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Geoinformation and Big Data Research Lab

Autonomous GIS: the next-generation AI-powered GIS

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The 14th ISDE International Lectures
January 21, 2025

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Geoinformation and Big Data Research Lab (GIBD)

Research Areas

- Geospatial big data analytics
- Spatiotemporal computing
- Geospatial artificial intelligence

To address a broad range of geographic questions about hazards, public health, population mobility, environment and climate change.

To advance knowledge discovery and decision making.

Current Graduate Students

Huan Ning
PhD

Naser Lessani
PhD

Temitope Akinboyewa
PhD

Ali Kazazi
PhD

Bibian Robert
MS

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https://giscience.psu.edu

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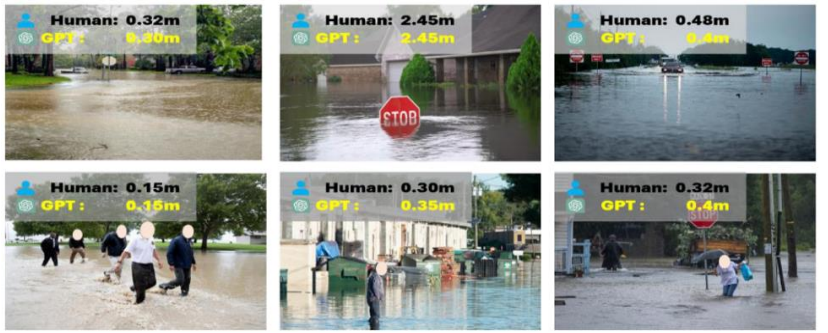
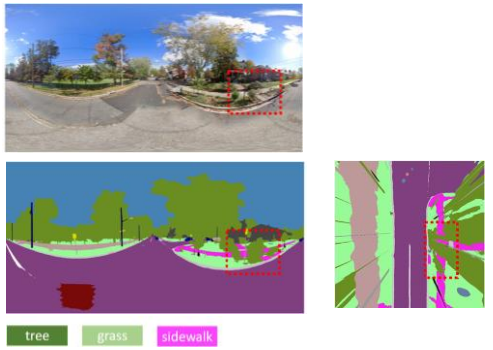
Artificial Intelligence in GIScience

1 AI as information extractors

- Extract sidewalk from street view images
- Extract water depth from flood photos
- Extract suicide tweets
- …



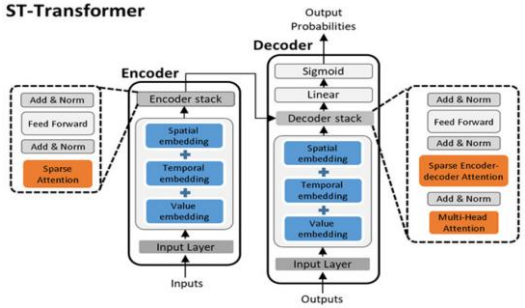
Akinboyewa, T., Ning, H., Lessani, M. N., & Li, Z. (2024). Automated floodwater depth estimation using large multimodal model for rapid flood mapping. *Computational Urban Science*, 4(1), 12.



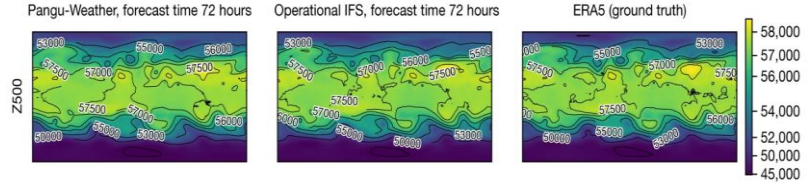
Ning, H., Li, Z., Wang, C., Hodgson, M. E., Huang, X., & Li, X. (2022). Converting street view images to land cover maps for metric mapping: A case study on sidewalk network extraction for the wheelchair users. *Computers, Environment and Urban Systems*, 95, 101808.

2 AI as spatial models

- Air quality (PM 2.5) prediction
- Weather forecasting
- Satellite image segmentation
- …



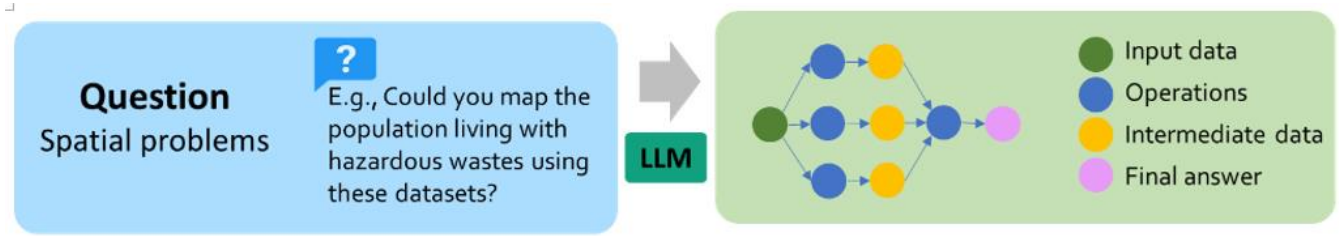
Yu, M., Masrur, A., & Blaszczak-Boxe, C. (2023). Predicting hourly PM2. 5 concentrations in wildfire-prone areas using a SpatioTemporal Transformer model. Science of The Total Environment, 860, 160446.



Bi, K., Xie, L., Zhang, H., Chen, X., Gu, X., & Tian, Q. (2023). Accurate medium-range global weather forecasting with 3D neural networks. *Nature*, 619(7970), 533-538.

3 AI as GIS Agents

- Building blocks of Autonomous GIS
  - Autonomous spatial analysis agents
  - Autonomous data discovery and retrieval agents
  - Autonomous mapping/cartography agents
  - …..



Li, Z., & Ning, H. (2023). Autonomous GIS: the next-generation AI-powered GIS. International Journal of Digital Earth, 16(2), 4668-4686.

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Definition of Autonomous GIS

We define Autonomous GIS as *"…an AI-powered GIS that leverages LLM's (or GenAI/AGI) general abilities in natural language understanding, reasoning, and coding to address spatial problems with automatic spatial data collection, analysis, and visualization."*

By using AI as the decision-making core ("brain"), and executable programs (e.g., Python) as its digital 'hands', autonomous GIS will be capable of performing spatial analysis autonomously by

- searching and retrieving needed spatial data from extensive existing online geospatial data catalogs or collecting new data from sensors.
- using existing GIS tools or developing new ones to process gathered data to generate the final results, e.g., maps, charts, and reports.

The key is to build and run the geoprocessing workflow in an automated way.

Li., Z., Ning H. (2023). Autonomous GIS: the next-generation AI-powered GIS, *International Journal of Digital Earth*, 16(20) p. 4668-4686 https://doi.org/10.1080/17538947.2023.2278895

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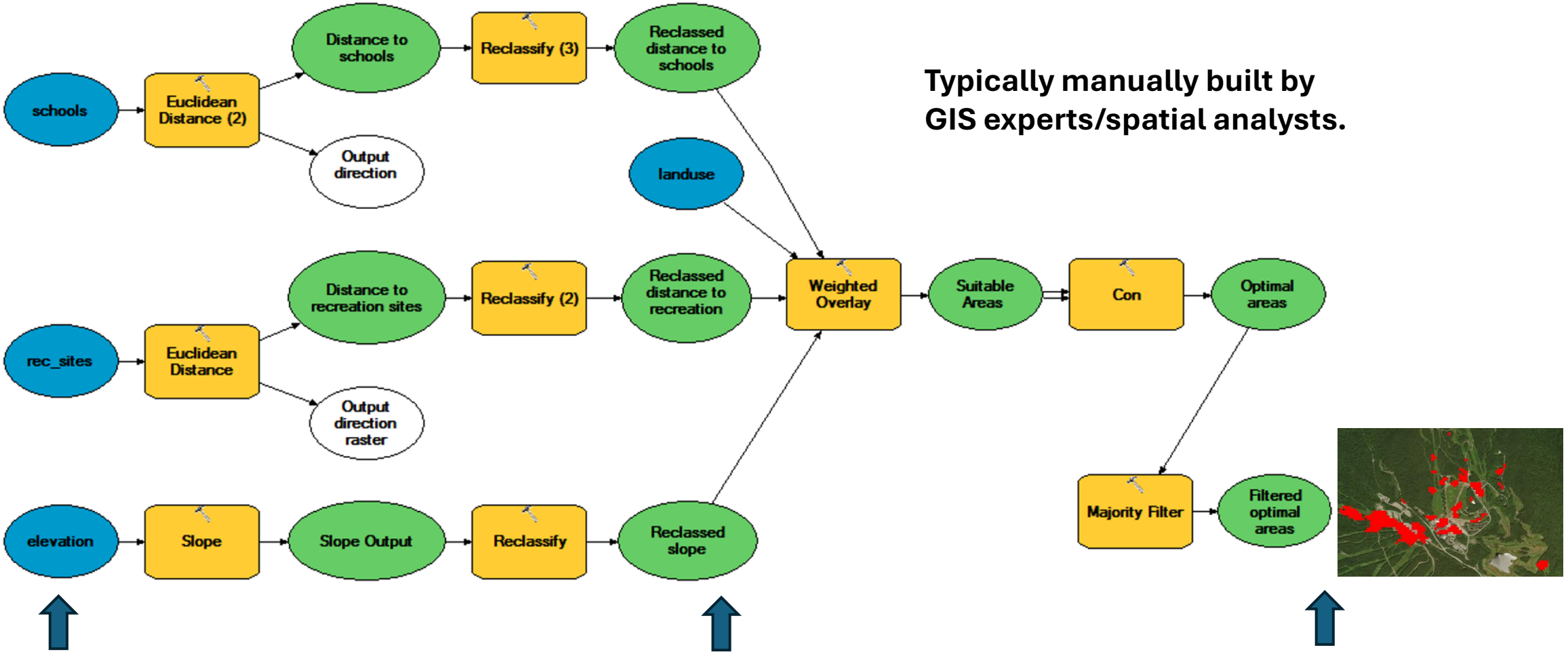
Spatial analyses as geoprocessing workflows

A geoprocessing workflow built with ArcGIS Model Builder to identify the suitable areas for a new school (a typical **site selection** problem in GIS).



