

GeoAI: From Geospatial Questions to Intelligence

Prof. Song Gao

Department of Geography & Computer Science & Data Science Institute

University of Wisconsin–Madison

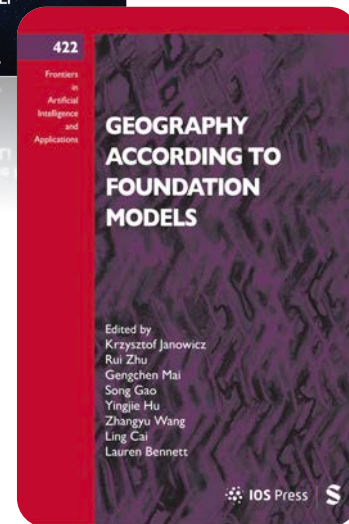
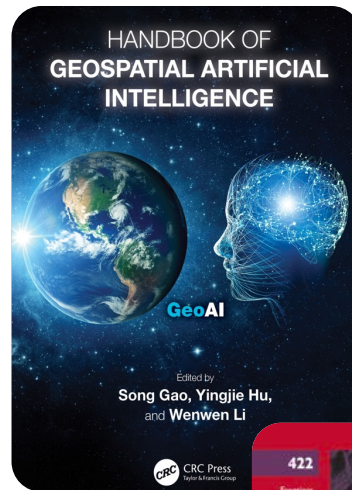
Email: song.gao@wisc.edu



<https://geods.geography.wisc.edu/>

What is GeoAI?

- GeoAI is the integration of geospatial technologies and AI, especially for developing **data-driven** and **knowledge-guided** **spatially-explicit** machine learning methods.
- GeoAI can be considered as a subject to develop intelligent computer programs (e.g. agents) to **mimic the processes of human perception, spatial reasoning, and discovery** about geographical phenomena and dynamics.



What is GeoAI?



Cognitive (Symbolic) Approach

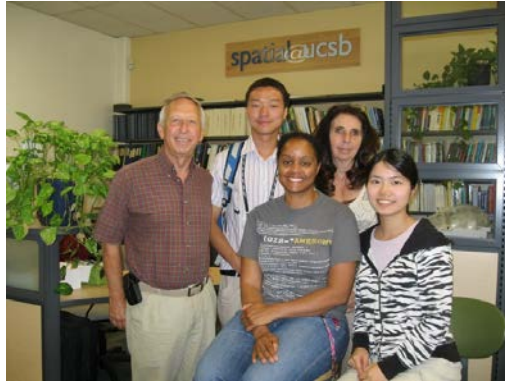
Focuses on mimicking human reasoning through symbolic representations and logic-based rules.



Engineering (Data-Driven) Approach

Prioritizes performance and statistical patterns, using massive datasets to train deep neural networks.

Human GIS Assistant: Spatial Questions and Workflows



- NLP Query
- GIS & Domain Knowledge
- Data
- Analysis Workflow
- Map Visualization
- ...

GIS Helpdesk at Spatial@UCSB

- Joining survey tables to existing spatial data (Psychology)
- Batch processing of converting geographic features in different folders into new geodatabase classes (Library)
- Habitat mapping for conservation (School of Environment)

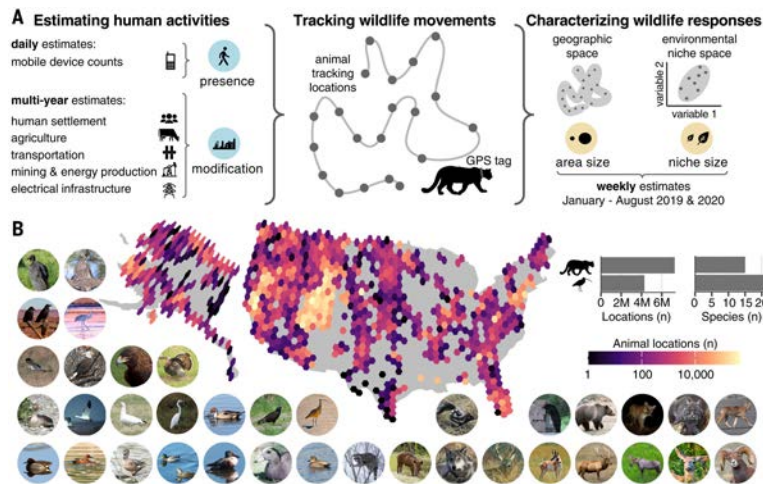


Human GIS Assistant: Spatial Questions and Workflows

Question: How to analyze the impact of human mobility on animal movement and habitat?

Workflow:

1. Data collection (animal GPS trajectories, human mobility, environmental variables)
2. Data processing and spatiotemporal alignment
3. Human movement analysis and activity estimation
4. Animal movement analysis and ecological niche modeling
5. Human–wildlife interaction & response analysis
6. Result interpretation and mapping



Interacting effects of human presence and landscape modification on birds and mammals

