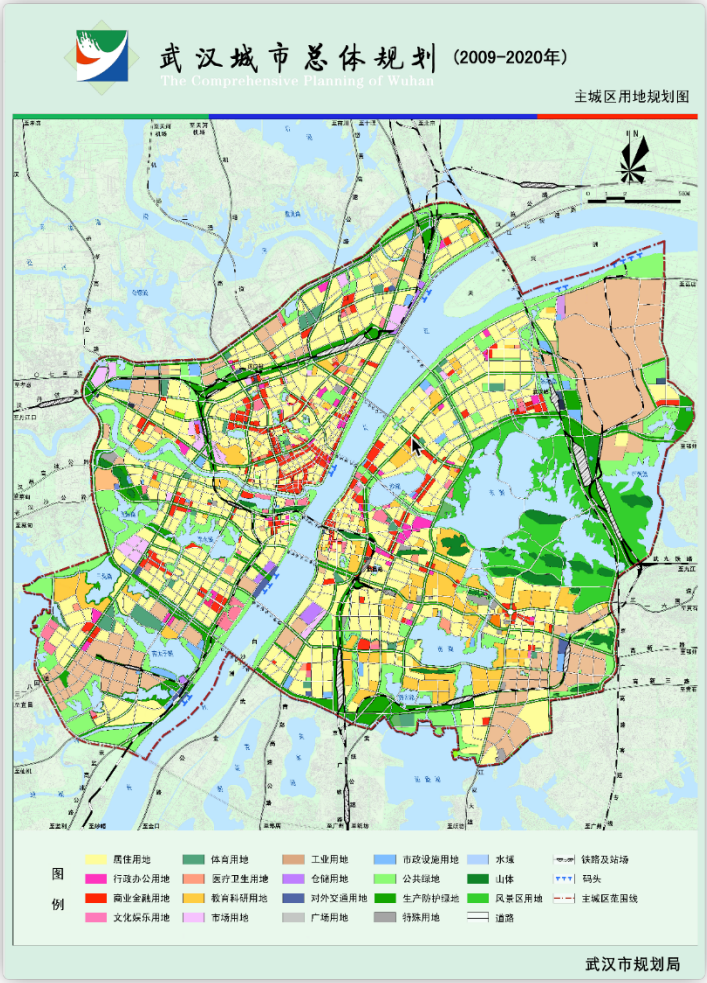
Jaeger, Jochen AG, et al. "Urban permeation of landscapes and sprawl per capita: New measures of urban sprawl." *Ecological Indicators* 10.2 (2010): 427-441.

Chen, Mingxing, Weidong Liu, and Xiaoli Tao. "Evolution and assessment on China's urbanization 1960–2010: under-urbanization or over-urbanization?" *Habitat International* 38 (2013): 25-33.

Background

- **Urban functional regions/zones**
  - One of classic geographical analysis units
  - Carriers of various functions of the city
- **Urban planning maps**
  - Only reflect the expected goals of functional-zone construction in a certain time
  - High labor intensity and long update period

How to require urban functional information timely, accurately, and efficiently?

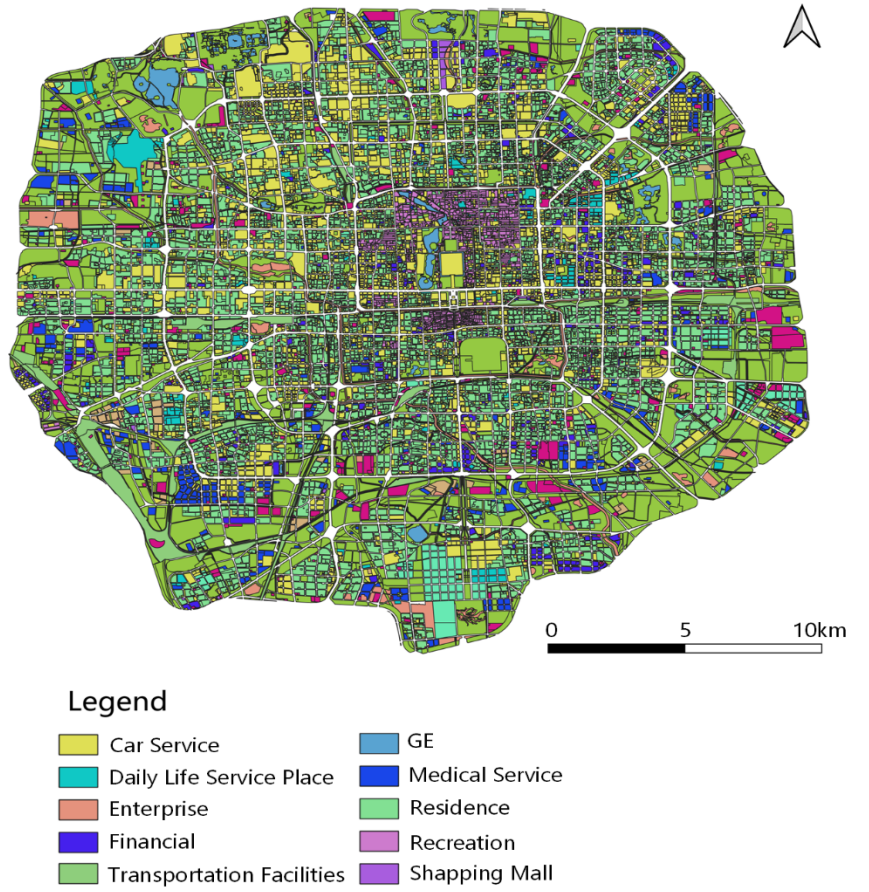


An example of urban planning in Wuhan

Gao, Song, Krzysztof Janowicz, and Helen Couclelis. "Extracting urban functional regions from points of interest and human activities on location-based social networks." Transactions in GIS 21, no. 3 (2017): 446-467.