Typically manually built by GIS experts/spatial analysts.

Input spatial datasets

Spatial operations/tools and intermediate data outputs

Output map

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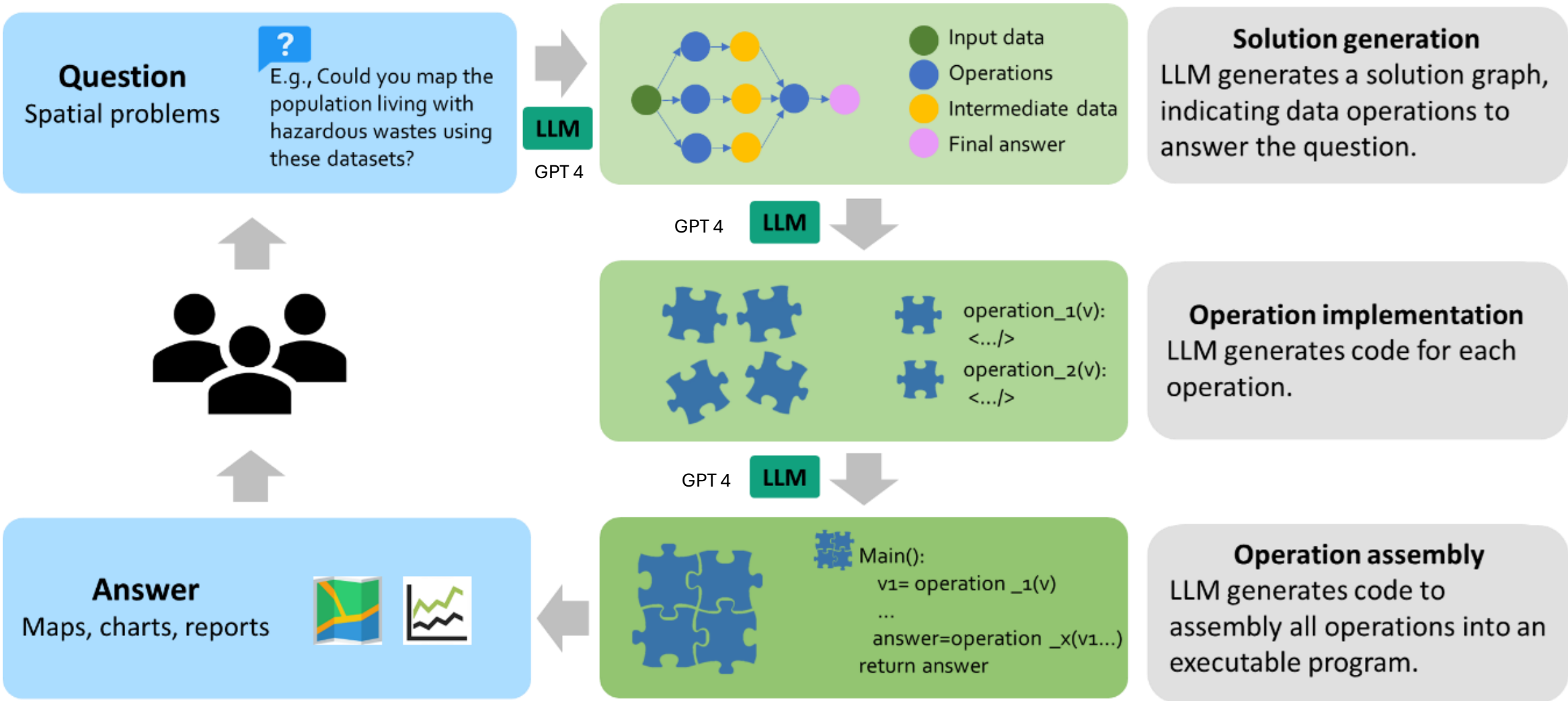
LLM-Geo: a prototype of Autonomous GIS



Overall workflow of LLM-Geo

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Case 1: Human mobility data retrieval and trend visualization

Task:

1) Show the monthly change rates of population mobility for each administrative regions in a France map. Each month is a sub-map in a map matrix. The base of the change rate is January 2020.

2) Draw a line chart to show the monthly change rate trends of all administrative regions. Th x-axis is month.

Data locations:

1. ESRI shapefile for France administrative regions: https://github.com/gladcolor/LLM-Geo/raw/master/REST_API/France.zip. The 'GID_1' column is the administrative region code, 'NAME_1' column is the administrative region name.

2. REST API URL with parameters for mobility data access: http://gis.cas.sc.edu/GeoAnalytics/REST?operation=get_daily_movement_for_all_places&source=twitter&scale=world_first_level_admin&begin=01/01/2020&end=12/31/2020. The response is in CSV format. There are three columns in the response: place, date (format:2020-01-07), and intra_movement. 'place' column is the administrative region code, France administrative regions start with 'FRA'.

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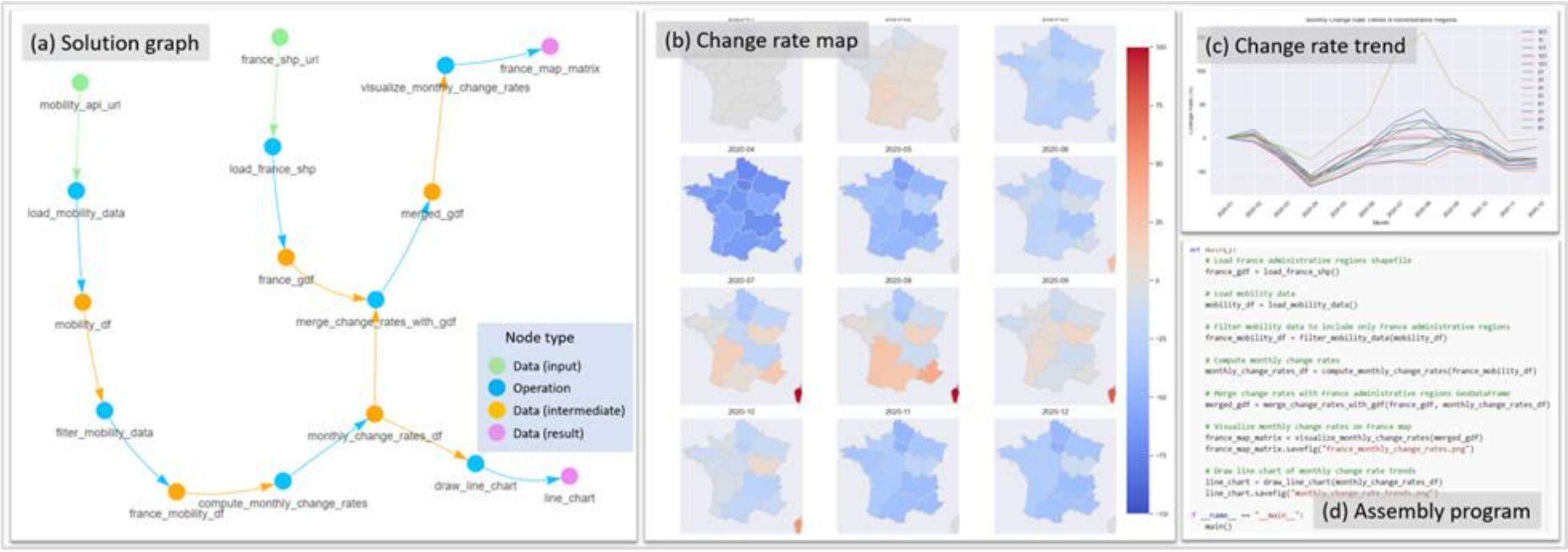
Case 1 results automatically generated by LLM-Geo



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Case 2: COVID-19 death rate analysis and visualization at the US county level

Task:

*1) Draw a map to show the death rate (death/case) of COVID-19 among the countiguous US counties. Use the accumulated COVID-19 data of 2020.12.31 to compute the death rate. Use scheme ='quantiles' when plotting the map. Set map projection to 'Conus Albers'. Set map size to 15*10 inches.*

*2) Draw a scatter plot to show the correlation and trend line of the death rate with the senior resident rate, including the r-square and p-value. Set data point transparency to 50%, regression line as red. Set figure size to 15*10 inches.*

Data locations:

1) COVID-19 data case in 2020 (county-level): https://github.com/nytimes/covid-19-data/raw/master/us-counties-2020.csv. This data is for daily accumulated COVID cases and deaths for each county in the US. There are 5 columns: date (format: 2021-02-01), county, state, fips, cases, deaths.