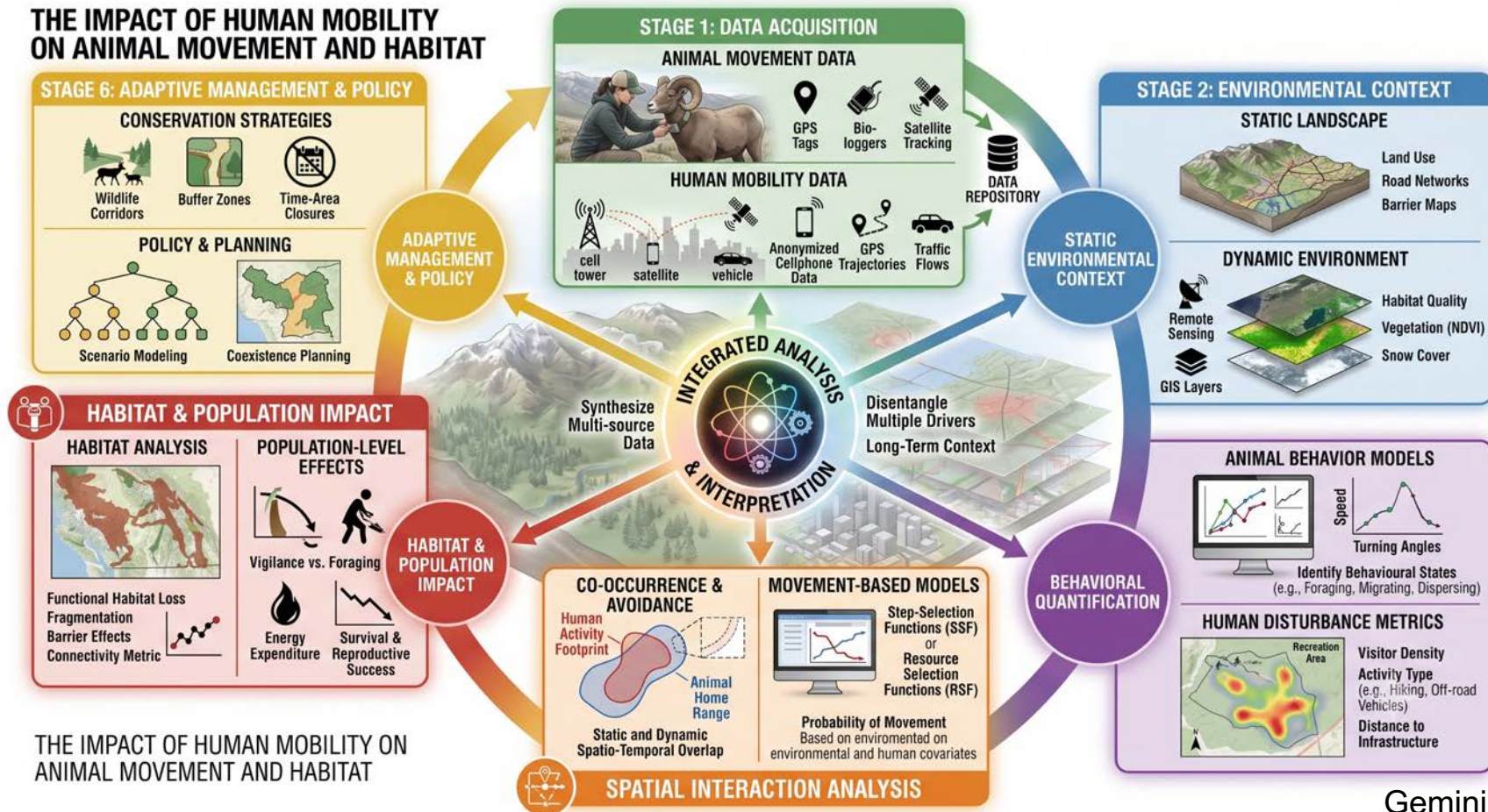
OLIVER, OLIVER • SCOTT, W. YAMMO • DIEGO, J. L. SOTO • BRETHER, R. J. • J. A. NET, COHEN • SONG, S. • ROBERT, PATCHETT • TAL, A. • KEITH, BLISTEN, L. J. AND, HANLEY, J. C. • +82 authors Authors Info & Affiliations

SCIENCE • 21 May 2024 • Vol. 392, Issue 6800 • pp. 879-888 • DOI: 10.1126/science.ade3225

Oliver et al. (2026, Science)

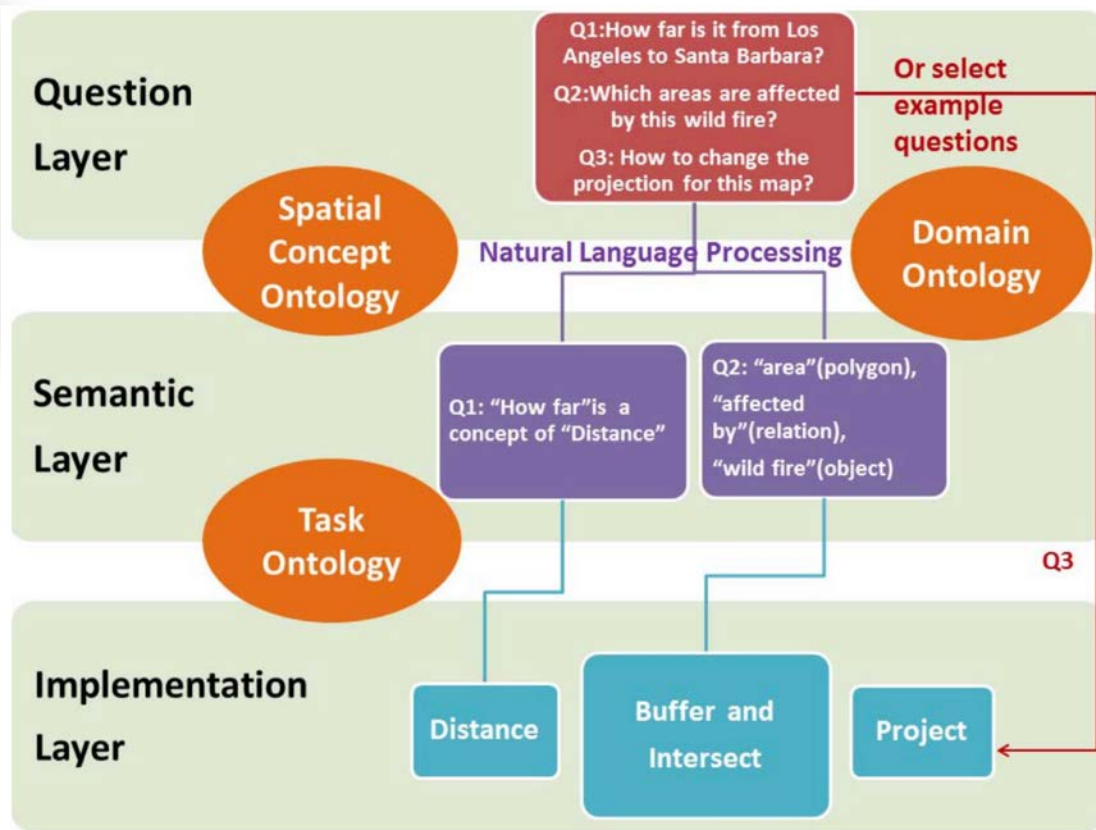
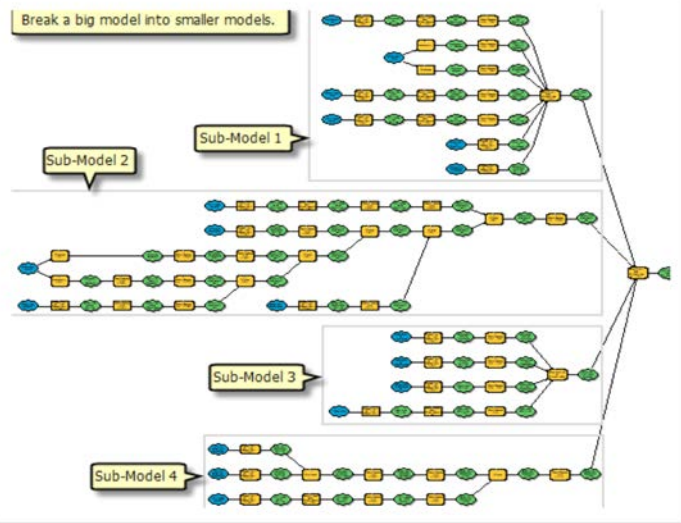
Artificial GIS Assistant: Workflow Generation