Background

- **Functional regions**
  - **Definition**: activities & structure.
  - **Approach**: journey-to-work commuting flows
  - **Objection**: interactions
  - **Regionalization**: hierarchical clustering; modularity-based network approaches

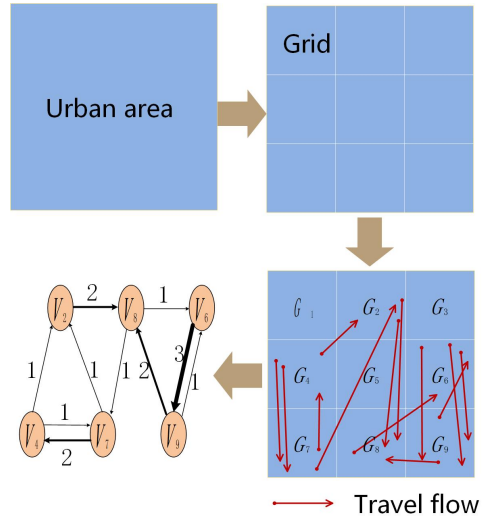


An example of urban functional regions in Beijing

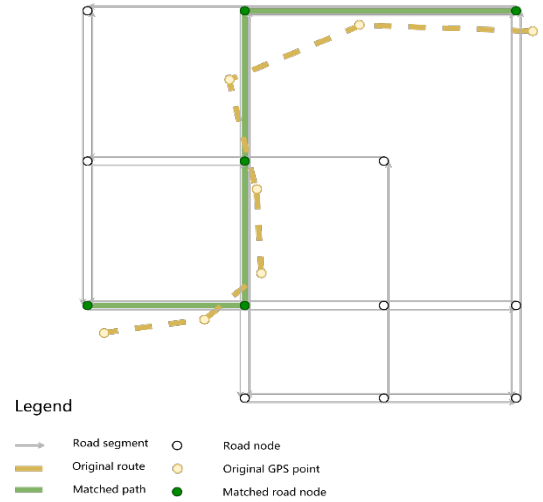
Gao, Song. Extracting Computational Representations of Place with Social Sensing. University of California, Santa Barbara, 2017.

Background

- **Spatially embedded graph/network**
  - Introduction of complex network approaches
  - Significant functional structures can be revealed



- **Urban road network abstraction model**
  - Urban road network embeds as a fine-grained graph
  - Topological structure reflects hierarchical communities



- Chen, Yu, Jun Xu, and Minzheng Xu. "Finding community structure in spatially constrained complex networks." International Journal of Geographical Information Science 29, no. 6 (2015): 889-911.
- Zhong, Chen, Stefan Müller Arisona, Xianfeng Huang, Michael Batty, and Gerhard Schmitt. "Detecting the dynamics of urban structure through spatial network analysis." International Journal of Geographical Information Science 28, no. 11 (2014): 2178-2199.

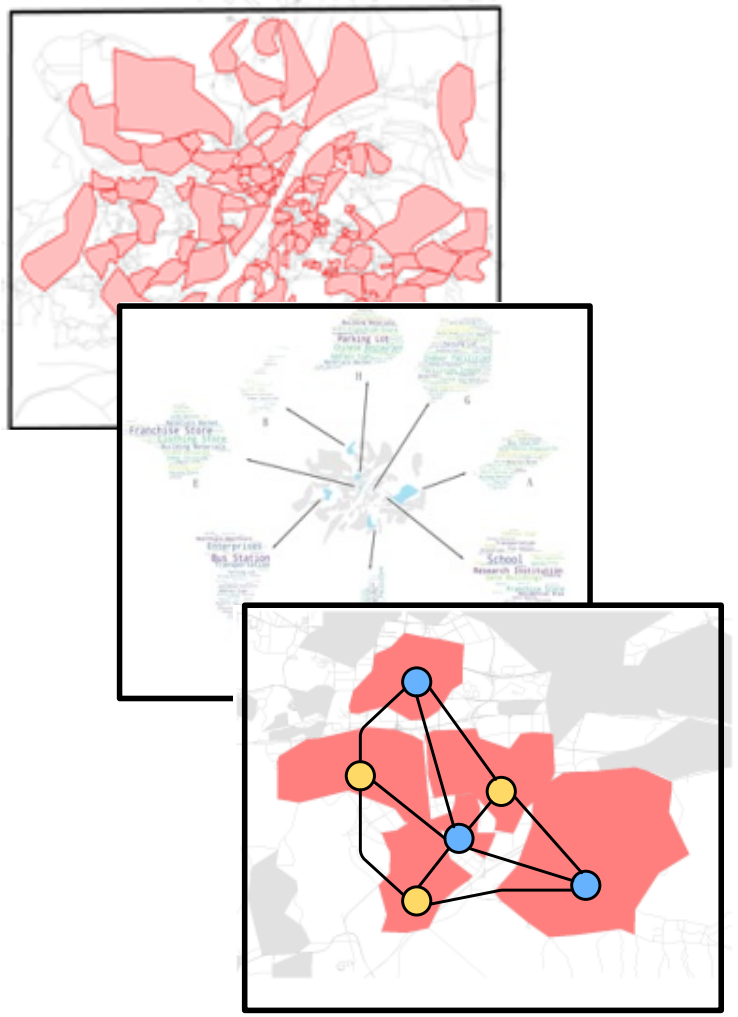
Questions

- **Abstract regional units**

  Spatially embedded graph models an entire city to explore the underlying urban spatial structure using **individual travel flows**, but the regional units are large and abstract.