2) Contiguous US county boundary (ESRI shapefile): https://github.com/gladcolor/spatial_data/raw/master/contiguous_counties.zip. The county FIPS column is 'GEOID'.

3) Census data (ACS2020): https://raw.githubusercontent.com/gladcolor/spatial_data/master/Demography/ACS2020_5year_county.csv. The needed columns are: 'FIPS', 'Total Population', 'Total Population: 65 to 74 Years', 'Total Population: 75 to 84 Years', 'Total Population: 85 Years and Over'.

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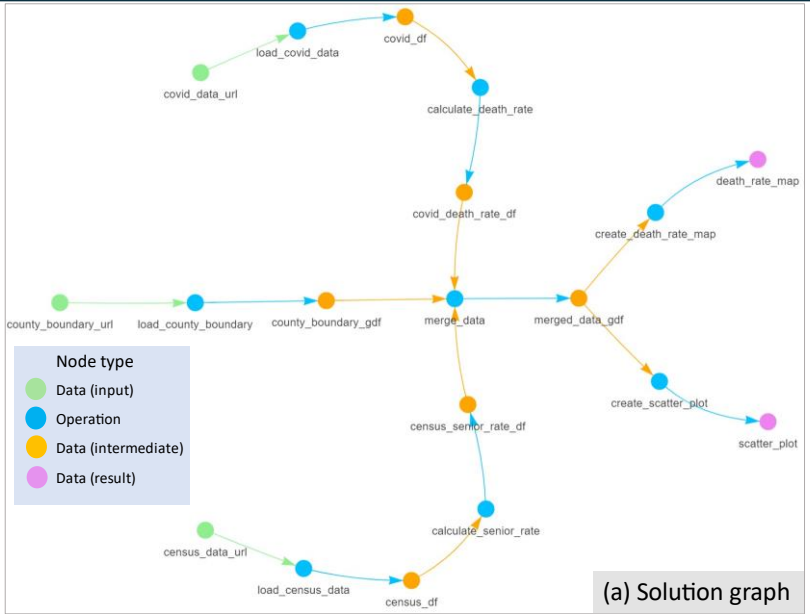
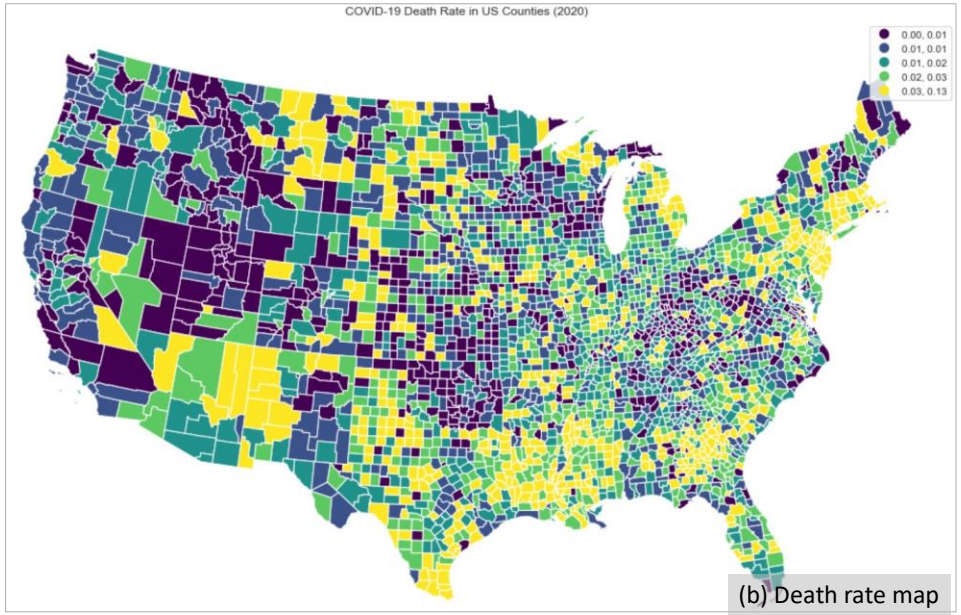
Case 2 results automatically generated by LLM-Geo



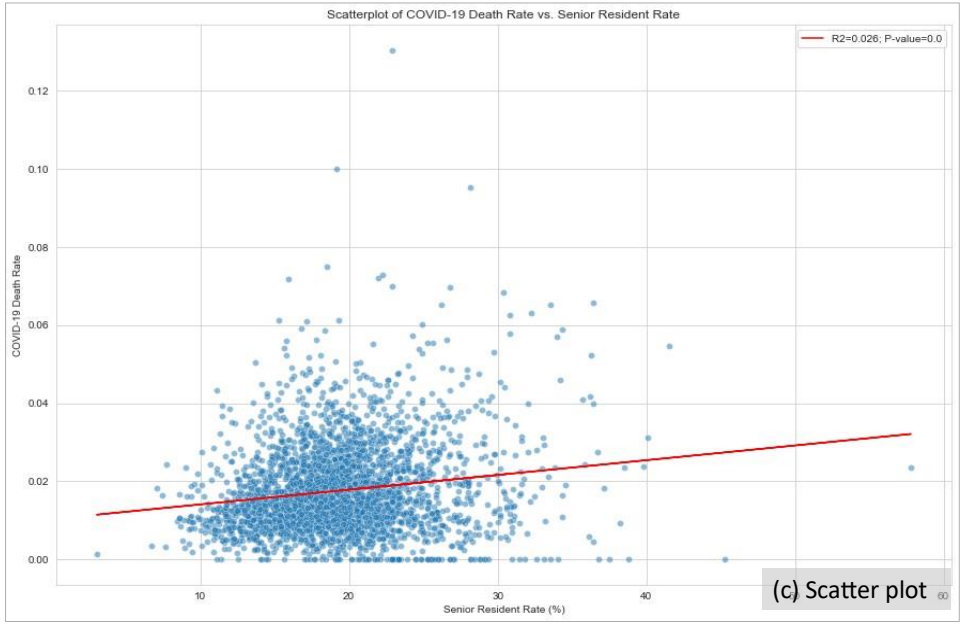
(a) Solution graph



(b) Death rate map

```python
def main():
    # Load data
    covid_df = load_covid_data()
    county_boundary_gdf = load_county_boundary()
    census_df = load_census_data()

    # Calculate death rate and senior rate
    covid_death_rate_df = calculate_death_rate(covid_df)
    census_senior_rate_df = calculate_senior_rate(census_df)

    # Merge data
    merged_data_gdf = merge_data(county_boundary_gdf, covid_death_rate_df,
                                 census_senior_rate_df)

    # Create and save death rate map
    death_rate_map = create_death_rate_map(merged_data_gdf)
    death_rate_map.savefig("death_rate_map.png")

    # Create and save scatter plot
    scatter_plot = create_scatter_plot(merged_data_gdf)
    scatter_plot.savefig("scatter_plot.png")


if __name__ == "__main__":
    main()
```