THE IMPACT OF HUMAN MOBILITY ON ANIMAL MOVEMENT AND HABITAT



THE IMPACT OF HUMAN MOBILITY ON ANIMAL MOVEMENT AND HABITAT

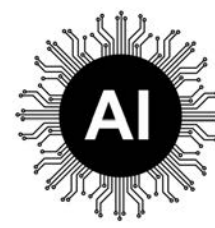
Artificial GIS Assistant: Semantic Parsing and Tool Calling



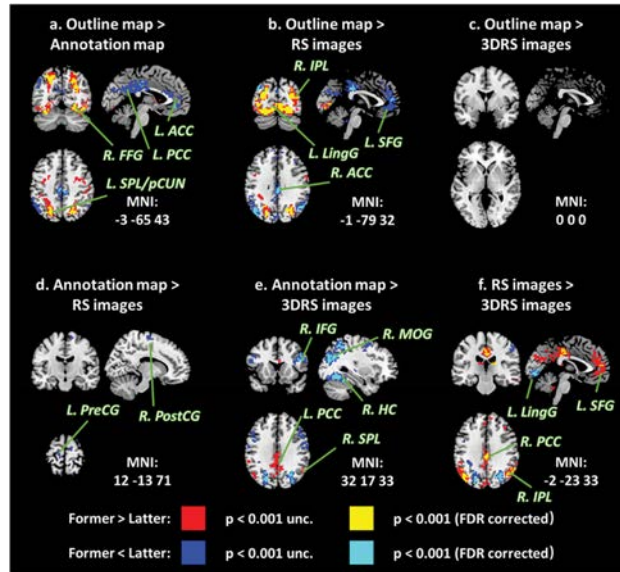
Gao & Goodchild (2013), Asking spatial questions to identify GIS functionality.



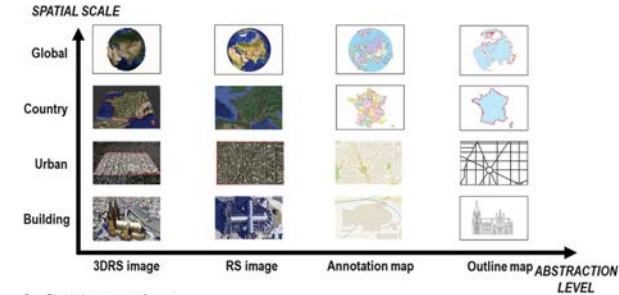
Human GIS Assistant



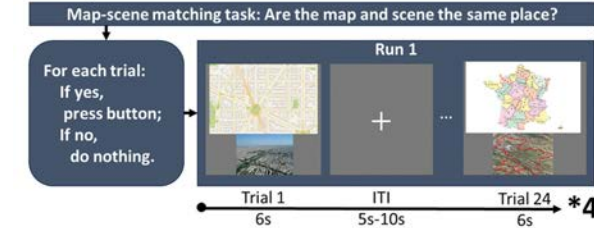
Artificial GIS Assistant



a. Geovisualization stimuli

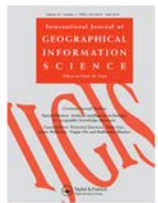


b. fMRI procedure



- Neural representation of geoinformation in the human brain (Yang et al & Dong. 2025, *Annals of GIS*)
- NeuroCognitive Geography** (Yang et al & Dong. 2025, *Science Bulletin*)

GeoAI Moonshot: Can we develop **an artificial GIS analyst** that passes a domain-specific Turing Test by 2030?



International Journal of Geographical Information Science

ISSN: 1365-8816 (Print) 1362-3087 (Online) Journal homepage: <https://www.tandfonline.com/loi/tgis20>



GeoAI: spatially explicit artificial intelligence techniques for geographic knowledge discovery and beyond

Krzysztof Janowicz, Song Gao, Grant McKenzie, Yingjie Hu & Budhendra Bhaduri

To cite this article: Krzysztof Janowicz, Song Gao, Grant McKenzie, Yingjie Hu & Budhendra Bhaduri (2020) GeoAI: spatially explicit artificial intelligence techniques for geographic knowledge discovery and beyond, International Journal of Geographical Information Science, 34:4, 625-636, DOI: [10.1080/13658816.2019.1684500](https://doi.org/10.1080/13658816.2019.1684500)

- ✓ self-generating
- ✓ self-executing
- ✓ self-verifying
- ✓ self-organizing
- ✓ self-growing



International Journal of Digital Earth

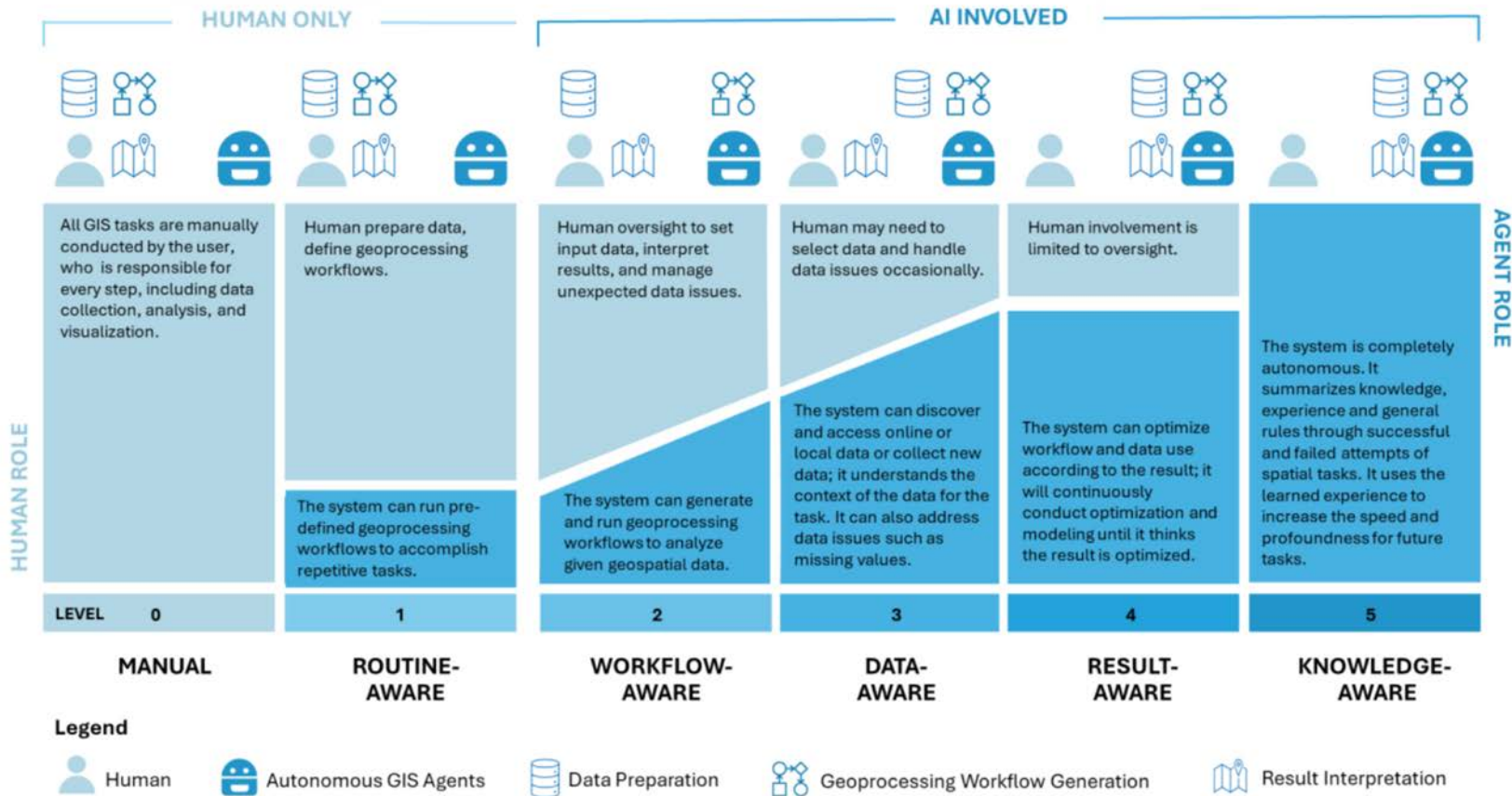
ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tjde20