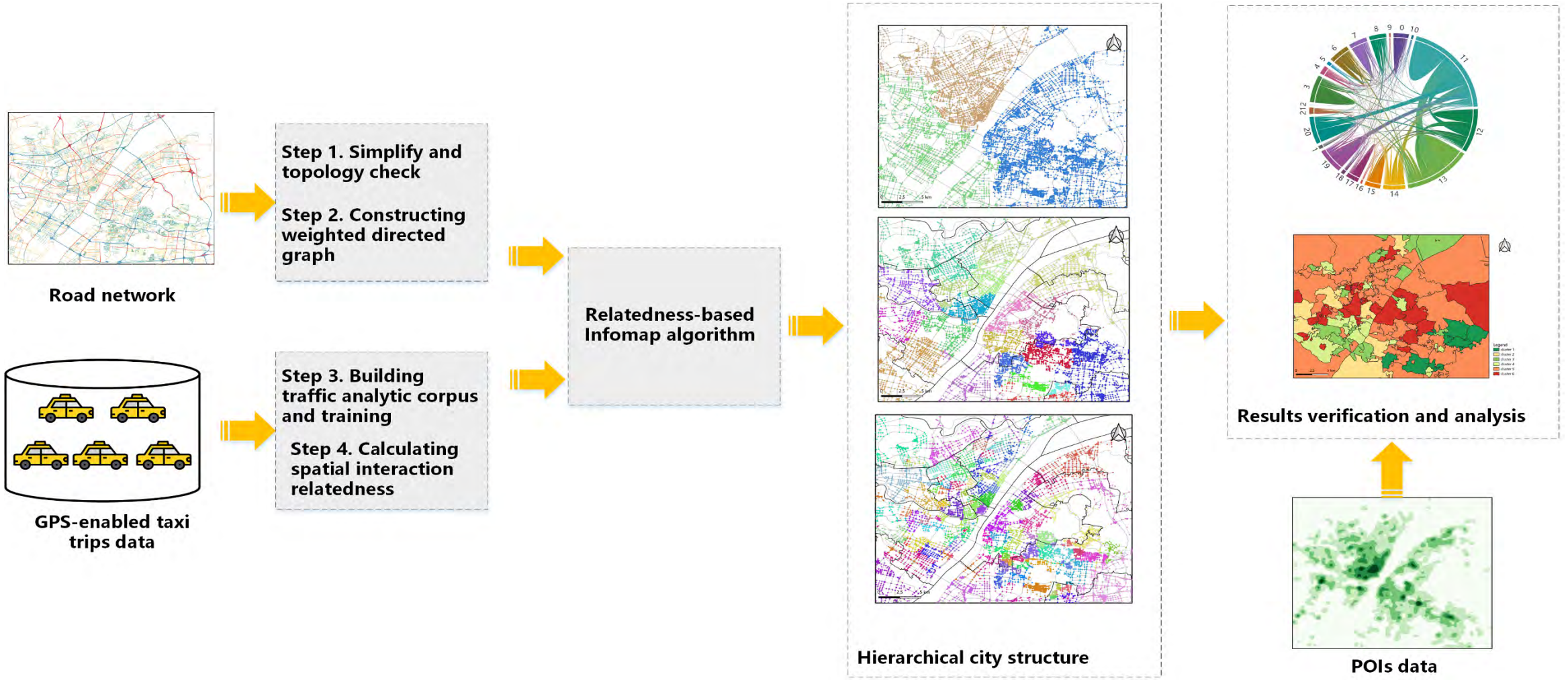
- **Integration of travel flows**

  Network abstraction model primarily focus on **the inner topology of the road network**, but do not consider the role of human movements along with the road network.



Zhu, Di, Ninghua Wang, Lun Wu, and Yu Liu. "Street as a big geo-data assembly and analysis unit in urban studies: A case study using Beijing taxi data." Applied Geography 86 (2017): 152-164.

Workflow



The flowchart of the proposed framework

Presumption

Urban Elements

- POIs
- Functions
- Trajectories
- Region

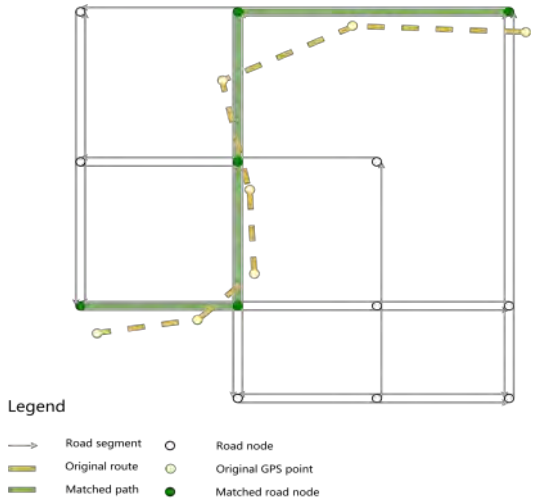
Textual materials

- Words
- Topics
- Documents
- A Coprus

- As a result, we can use the corpus to represent the study area.