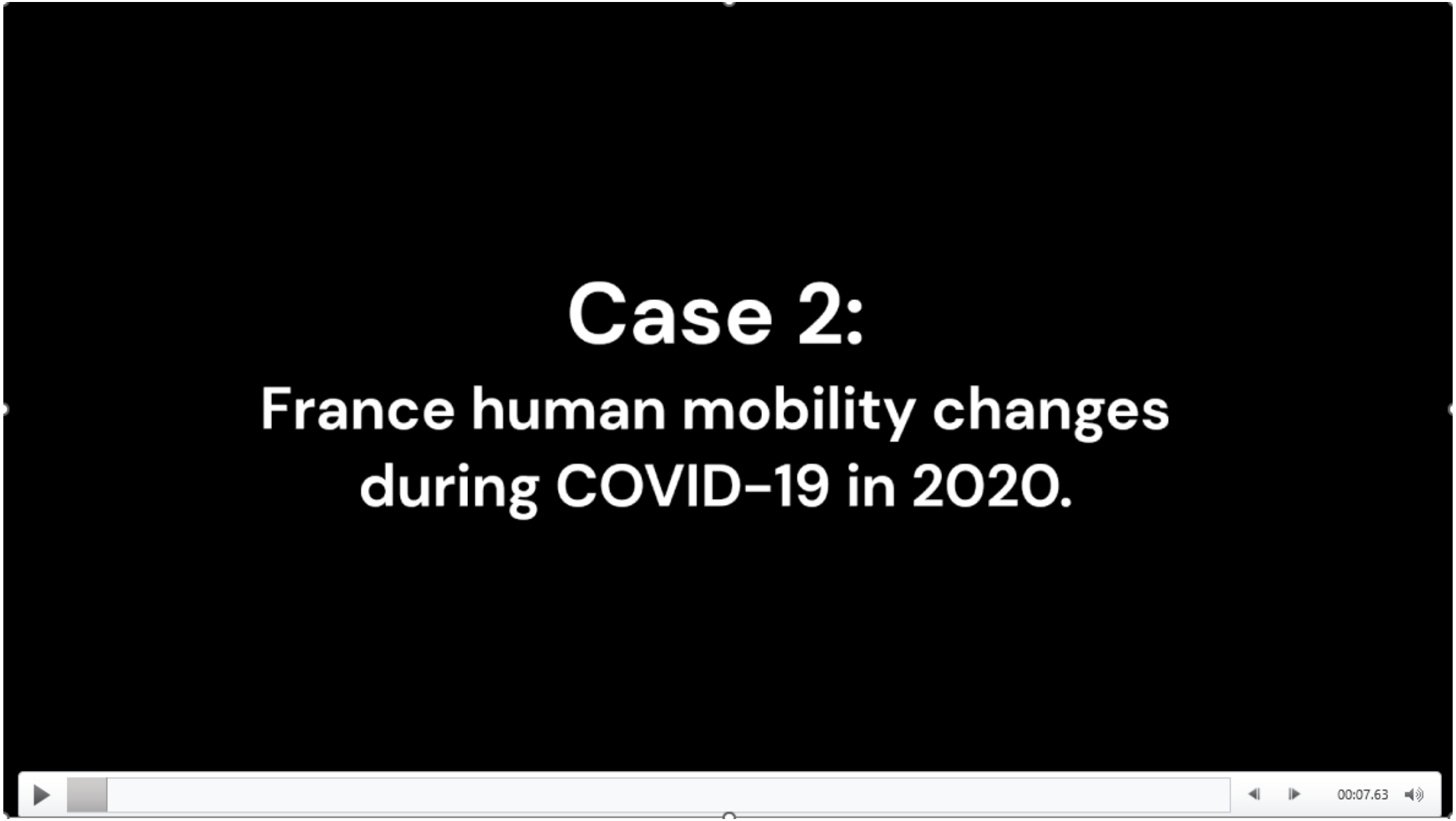
(d) Assembly program



(c) Scatter plot

Video demonstrations for the case studies

- Case 1: https://youtu.be/ot9oA_6Llys
- Case 2: https://youtu.be/ut4XkMcqgvQ
- Case 3: https://youtu.be/4q0a9xKk8Ug



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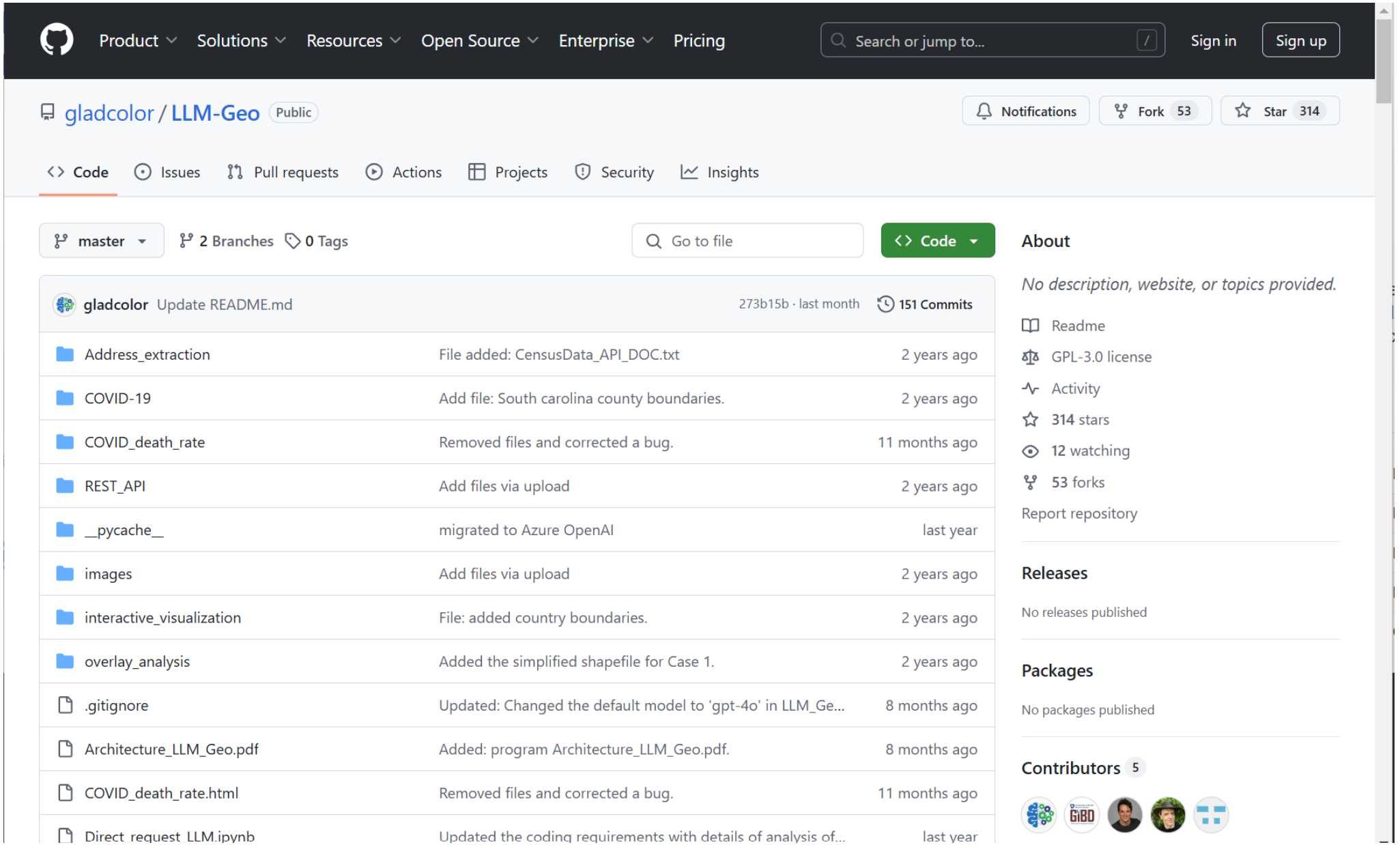
We invite you to explore, test, and contribute to the LLM-Geo project



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gladcolor / LLM-Geo Public

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gladcolor Update README.md 273b15b · last month 151 Commits

Address_extraction	File added: CensusData_API_DOC.txt	2 years ago
COVID-19	Add file: South carolina county boundaries.	2 years ago
COVID_death_rate	Removed files and corrected a bug.	11 months ago
REST_API	Add files via upload	2 years ago
__pycache__	migrated to Azure OpenAI	last year
images	Add files via upload	2 years ago
interactive_visualization	File: added country boundaries.	2 years ago
overlay_analysis	Added the simplified shapefile for Case 1.	2 years ago
.gitignore	Updated: Changed the default model to 'gpt-4o' in LLM_Ge...	8 months ago
Architecture_LLM_Geo.pdf	Added: program Architecture_LLM_Geo.pdf.	8 months ago
COVID_death_rate.html	Removed files and corrected a bug.	11 months ago
Direct_request_LLM.ipynb	Updated the coding requirements with details of analysis of...	last year

About

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Contributors 5

GitHub (source code)
https://github.com/gladcolor/LLM-Geo

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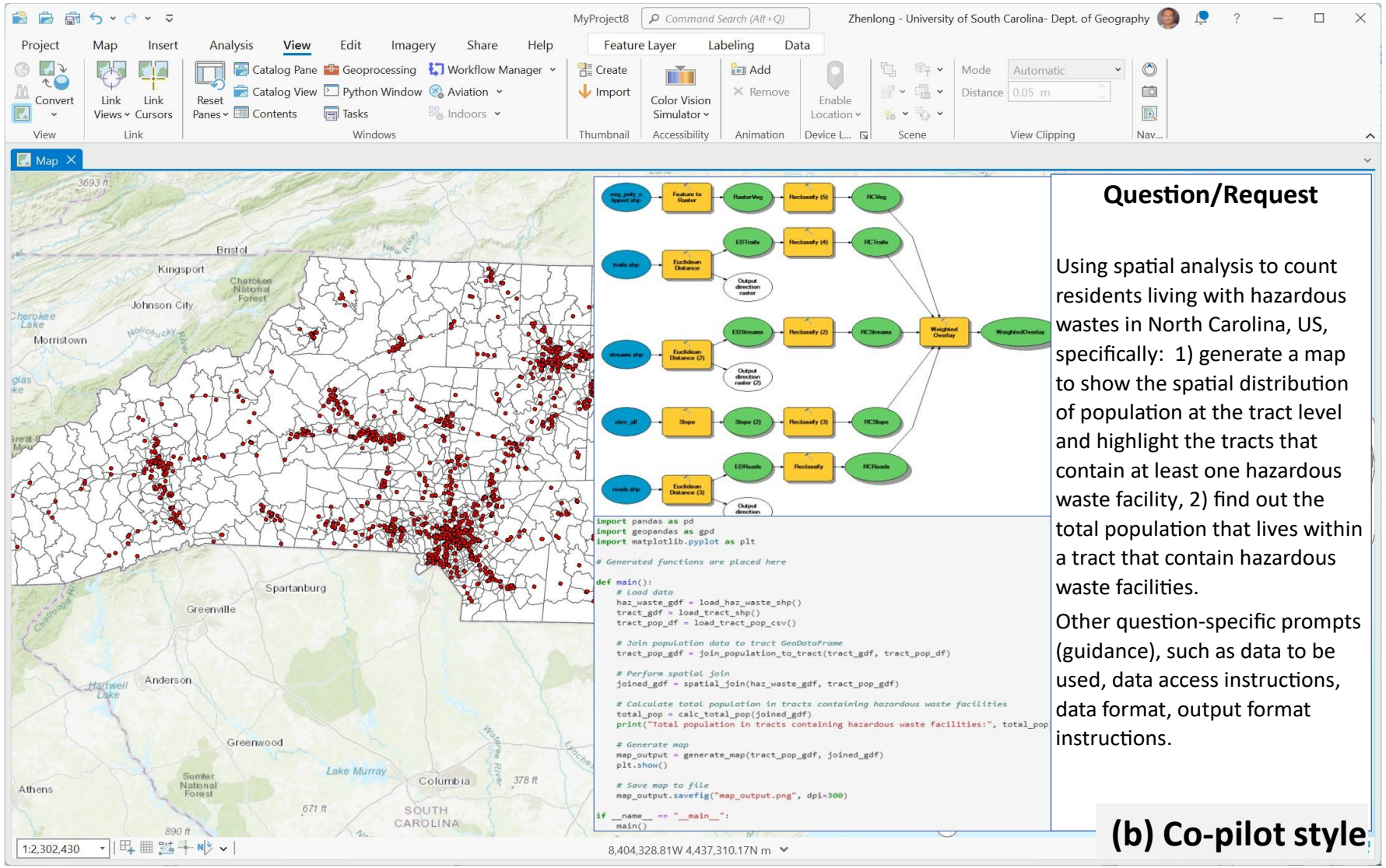
Copilot for GIS (one type of implementations of autonomous GIS)



