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Spatial analysis in GeoAI with the use of graph neural networks: Quality of life prediction in urban areas case

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Abstract:

This paper presents a novel approach to GIS analysis using graph neural networks applied to an RDF (Resource Description Framework) representation of spatial data. Graphs are frequently utilized for representing linear objects in spatial contexts for routing purposes. The authors present an example of the application of graph neural networks (GNNs) to urban quality of life (QOL) prediction, where spatial data was modeled with an RDF graph.

Various methods for creating graph models of a city and for determining embedding vectors for city spatial objects are described. Neural networks are widely used in GIS, where spatial data is represented in a raster model. This is due to their grid-like structure, which can be directly utilized by neural networks (Janowicz et al.,2020; Liu et al., 2022) The situation is different in the case of a vector data model, where it is more difficult to encode topological relations for machine learning purposes.

Another way to leverage topological dependencies is by employing a graph structure. A graph city model is suitable for a more natural representation of spatial data, taking into account both the topology of objects and their relationships. To achieve the goal, the authors employ the Knowledge Base of Real Estates (KBRE) database[1], where Polish cities of Wrocław and Kraków were modeled in an RDF graph.

Artificial Intelligence (AI) has undergone a significant transformation in recent years, driven primarily by the success of deep neural networks. These networks, particularly large language models (LLMs) such as BERT, T5, and GPT, have revolutionized natural language processing, while graph neural networks, such as GraphSAGE or AlphaFold, have made remarkable strides in knowledge base analysis.

The vectorized representation of symbolic knowledge, which preserves the original semantic relationships between concepts and facts, has been a hallmark of these models. However, this sub-symbolic representation, also known as embedding, has not yet been fully established for Geographic Information System (GIS) data (Cai et al., 2022; Mai et al., 2022).

While GIS data has been widely used in fields such as geology and environmental science, its processing and analysis using deep learning methods have been limited (Scheider et al., 2023). Recent research has attempted to bridge this gap by investigating the use of graph neural networks (GNNs) for GeoAI research (Liu et al., 2022, Kaczmarek et al., 2023 or Li et al., 2019). This area of research is poised to advance significantly, providing new insights and applications in fields such as climate science, agriculture, ecology, or quality of life prediction.

Quality of life is a multidimensional concept and can be considered from various perspectives. These are among others: level of noise, access to green areas and public services, public transportation, population density or real estate prices. In the presented works all of them were modeled in the described city graphs and different methods of creating embedding vectors from the graphs were evaluated. State-of-the-art data2vec model from Meta AI, dedicated to

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multimodal data (photos and press texts describing objects), was one such method. The sophisticated vector representation was further processed by graph neural networks, of which many were tested.

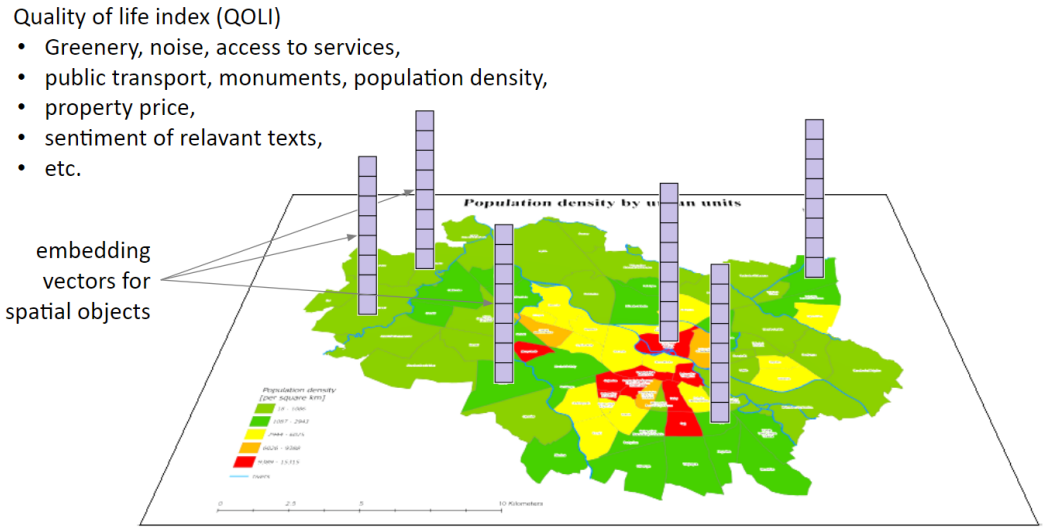

Figure 1. Embedding vectors were calculated for different city nodes and represented various attributes of each spatial object.