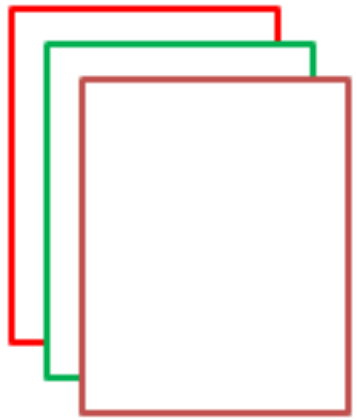
Yao, Yao, Xia Li, Xiaoping Liu, Penghua Liu, Zhaotang Liang, Jinbao Zhang, and Ke Mai. "Sensing spatial distribution of urban land use by integrating points-of-interest and Google Word2Vec model." International Journal of Geographical Information Science 31, no. 4 (2017): 825-848.

Presentation of travel flows

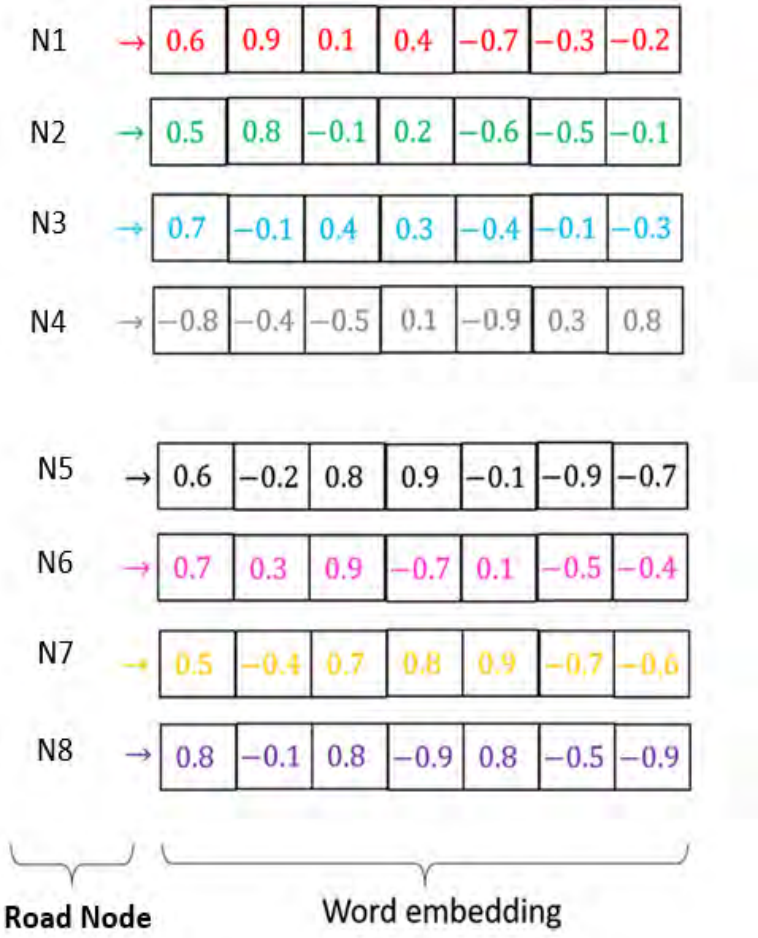


Map matching

Taxi trajectories



Functional corpus



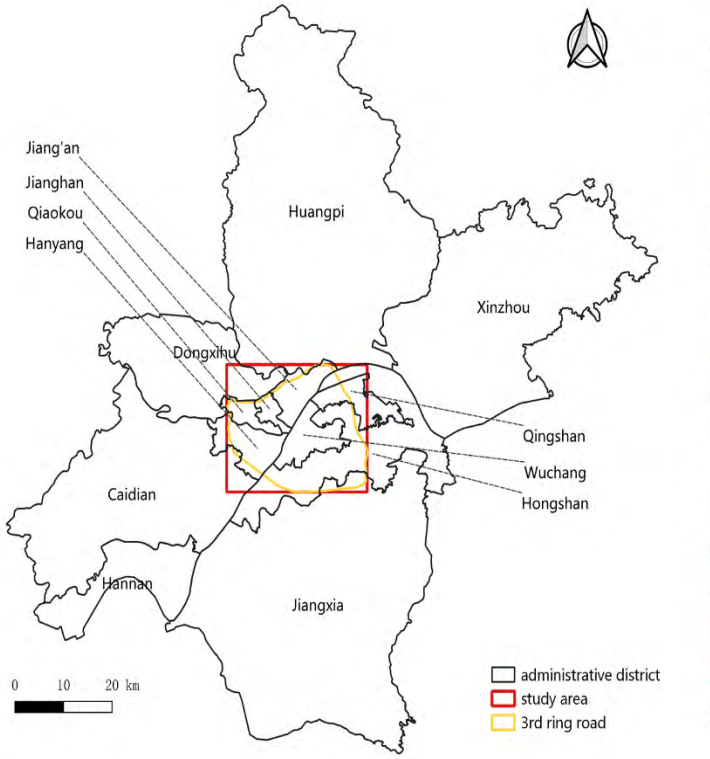
Presentation of word embedding

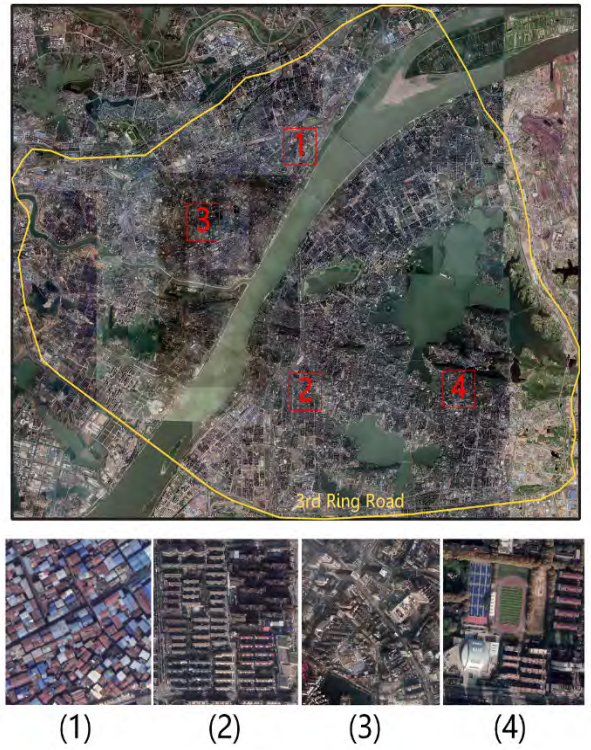
Identification of spatial structure

- **Road network abstraction model**
  - OSM road network data