We envisioned that "*autonomous GIS can serve as a **co-pilot for traditional GIS software**, using natural language to communicate with users and automate spatial data processing and analysis tasks.... For example, an autonomous GIS panel alongside the map view can be integrated into **ArcGIS and QGIS**, displaying the chatbox, generated solution graph, and codes as illustrated in Figure 7 (b)*" (Li & Ning, 2023)

https://mediaspace.esri.com/media/t/1_opret32t/
(From Esri February 13th, 2024)

GIS Copilot: Towards an Autonomous GIS Agent for Spatial Analysis

arXiv > cs > arXiv:2411.03205

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Computer Science > Artificial Intelligence

[Submitted on 5 Nov 2024 (v1), last revised 22 Nov 2024 (this version, v4)]

GIS Copilot: Towards an Autonomous GIS Agent for Spatial Analysis

Temitope Akinboyewa, Zhenlong Li, Huan Ning, M. Naser Lessani

Recent advancements in Generative AI offer promising capabilities for spatial analysis. Despite their potential, the integration of generative AI with established GIS platforms remains underexplored. In this study, we propose a framework for integrating LLMs directly into existing GIS platforms, using QGIS as an example. Our approach leverages the reasoning and programming capabilities of LLMs to autonomously generate spatial analysis workflows and code through an informed agent that has comprehensive documentation of key GIS tools and parameters. The implementation of this framework resulted in the development of a "GIS Copilot" that allows GIS users to interact with QGIS using natural language commands for spatial analysis. The GIS Copilot was evaluated with over 100 spatial analysis tasks with three complexity levels: basic tasks that require one GIS tool and typically involve one data layer to perform simple operations; intermediate tasks involving multi-step processes with multiple tools, guided by user instructions; and advanced tasks which involve multi-step processes that require multiple tools but not guided by user instructions, necessitating the agent to independently decide on and executes the necessary steps. The evaluation reveals that the GIS Copilot demonstrates strong potential in automating foundational GIS operations, with a high success rate in tool selection and code generation for basic and intermediate tasks, while challenges remain in achieving full autonomy for more complex tasks. This study contributes to the emerging vision of Autonomous GIS, providing a pathway for non-experts to engage with geospatial analysis with minimal prior expertise. While full autonomy is yet to be achieved, the GIS Copilot demonstrates significant potential for simplifying GIS workflows and enhancing decision-making processes.

Subjects: **Artificial Intelligence (cs.AI)**; Emerging Technologies (cs.ET); Human-Computer Interaction (cs.HC); Software Engineering (cs.SE)

Cite as: arXiv:2411.03205 **[cs.AI]**

(or arXiv:2411.03205v4 **[cs.AI]** for this version)

https://doi.org/10.48550/arXiv.2411.03205

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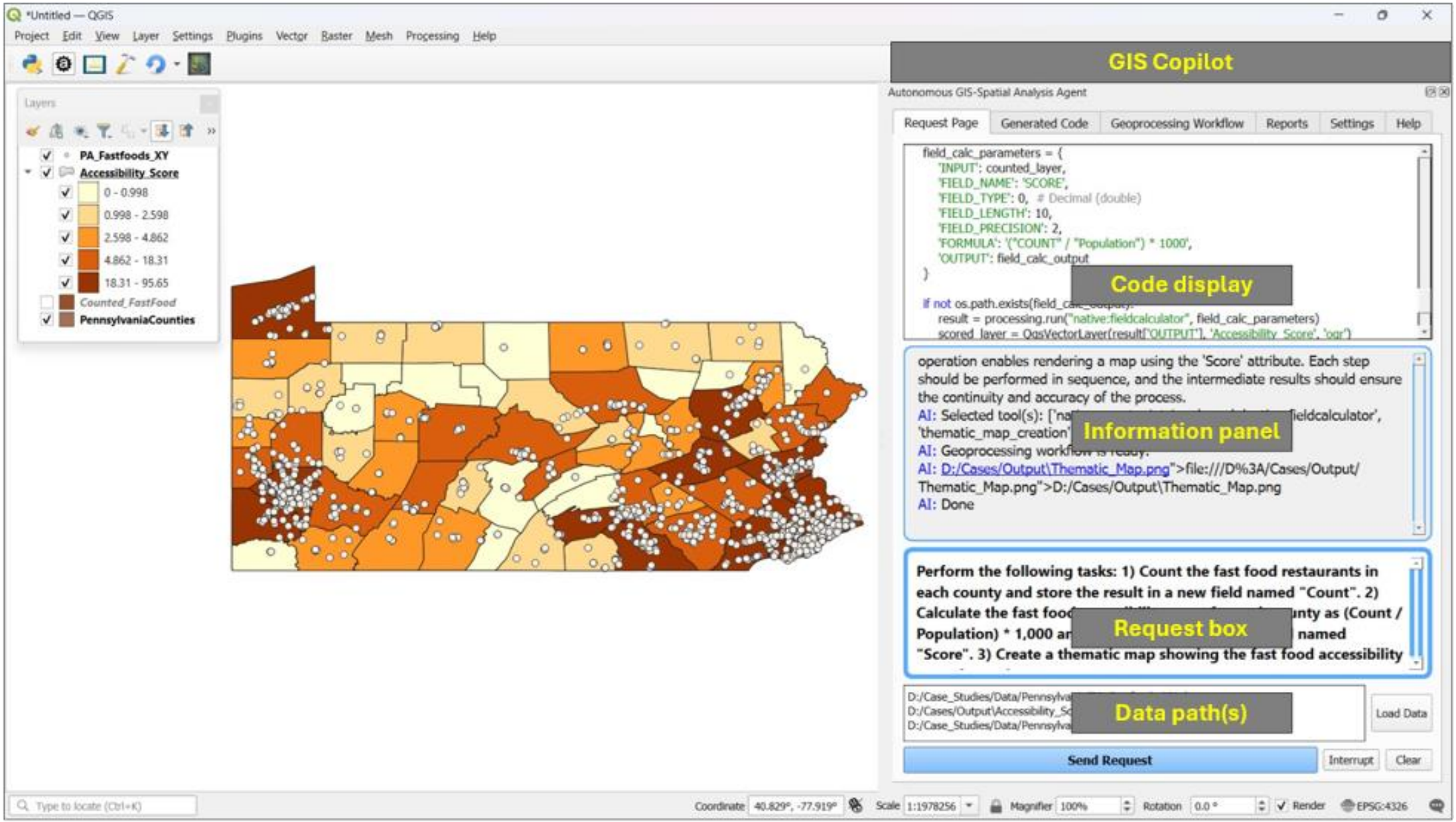
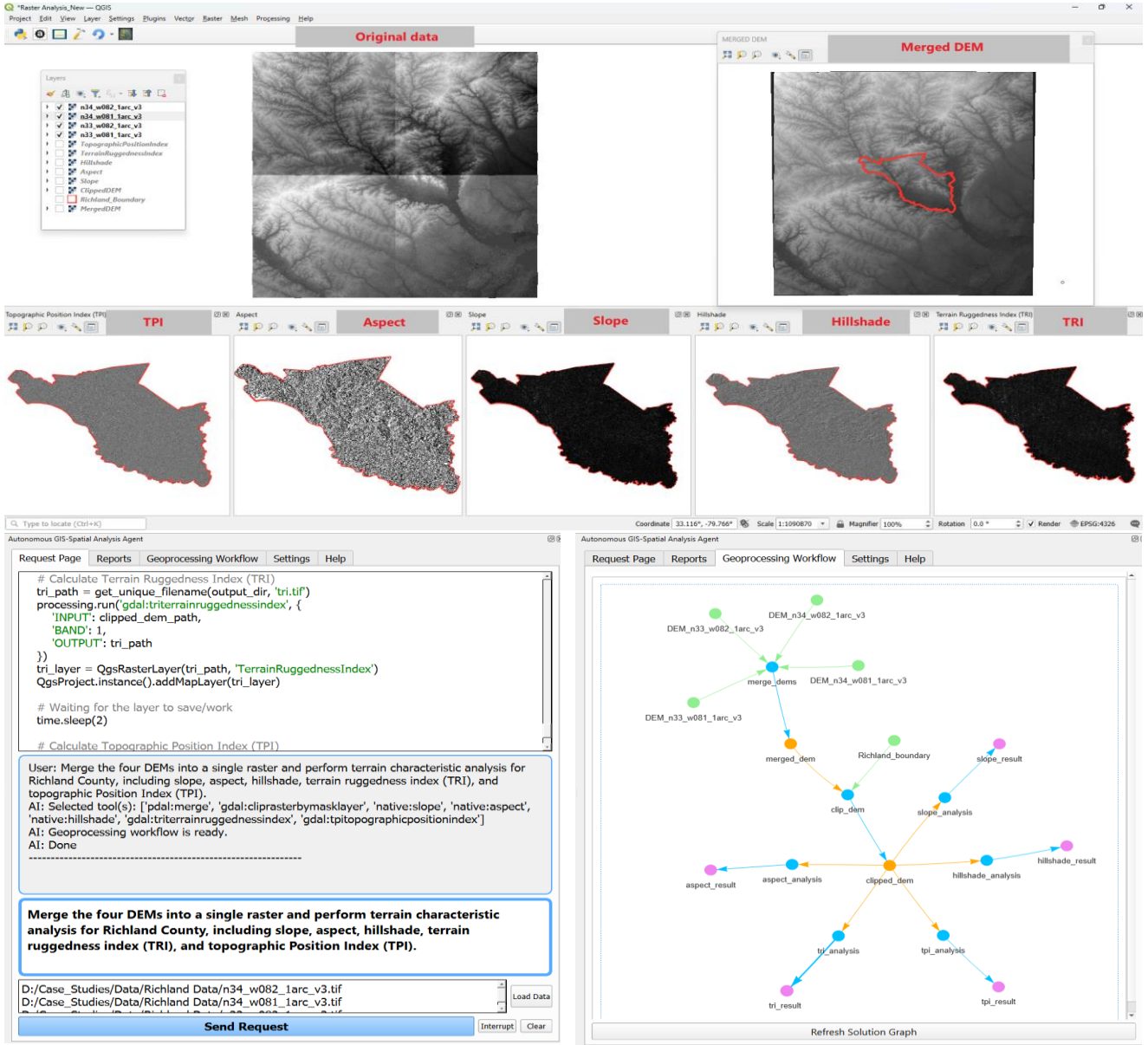
Graphic user interface of the GIS Copilot