Autonomous GIS: the next-generation AI-powered GIS

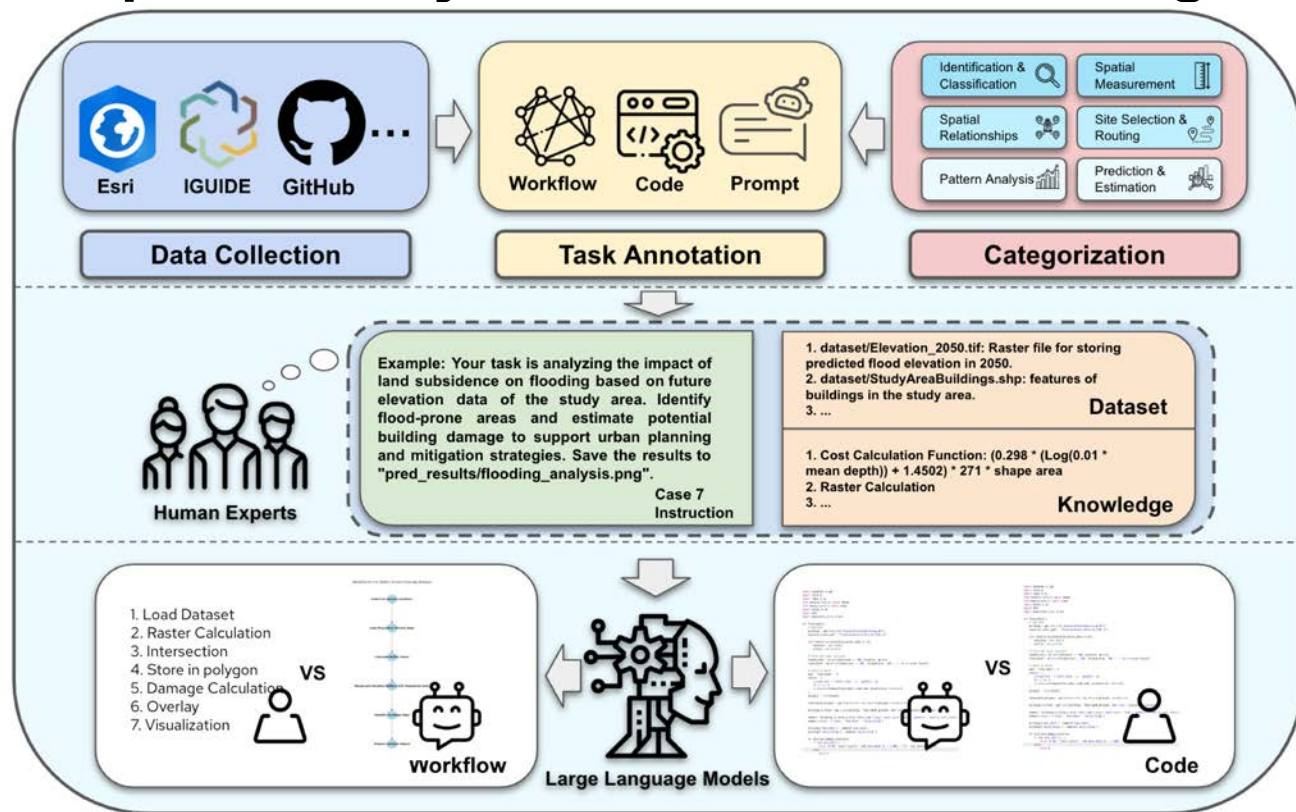
Zhenlong Li & Huan Ning

To cite this article: Zhenlong Li & Huan Ning (2023) Autonomous GIS: the next-generation AI-powered GIS, International Journal of Digital Earth, 16:2, 4668-4686, DOI: [10.1080/17538947.2023.2278895](https://doi.org/10.1080/17538947.2023.2278895)

Five Levels of Autonomous GIS

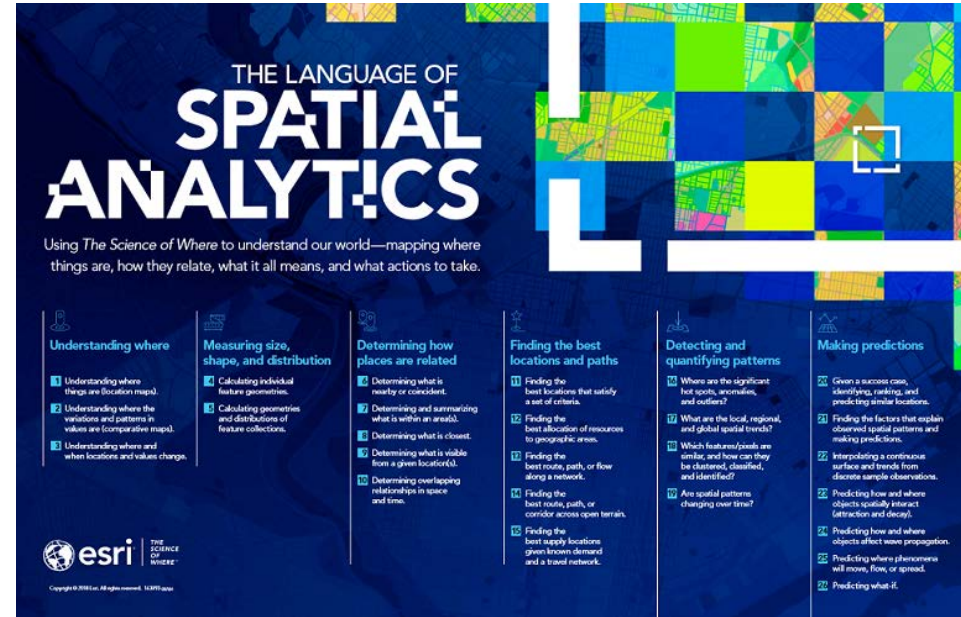


GeoAnalystBench: A GeoAI benchmark for assessing LLMs for spatial analysis workflow and code generation