  - weighted directed graph $G \equiv (V, E, W)$
- **Representing sub-region patterns with Community detection**
  - group or divide graph vertexes into a few subsets based on their interaction pattern
  - Infomap community detection algorithm

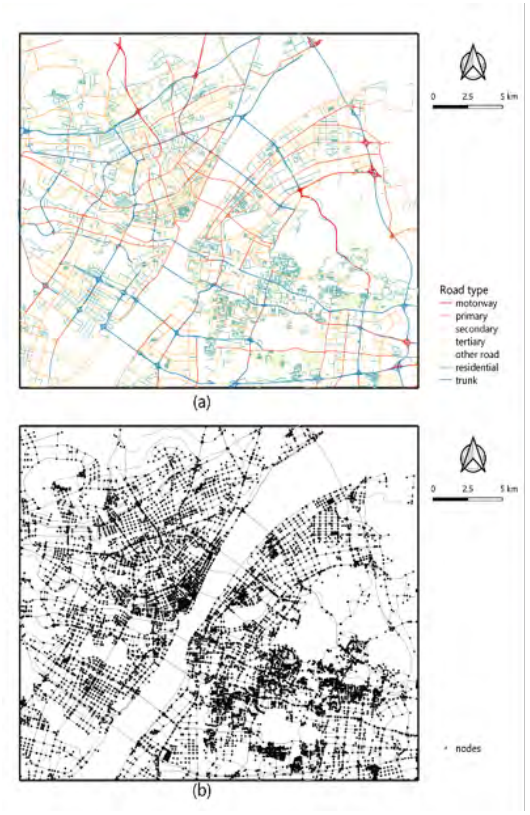
- Gao, Song, Yu Liu, Yaoli Wang, and Xiujun Ma. "Discovering spatial interaction communities from mobile phone data." Transactions in GIS 17, no. 3 (2013): 463-481.
- Hong, Ye, and Yao Yao. "Hierarchical community detection and functional area identification with OSM roads and complex graph theory." International Journal of Geographical Information Science 33, no. 8 (2019): 1569-1587.