Demo: Richland county terrain analysis

Task prompt:

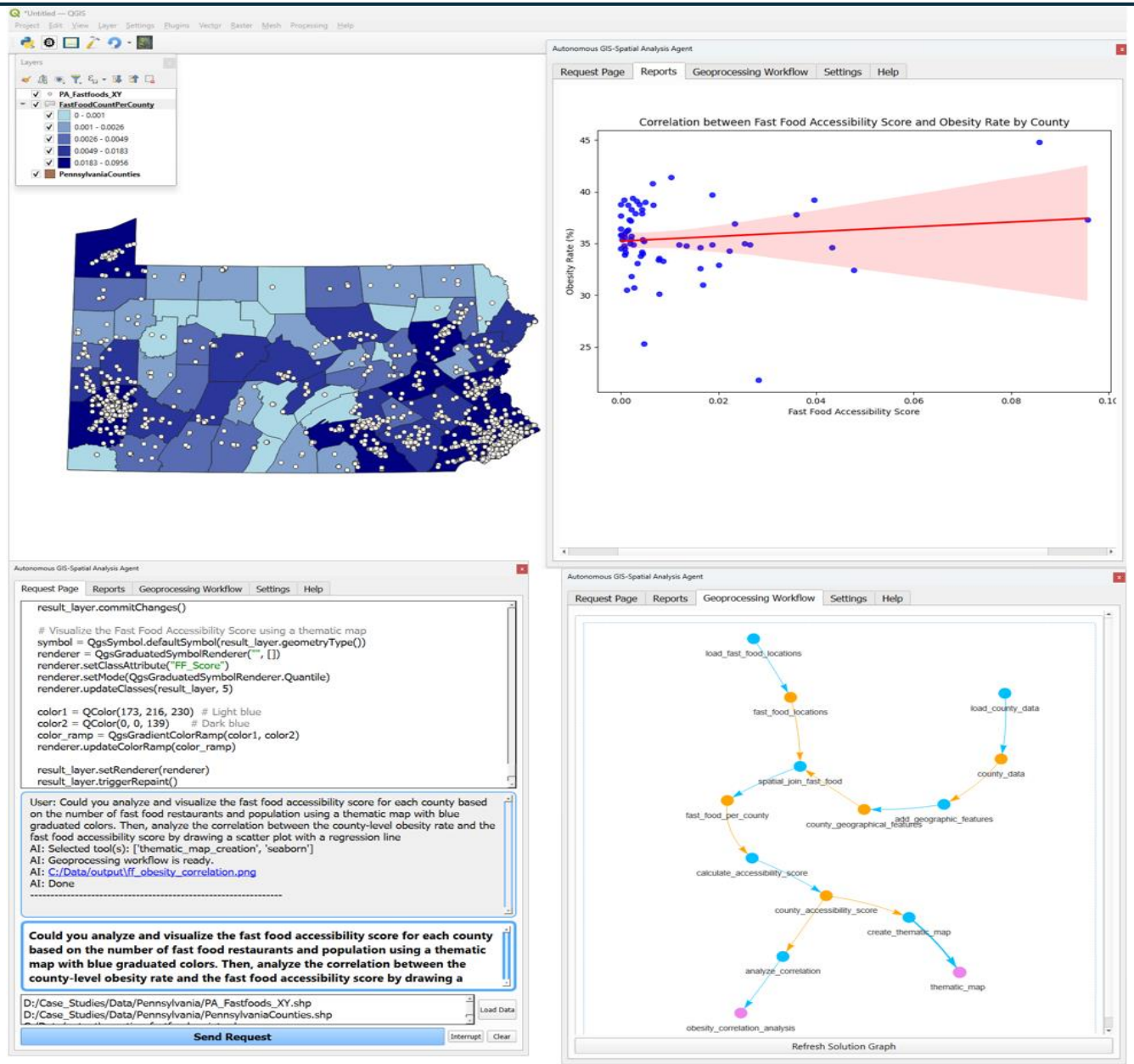
"Merge the four DEMs into a single raster and perform terrain characteristic analysis for Richland County, including slope, aspect, hillshade, terrain ruggedness index (TRI), and topographic Position Index (TPI)."



Demo: Fast food accessibility analysis

Task prompt:

"Could you analyze and visualize the fast food accessibility score for each county based on the number of fast food restaurants and population using a thematic map with blue graduated colors. Then, analyze the correlation between the county-level obesity rate and the fast food accessibility score by drawing a scatter plot with a regression line."



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Community reactions

Zhenlong Li • You
Associate Professor
2mo •

I'm excited to share our recent research on autonomous GIS with the development of a "GIS Copilot" that allows users to perform spatial analysis in QGIS using natural language for both vector and raster data. The Copilot was tested with more than 100 spatial analysis tasks spanning various complexity levels. The result shows that the GIS Copilot has strong potential in automating foundational GIS operations, with a high success rate for basic and intermediate tasks, while challenges remain in achieving full autonomy for more complex tasks without explicit guidance. This work represents a promising step toward the development of autonomous GIS, aiming to make spatial analysis more accessible to all.

David Kennewell and 2,849 others — 78 comments · 273 reposts

Reactions

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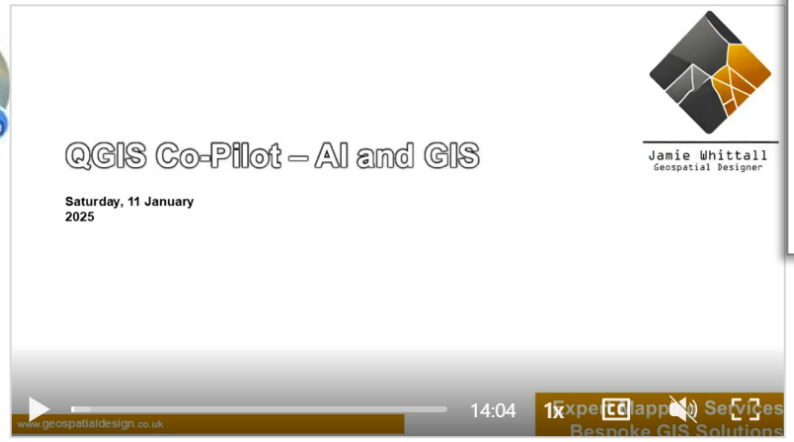


Yuki Sasaki • 3rd+ — 2mo
Artificial Intelligence Engineer at Northern System Services

I tested out the QGIS plugin, and it literally feels like the app is supercharged with some magical power. All of a sudden, a person without deep expertise in GIS (like me) can leverage the functionality of hundreds of QGIS/gdal/GRASS GIS features, creating all sorts of maps and analyzing geospatial data.

I was so impressed that I did a demo in the FOSS4G Japan event last Sunday, and people there were... kind of shocked that this is now possible.