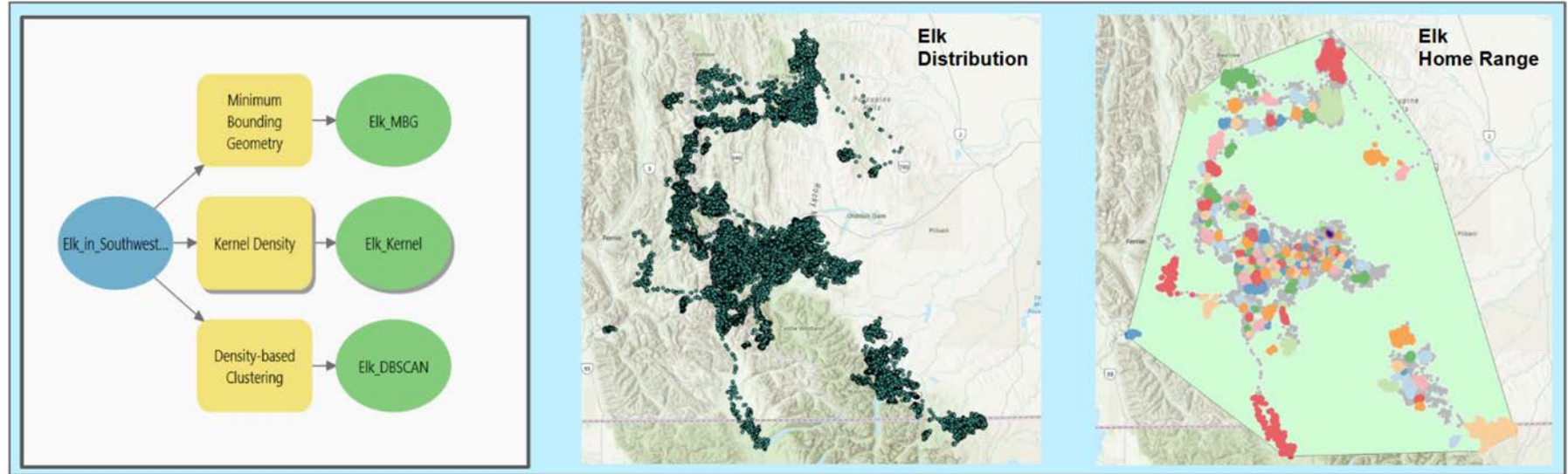
Spatial Analysis Tasks in GeoAnalystBench

- Understanding where
- Measuring size, shape, and distribution
- Determining how places are related
- Finding the best locations and paths
- Detecting and quantifying patterns
- Spatial interpolation and prediction



<https://github.com/GeoDS/GeoAnalystBench>

Example: Identification of Home Range and Spatial Clusters from Animal Movements



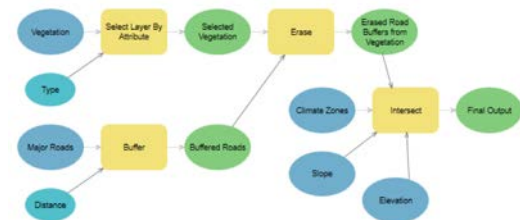
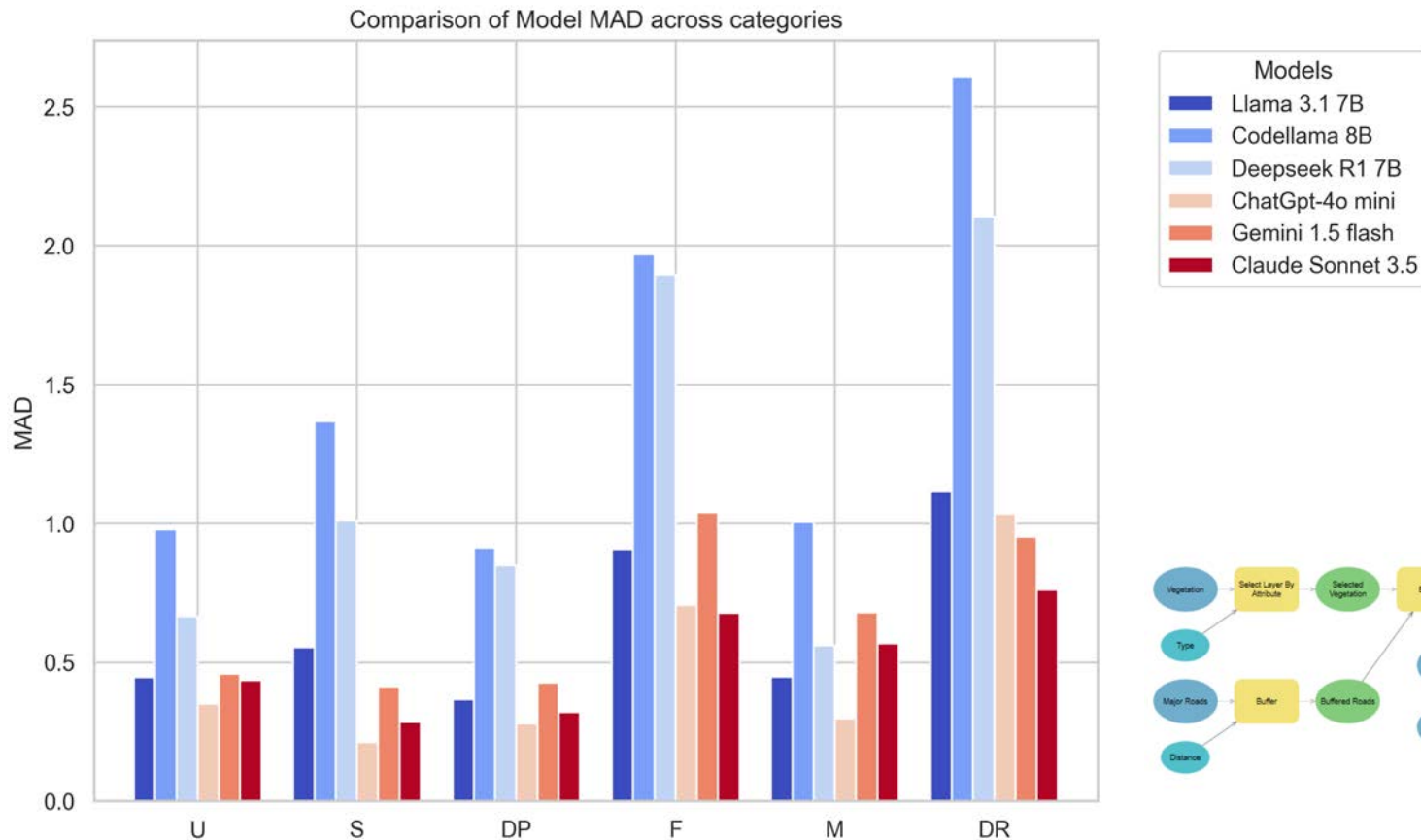
ChatGPT