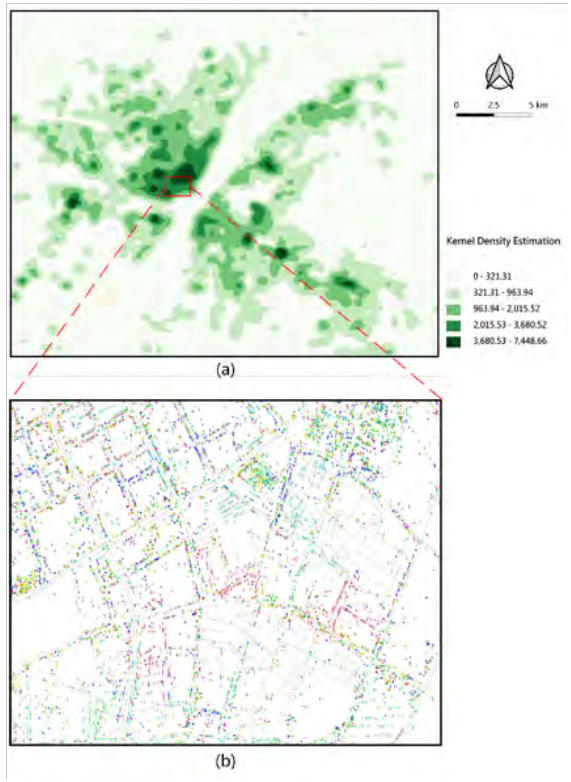
Study area and data





The study area - the main urban area of Wuhan city

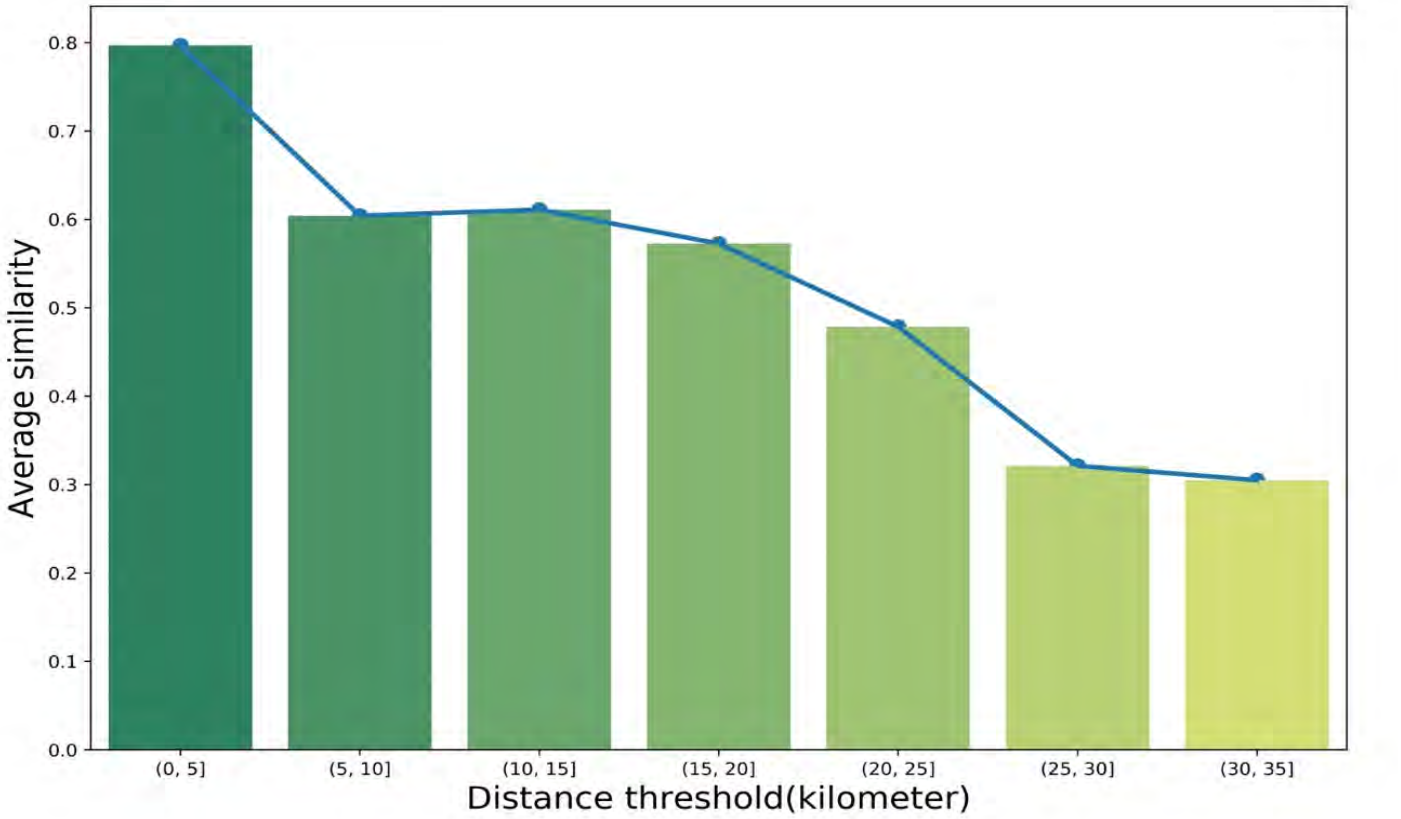




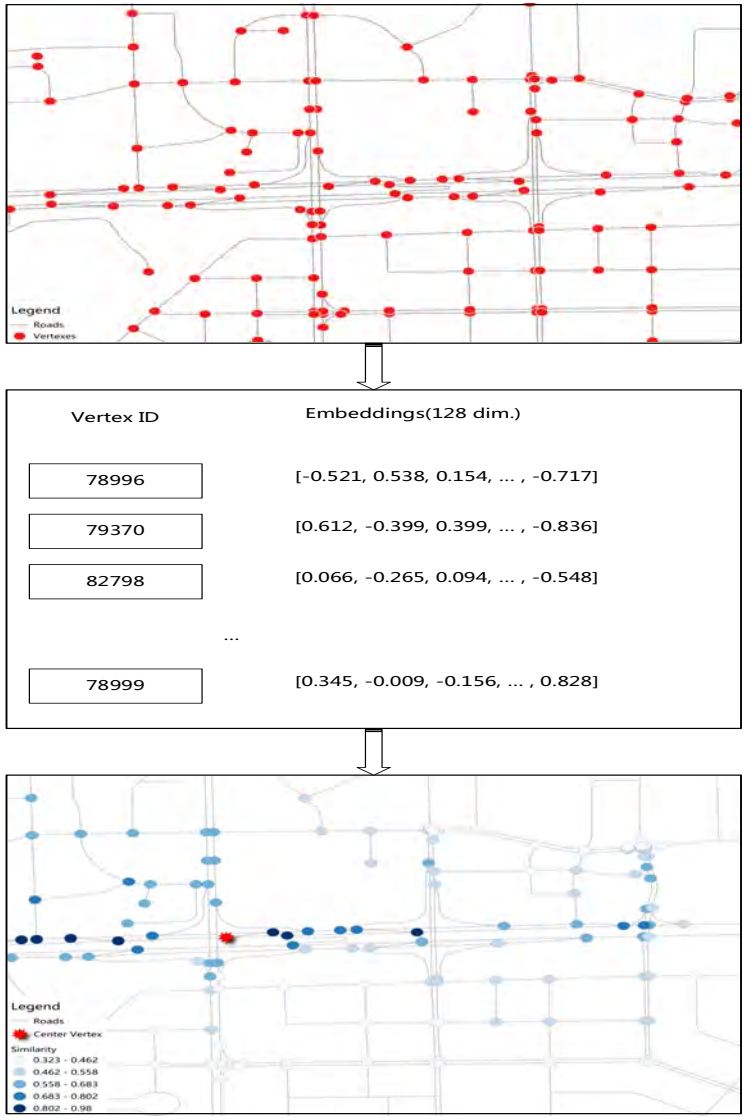
Data schema of the road network and POIs