Amazing work! 👏

Like · 11 | Reply

Jamie Whittall • 1st
GIS Specialist - Development Planning with Custom GIS Solutions & Expert Tr...
6d • Edited •

An Industry First? – Pulling together QGIS and LLM for GIS tasks

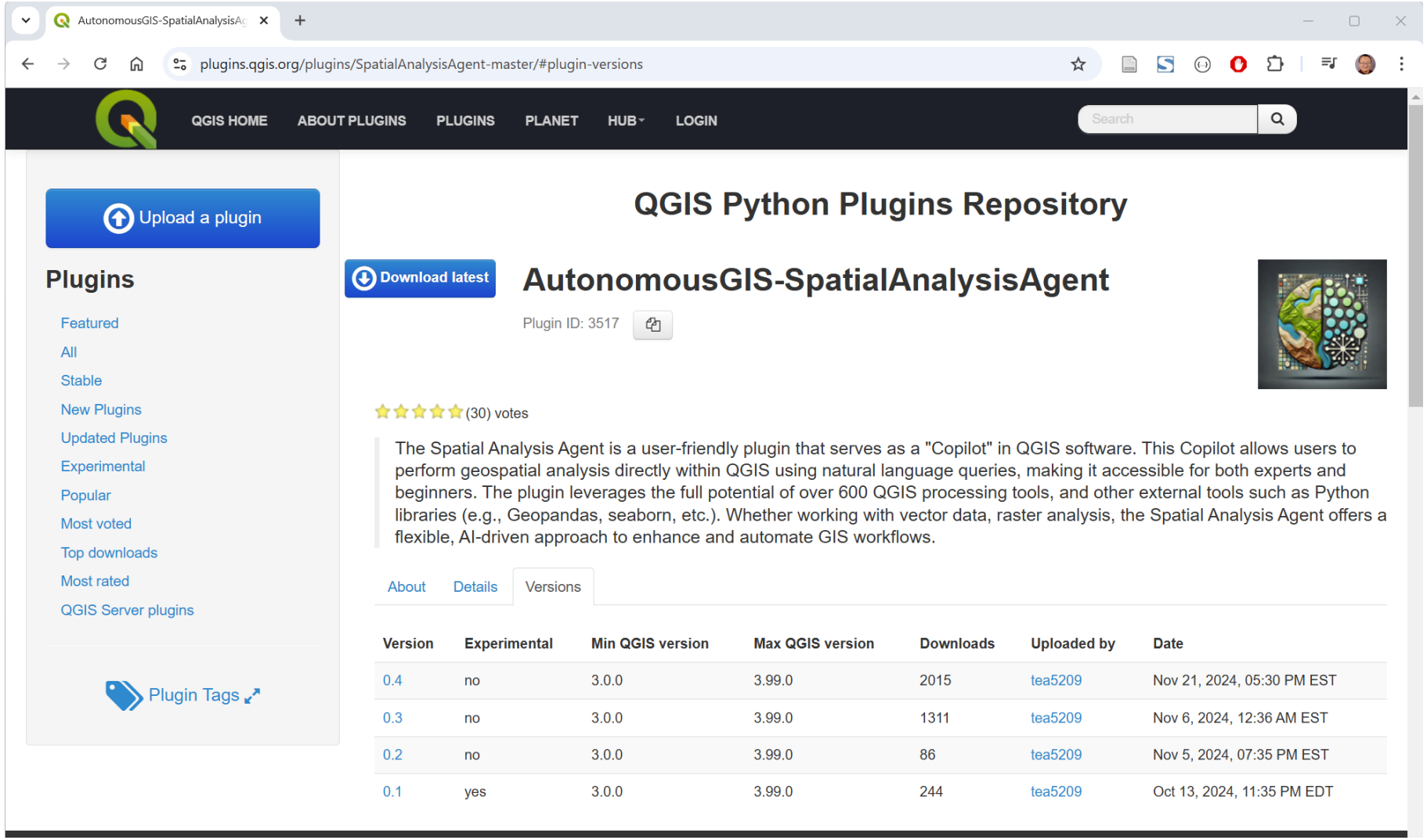
Like a lot of people, I am equal parts fascinated and terrified by AI. I can recognise how it can make our work more efficient. At the same time, I can't help but worry things get so efficient we make ourselves obsolete. Nothing groundbreaking with that view, but it always seems like something far away in the future.

When I saw this paper published by the Pennsylvania State University I had the sudden knee jerk reaction: I could be replaced tomorrow.

See the full post and video in the link below:

https://www.linkedin.com/posts/jamie-whittall_an-industry-first-pulling-together-qgis-activity-7284928587470700545-f02M

We invite you to explore and test this GIS Copilot tool



https://plugins.qgis.org/plugins/SpatialAnalysisAgent-master/#plugin-versions

Note: OpenAI API is needed to use the tool.

More demos:

https://giscience.psu.edu/gis-copilot-demonstrations/

https://www.youtube.com/playlist?list=PL6ON3gdLloDEikee1iugr4mKjQ8Tfvn7X

110 test cases and datasets: https://giscience.psu.edu/copilot_test/

GitHub (source code): https://github.com/Teakinboyewa/SpatialAnalysisAgent

An Autonomous GIS Agent Framework for Geospatial Data Retrieval

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COVID-19 e-print

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[Submitted on 13 Jul 2024 (v1), last revised 8 Aug 2024 (this version, v2)]

An Autonomous GIS Agent Framework for Geospatial Data Retrieval

Huan Ning, Zhenlong Li, Temitope Akinboyewa, M. Naser Lessani

Powered by the emerging large language models (LLMs), autonomous geographic information systems (GIS) agents have the potential to accomplish spatial analyses and cartographic tasks. However, a research gap exists to support fully autonomous GIS agents: how to enable agents to discover and download the necessary data for geospatial analyses. This study proposes an autonomous GIS agent framework capable of retrieving required geospatial data by generating, executing, and debugging programs. The framework utilizes the LLM as the decision-maker, selects the appropriate data source (s) from a pre-defined source list, and fetches the data from the chosen source. Each data source has a handbook that records the metadata and technical details for data retrieval. The proposed framework is designed in a plug-and-play style to ensure flexibility and extensibility. Human users or autonomous data scrawlers can add new data sources by adding new handbooks. We developed a prototype agent based on the framework, released as a QGIS plugin (GeoData Retrieve Agent) and a Python program. Experiment results demonstrate its capability of retrieving data from various sources including OpenStreetMap, administrative boundaries and demographic data from the US Census Bureau, satellite basemaps from ESRI World Imagery, global digital elevation model (DEM) from this http URL, weather data from a commercial provider, the COVID-19 cases from the NYTimes GitHub. Our study is among the first attempts to develop an autonomous geospatial data retrieval agent.