1. Load GPS Data
2. Preprocess Data (Clean & Filter)
3. Plot GPS Tracks (Visualize Movements)
4. Estimate Home Range: Convex Hull (Minimum Bounding Geometry)
5. Compute Kernel Density Estimation
5. Apply DBSCAN Clustering
7. Analyze Home Range & Habitat Preferences
8. Store Outputs in Geodatabase



Performance of workflow generation in GeoAnalystBench



Performance of code generation in GeoAnalystBench

TABLE 5 Code evaluation results

Models	CodeBLEU	N-gram	Weighted N-gram	AST Syntax	Data-flow
Proprietary					
ChatGPT-4o-mini	0.390	0.077	0.107	0.563	0.282
Claude-3.5-Sonnet	0.370	0.070	0.089	0.532	0.249
Gemini-1.5-Flash	0.358	0.071	0.096	0.544	0.299
Open Source					
DeepSeek-R1-7B	0.272	0.032	0.044	0.405	0.265
Llama-3.1-8B	0.340	0.040	0.054	0.471	0.252
CodeLlama-7B	0.319	0.034	0.053	0.487	0.291

The evaluation captures both **text similarity** and **syntactic correctness** in programming.

Challenges in GeoAnalystBench (Cognitive)

- Analysis is more than “right answers”
- How to answer ambiguous or subjective answers? e.g., where to place a new solar powered farm?
- How should **AI agents** be designed into **systems of human judgement** rather than added as an acceptable alternative?



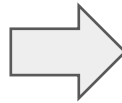
-- Lauren Bennett (Director of Spatial Data Science, Esri)

Challenges in GeoAnalystBench (Engineering)

Can LLMs generate ready to use code rather than just similar code?

`arcpy.HotSpotAnalysis_stats`

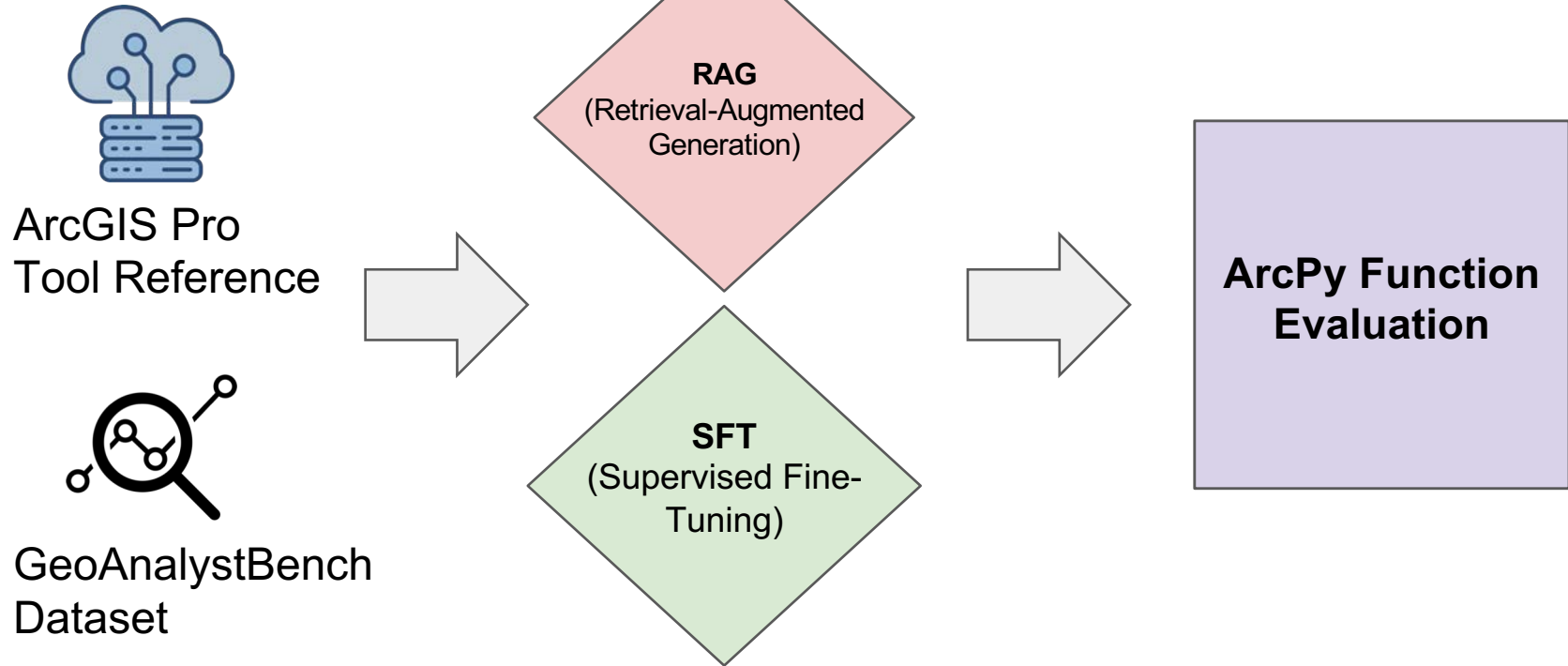
`arcpy.CreateHexagonalsiteFeatures_cartography`



`arcpy.mapping.ExportToPNG`

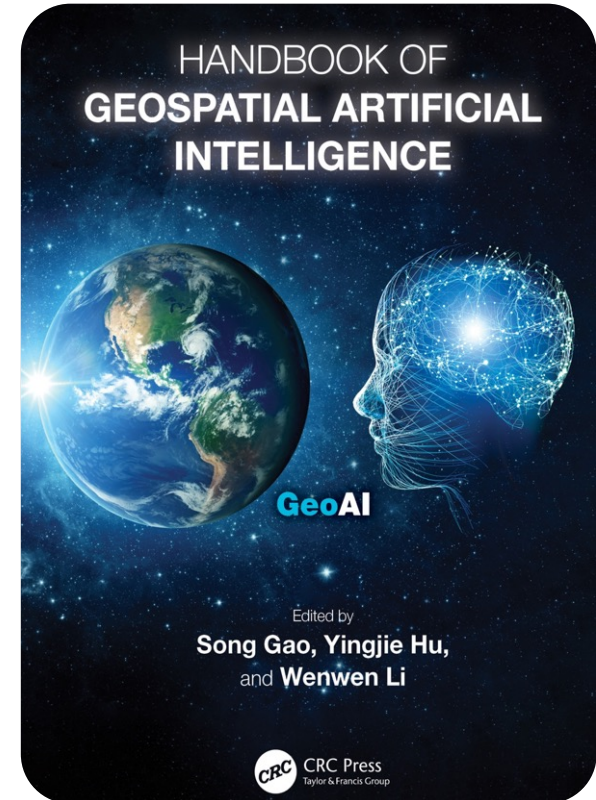
- **Misplacing toolbox and tool**
- **Hallucinated functions**
- **Out of date packages (arcpy.mp)**