Results

- **Spatial interaction relatedness of road nodes**



Average similarity & nodes distance



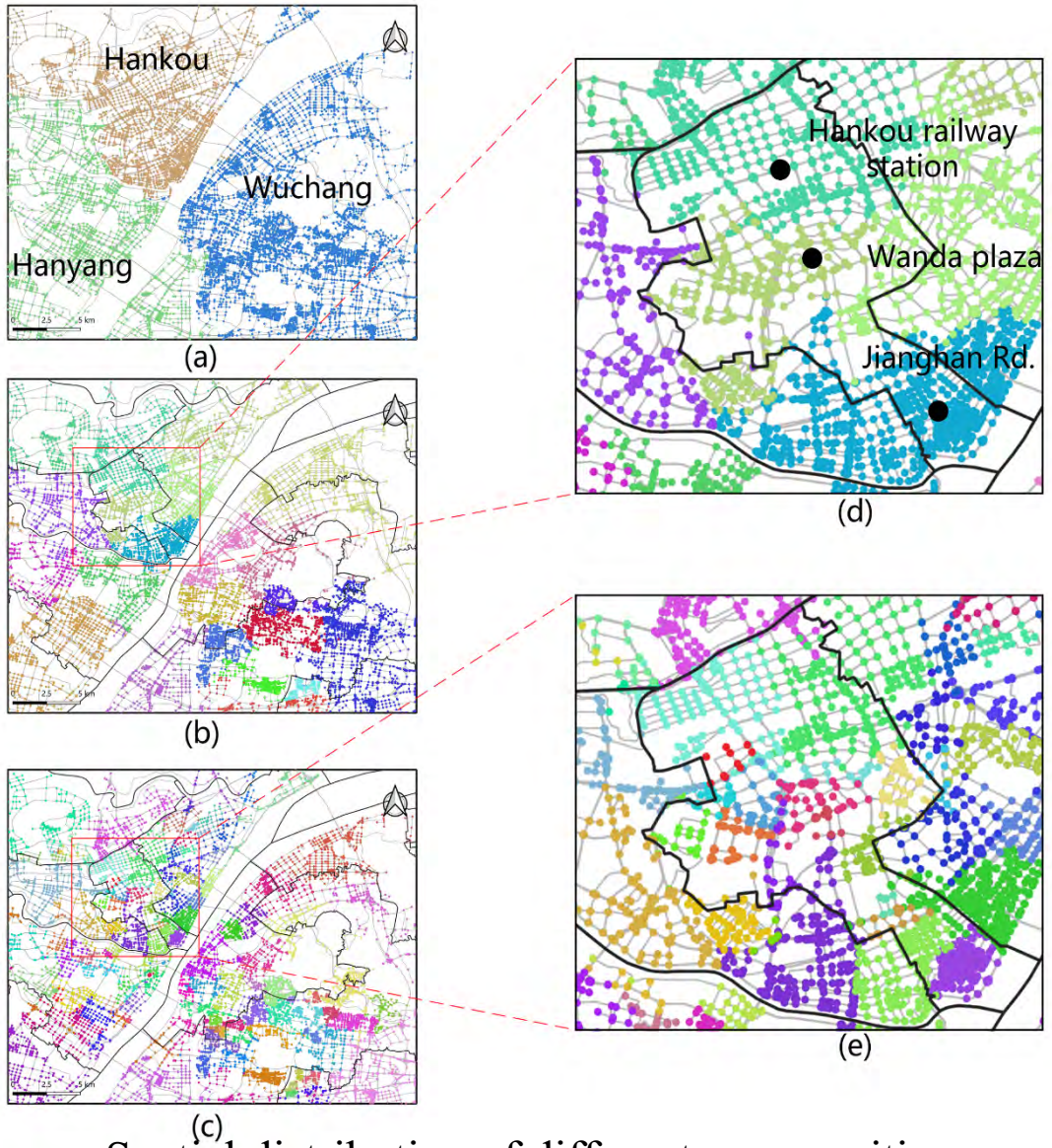
Embedding vectors in a road network graph

Results

- **Hierarchical urban spatial structure**

Different communities	Top-level	Second-level	Third-level
Total number of communities	3	22	127
Average edge weight (relatedness)	0.857	0.859	0.864