https://doi.org/10.48550/arXiv.2407.21024

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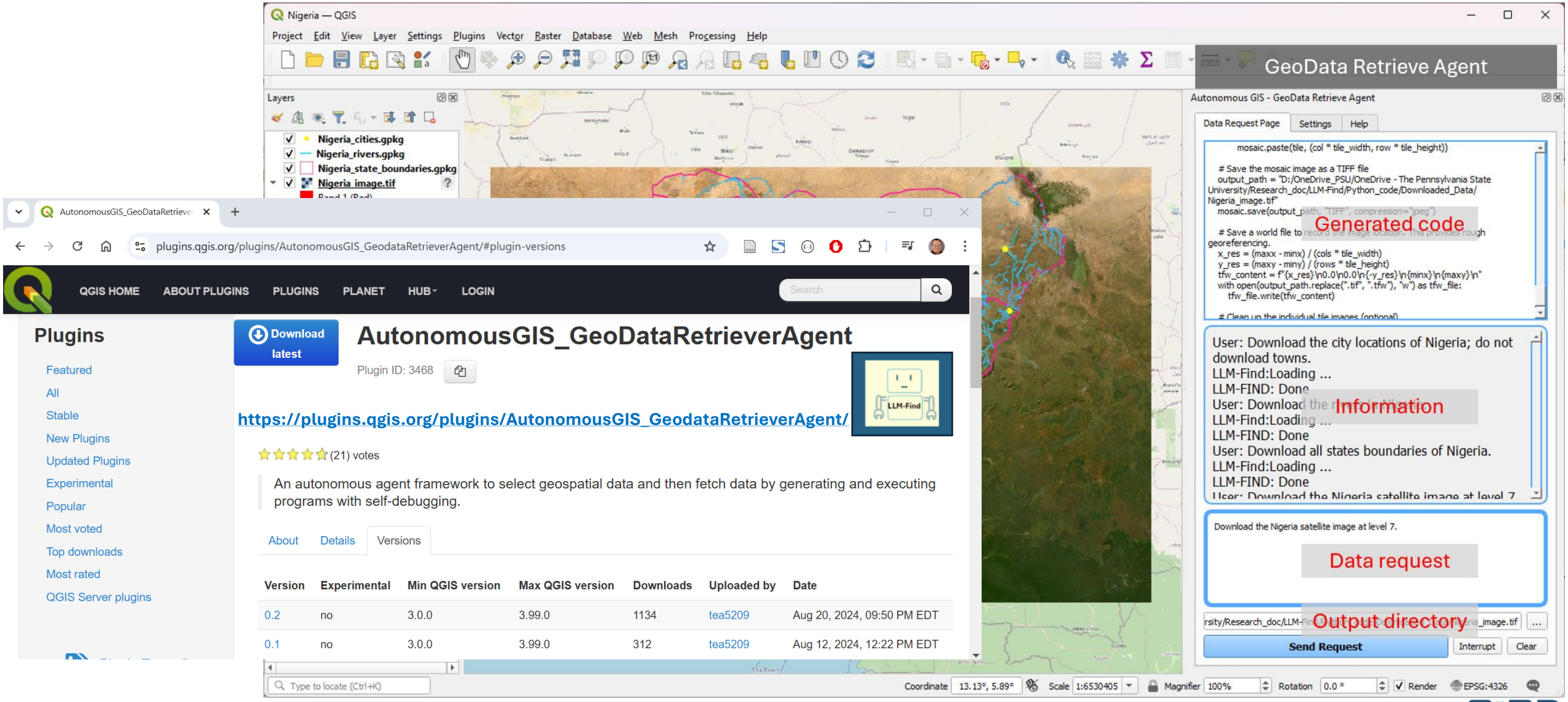
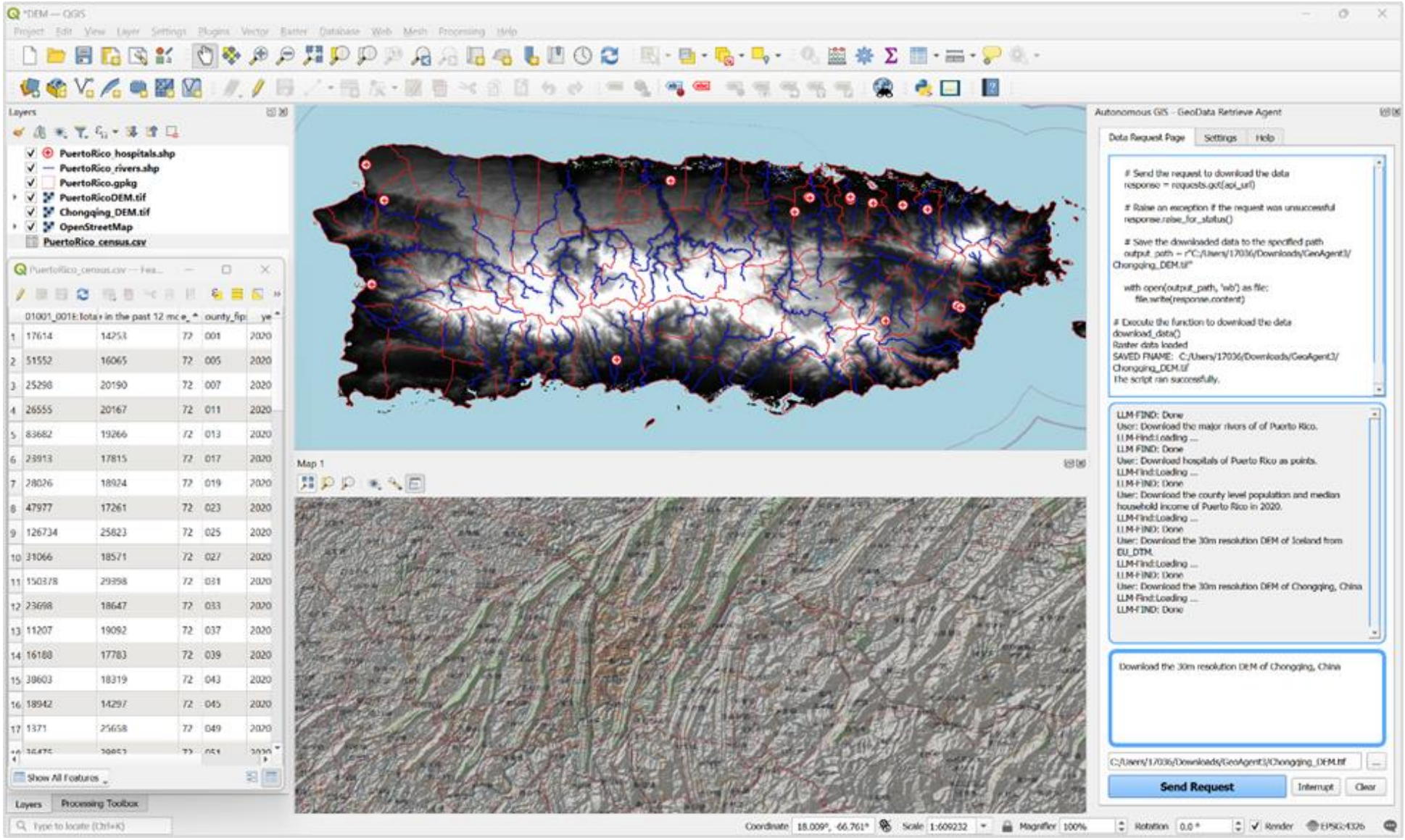
Geospatial Data Retrieve Agent (QGIS Plugin)



Ning H, Li Z, Akinboyewa T, Lessani N. (2024) An Autonomous GIS Agent Framework for Geospatial Data Retrieval. arXiv:2407.21024
https://arxiv.org/abs/2407.21024

Geospatial Data Retrieve Agent - Demo



Download the 90-meter resolution DEM data of Puerto Rico (county boundaries, major rivers, and hospitals)

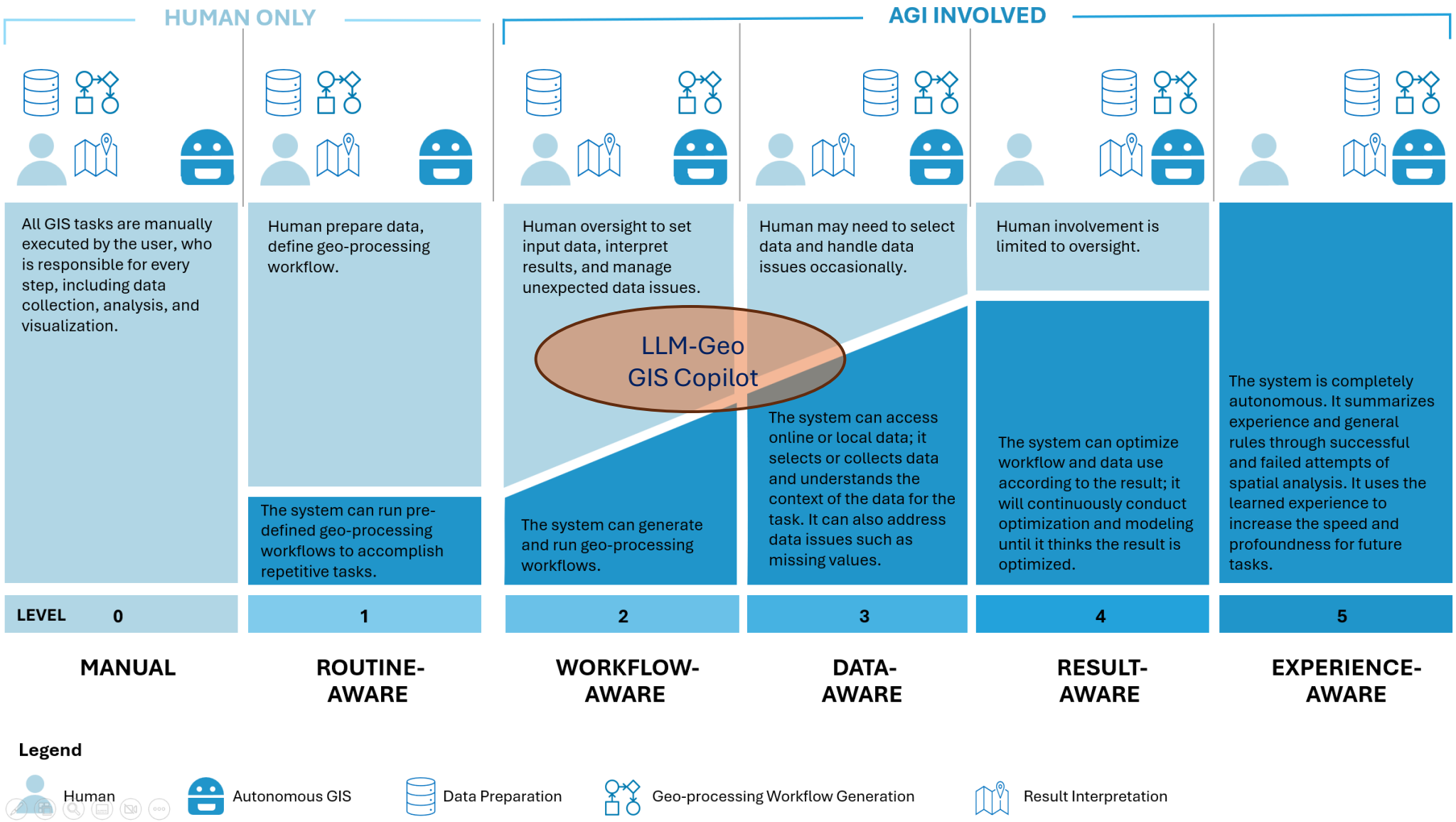
Download the county level population and median household income of Puerto Rico in 2020

Download the 30m resolution DEM of Chongqing, China

Video demos:
https://www.youtube.com/@GIBD_Lab/videos

GitHub:
https://github.com/Teakinboyewa/AutonomousGIS_GeodataRetrieverAgent

Levels of Autonomous GIS



Li Z. & Ning H. et al., (2025). GIScience in the Era of AGI: a Research Agenda towards Autonomous GIS (vision paper)

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Thank You!

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