Different graph neural network models were applied to the city graphs for predicting the quality of life. In the proposed solution for each graph node an embedding vector was constructed, which represented various attributes of spatial objects (see Fig.1 and Fig.2). GNNs learnt the categorization of nodes and predicted connections within the graph, and categorized city subgraphs.

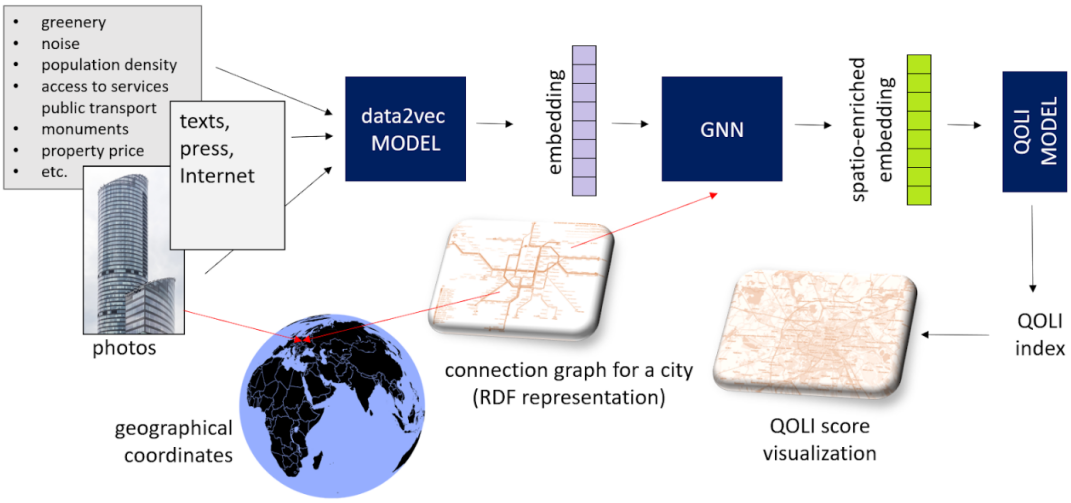

Figure 2. The quality of life modeling. Embedding vectors for specific locations are constructed on the basis of multimodal data (texts, photos, statistical data) and processed with the use of graph neural networks (GNNs).

A novel approach to GIS analysis for the quality of life in cities prediction is presented. We employ an RDF graph representation of city spatial data and trade on graph neural networks to accumulate obtainable knowledge. The article shows how the use of graphs enables a more natural representation of spatial data, and how GNNs cope with the effective prediction of the quality of life in different city locations.

Our model has great potential in the objective assessment of the quality of life for different spatial objects in a city. Such a model gives better insight into problems specific to different city districts and could help setting investment priorities. We also discuss the possibility of extending the model to other cities and other issues, such as traffic forecasting or crisis analysis.

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Bibliography

Cai, L., Janowicz, K., Zhu, R., Mai, G., Yan, B., & Wang, Z. (2022). HyperQuaternionE: A hyperbolic embedding model for qualitative spatial and temporal reasoning. GeoInformatica, 1-39.

Janowicz, K., Gao, S., McKenzie, G., Hu, Y., Bhaduri, B. (2020). Geoai: spatially explicit artificial intelligence techniques for geographic knowledge discovery and beyond. Int. J. Geogr. Inf. Sci., 34 (4), 625-636.

Kaczmarek, I., Iwaniak, A. & Świetlicka, A. (2023). Classification of Spatial Objects with the Use of Graph Neural Networks, ISPRS International Journal of Geo-Information 12 (3), 83.

Li, Y., Zhu, Z., Kong, D., Xu, M., & Zhao, Y. (2019, July). Learning heterogeneous spatial-temporal representation for bike-sharing demand prediction. In Proceedings of the AAAI conference on artificial intelligence (Vol. 33, No. 01, pp. 1004-1011).

Liu, P., & Biljecki, F. (2022). A review of spatially-explicit GeoAI applications in Urban Geography. International Journal of Applied Earth Observation and Geoinformation, 112, 102936.

Mai, G., Hu, Y., Gao, S., Cai, L., Martins, B., Scholz, J., ... & Janowicz, K. (2022). Symbolic and subsymbolic GeoAI: Geospatial knowledge graphs and spatially explicit machine learning. Transactions in GIS.

Scheider, S., Richter, K.F. & Janowicz, K. (2023). GeoAI and Beyond: Interview with Krzysztof Janowicz, Künstliche Intelligenz, 36.

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