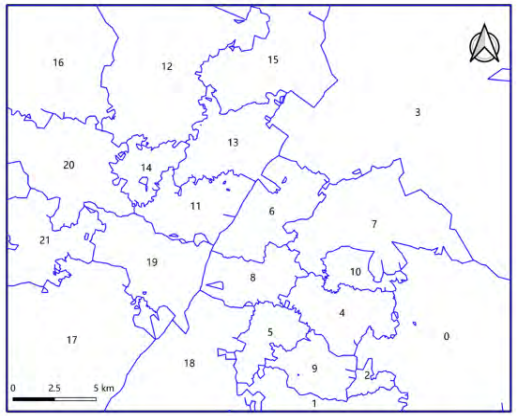
Comparison of different communities



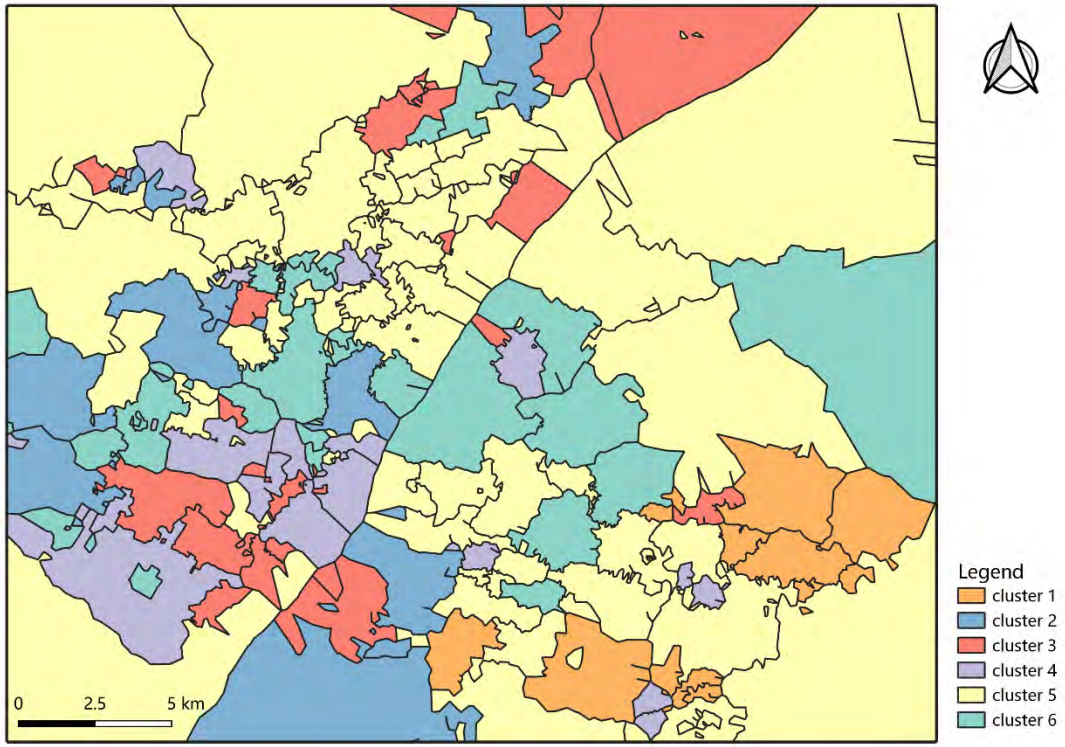
Spatial distribution of different communities

Results

- **Hierarchical urban spatial structure**



The chord diagram of traffic flows



The spatial distribution of urban functional areas

Results

- **Result verification**
  - **O-Infomap**: Original Infomap method with all weight of edges set to 1;
  - **D-Infomap**: Distance-weighted Infomap method with weight set as Euclidean length of each road segment;
  - **Our proposed method**: Relatedness-weighted Infomap method with weight set as spatial interaction relatedness between traffic nodes.

Methods	May 9, 2015	May 10, 2015	May 11, 2015	May 12, 2015	May 13, 2015	May 14, 2015	May 15, 2015
O-Infomap	0.294	0.288	0.312	0.292	0.299	0.297	0.300
D-Infomap	0.339	0.369	0.351	0.374	0.359	0.382	0.366
Proposed method	0.379	0.372	0.391	0.378	0.378	0.384	0.386

The percentage of taxi flows frequency

Methods	Number of divisions	R_i		H_i		D_i	
		Mean	Std.	Mean	Std.	Mean	Std.
O-Infomap	124	105.236	368.350	8.859	35.313	0.945	0.087
D-Infomap	147	55.508	102.843	4.014	6.694	0.953	0.036
Proposed method	127	37.417	64.454	3.156	5.614	0.956	0.037

Indices for mixed land use

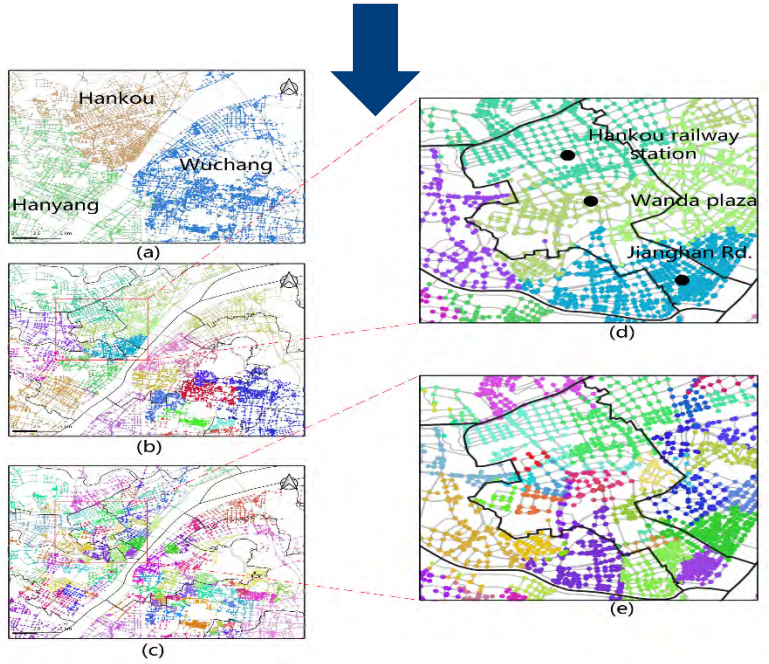
Contribution

01

We proposed an integrated framework for sensing the underlying hierarchical urban spatial structure.

02

We investigated the integration of human movement patterns into the urban road network abstration model.



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