Code Generation Optimization (Engineering)

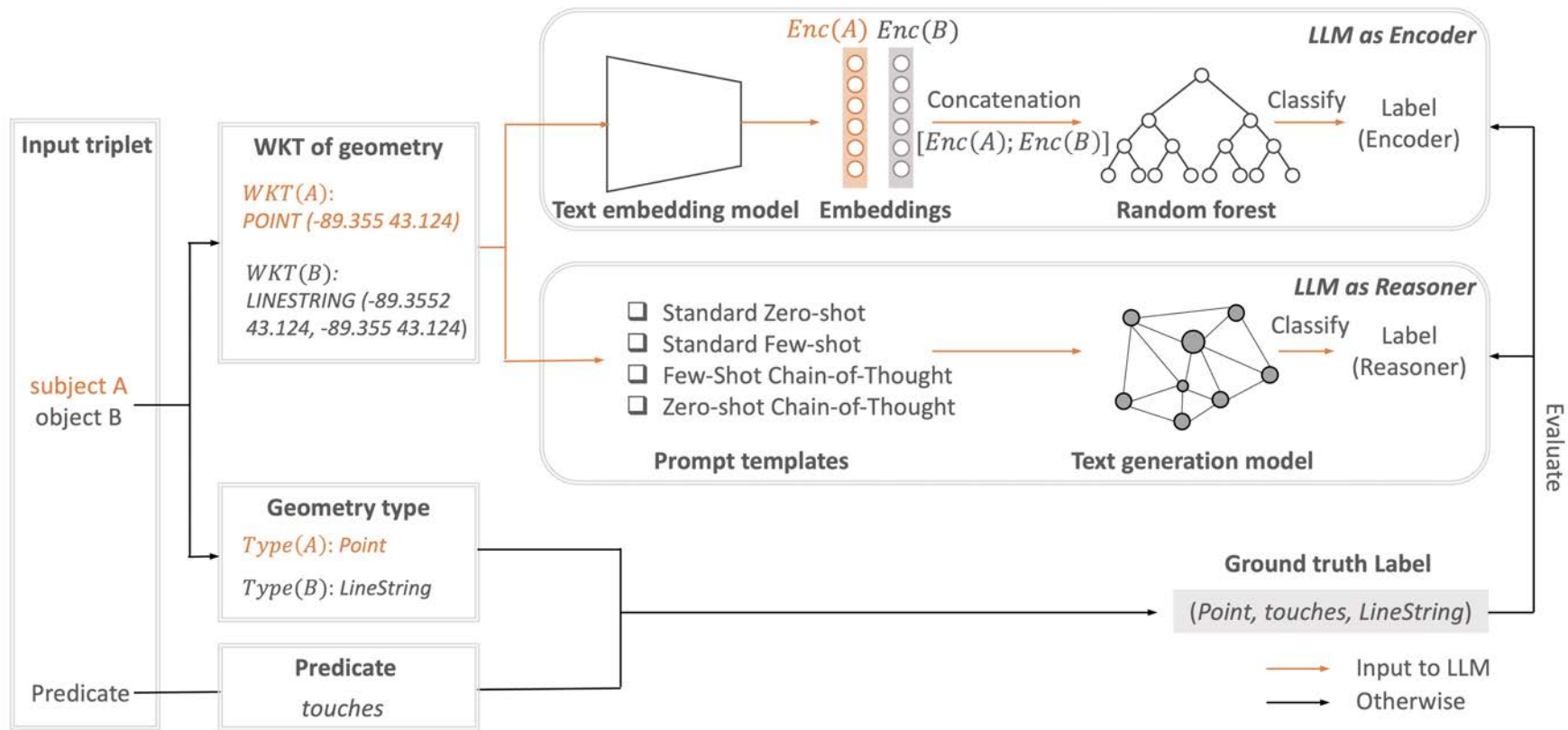


Challenges and Issues on GeoAI

- Uncertainty
- Biases
- Heterogeneity and Fairness
- Explainability
- Ethics and Privacy
- Reproducibility and Replicability
- Responsibility and Trustworthiness
- Sustainability

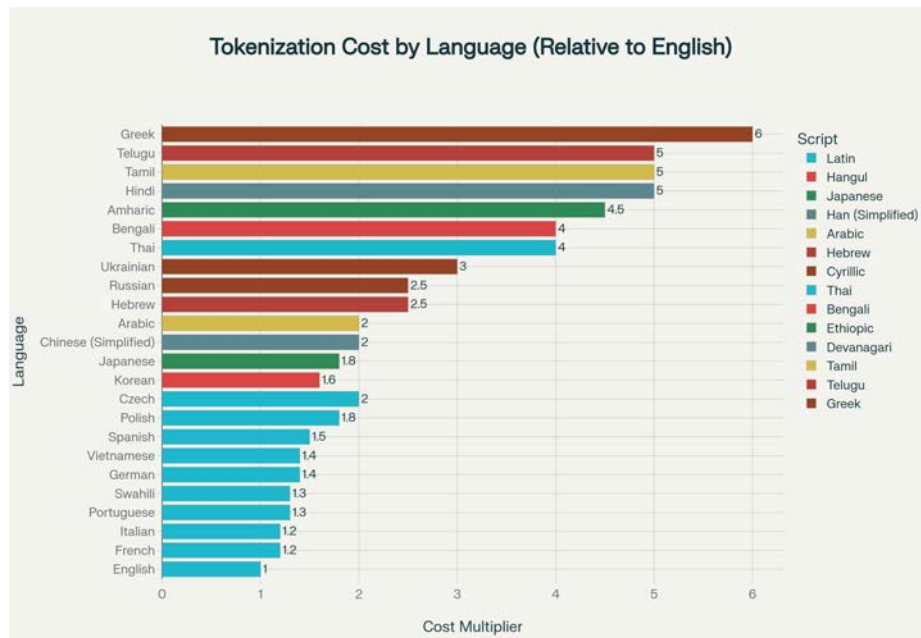


Representation Gap and Uncertainty



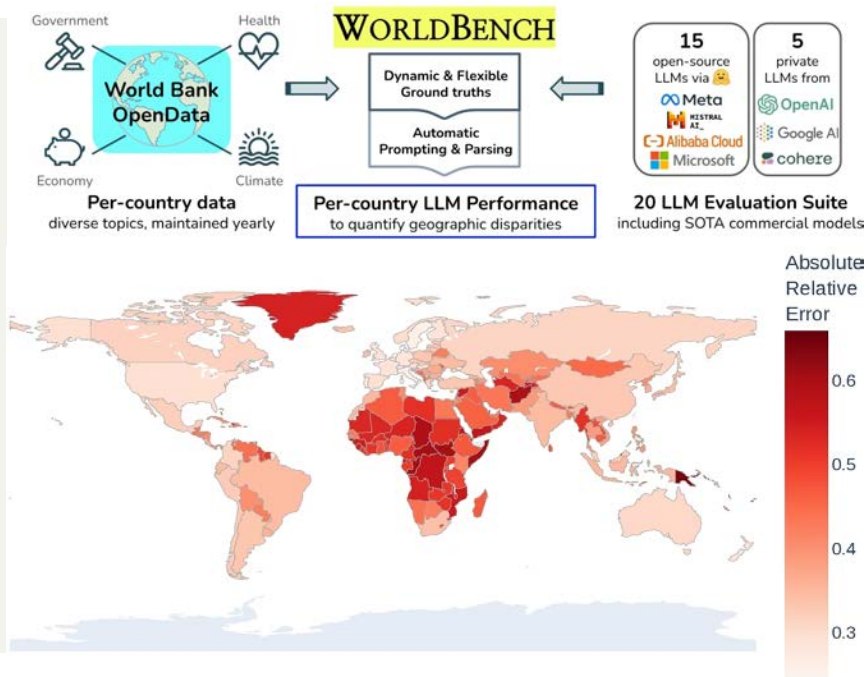
Geographic Biases and Fairness

The significant disparities in tokenization across different languages and geographic regions.



Petrov et al. (2023)

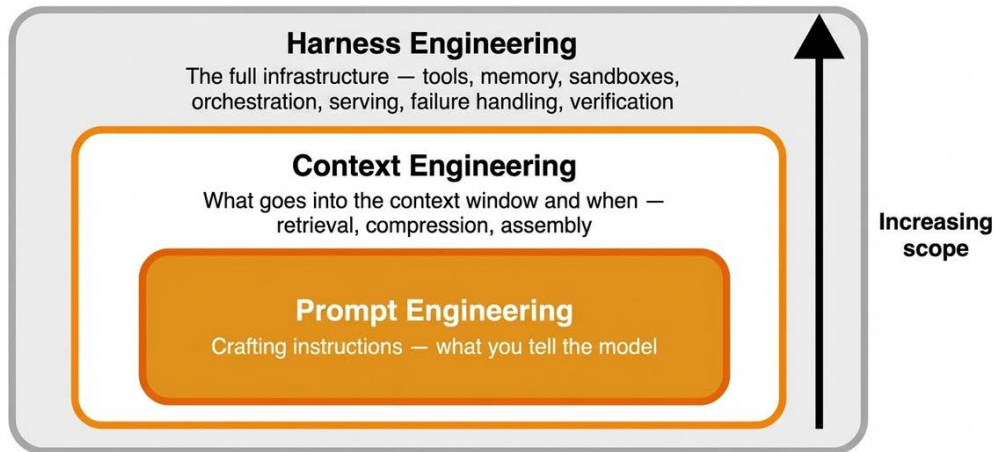
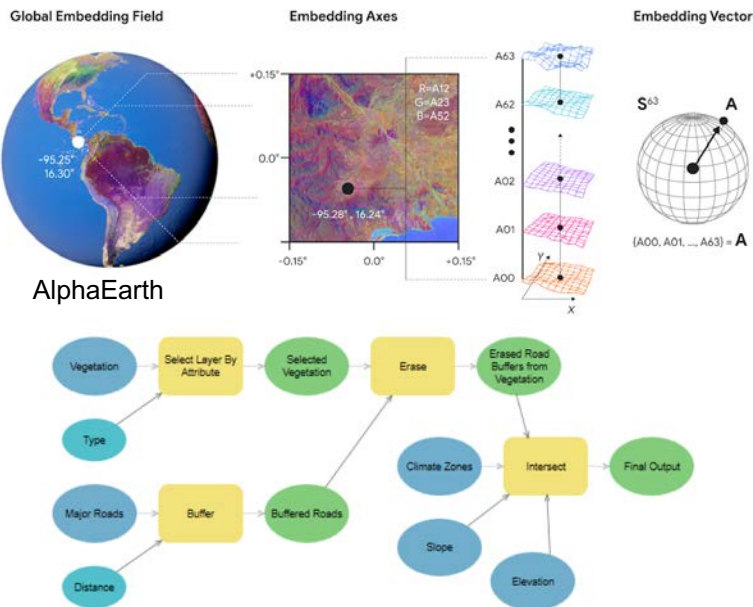
The geographic disparities by country in LLM factual recall performance.



Moayeri et al. (2024)

(Geo-)Agentic Harness Engineering

- Geo-Foundation Models + GIS/Spatial Analysis Tools + Agentic Framework
- What about the the role of human cognition and society ?



(Decoding AI Magazine, 2026)

Geo-alignment

- **Alignment** on foundation models and AI agents aims to prevent harmful biases, improve AI safety, and ensure AI systems behave according to **societal norms, values, and goals**.
- **Geo-alignment** offers a geographical perspective on alignment using **geospatial context and spatial distribution structure**.
- An AI system is said to be **geo-aligned** if for all queries $q \in Q$ and geographic contexts $g \in G$, the distribution of the system's output $S(o|q, g)$ resembles the locally (geographically) appropriate distribution of outputs $L(o|q, g)$ within a certain tolerance. More formally:

$$\forall q \in Q, g \in G, D(L(\cdot | q, g), S(\cdot | q, g)) < \epsilon$$

Thank you!

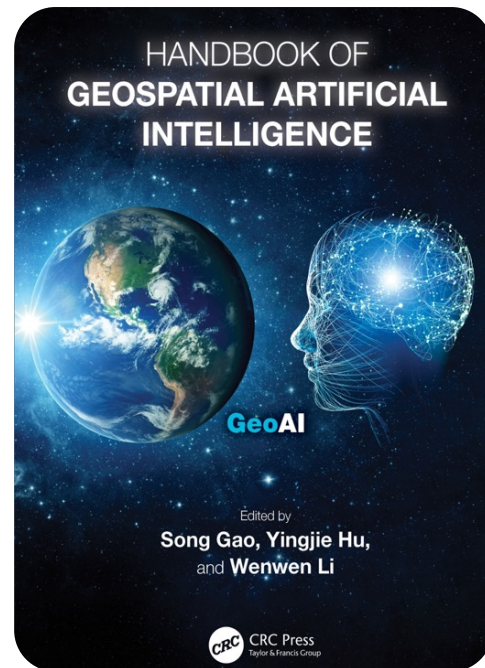
- AI <-> Geography
- GeoAI Benchmark for LLMs
- Uncertainty, Bias, Geo-Agentive and Alignment, etc.



Geospatial Data Science Lab



UW-Madison





GIScience 2027

Shanghai, China
October 18-22



<https://gisience2027.org/>

