The Place You See: Reconstructing Geographical Imagination from Brain Activities Using the Mind2Place Diffusion Model

Somang Kim [1], Junbo Wang [2] and Yuhao Kang [1*]

[1] Department of Geography and the Environment, The University of Texas at Austin, Austin, USA
[2] Department of Geography and Sustainability, University of Tennessee, Knoxville, USA
* yuhao.kang@austin.utexas.edu

Keywords: brain activity, brain-to-image reconstruction, diffusion model, geographical imagination, human-centered GeoAI, neural decoding

Introduction

Understanding how humans perceive and imagine geographic environments has long been a central question in geography. Environments are not only physical spaces but are shaped through human perception, memory, and emotion (Lukermann, 1964; Tuan, 1979; Kang, 2025). Within this perspective, geographical imagination refers to the internal representation of place through which individuals interpret and give meaning to geographic environments (Prince, 1962; Harvey, 1973; Gregory, 1994).

Prior empirical studies have examined related internal understandings of geographic imagination through interviews (Hung 2011; Liu et al., 2024; Li et al., 2025), surveys (Shamai 1991; McCunn and Gifford, 2018; Zhung et al. 2023), and sketch maps or mental maps (Lynch 1964; Downs and Stea 1973; Soini, 2001; Curtis et al., 2014). However, geographical imagination itself has rarely been studied as a direct empirical object. Instead, previous studies have examined related ideas such as sense of place, place meaning, and mental maps, and have often treated them interchangeably. While these approaches provide useful insights, they are indirect and limited in capturing internal cognitive and neural processes

Recent advances in neuroscience and artificial intelligence provide new possibilities for studying internal representations of place. Brain-to-image reconstruction studies have shown that visual experiences can be partially reconstructed from neural activity using deep learning models (Bai et al., 2023; Liu et al., 2024; Scotti et al., 2023; Takagi and Nishimoto, 2023). However, most of these studies focus on general objects or scenes and do not consider geographic meaning or place-based interpretation.

To address this limitation, this study proposes Mind2Place, a diffusion-based generative GeoAI framework that reconstructs geographic imagination from brain activity. The model integrates human geographic theory with neural decoding and GeoAI methods. Using paired data of brain signals and geographic images, the framework utilizes EEG, MEG, and fMRI to capture different aspects of neural responses.

The results show that geographic scenes can be reconstructed from brain activity. The reconstructed images preserve key characteristics such as differences between natural and built environments. This suggests that neural activity contains meaningful information about place, not only visual features. These findings provide empirical evidence on how geographic imagination is represented in the brain.

This study contributes to human-centered GeoAI by introducing a new way to connect human cognition with geospatial analysis. It also provides a methodological approach for studying internal spatial experience and human–environment relationships.

Method

This study proposes the Mind2Place framework, which reconstructs geographic scenes from brain activity by combining neural decoding and diffusion-based image generation (Figure 1). The pipeline consists of two stages: mapping brain signals to a shared visual semantic space, and generating images conditioned on these representations. We use three neuroimaging modalities, EEG, MEG, and fMRI, to capture complementary aspects of brain activity. For each modality, paired datasets of brain signals and geographic scenes are constructed. The datasets are restricted to outdoor environments, including both natural and built scenes. Each neural sample is aligned with its corresponding image to form training pairs. Brain activity is first projected into a shared semantic space. A pretrained vision encoder is used to extract image embeddings that represent high-level visual meaning. Modality-specific encoders are then trained to map EEG, MEG, and fMRI signals to this embedding space using regression and similarity-based objectives. The resulting embeddings are used as inputs to a diffusion model. The model generates images by progressively refining noise into realistic scenes conditioned on brain-derived representations. This enables direct reconstruction of geographic environments from neural activities.

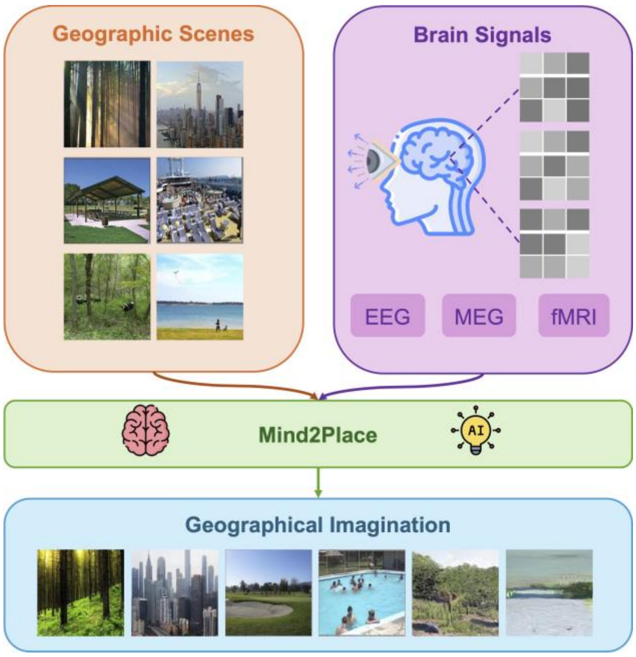

Figure 1: Mind2Place workflow

Results

Figure 2 shows qualitative comparisons between generated and ground-truth scenes across EEG, MEG, and fMRI. Overall, geographic scenes can be reconstructed from brain activity, with clear differences across modalities. EEG shows the strongest reconstructions, capturing both scene structure and semantic content. The generated images closely match the original scenes, preserving key elements such as forests, coastlines, roads, and urban skylines. MEG shows moderate performance, capturing general scene categories and layout but with reduced detail and occasional structural inconsistencies. fMRI demonstrates the weakest reconstruction quality, with outputs that often deviate from the original scenes and lack clear structural coherence. These results indicate a performance ranking of EEG, followed by MEG, and then fMRI.

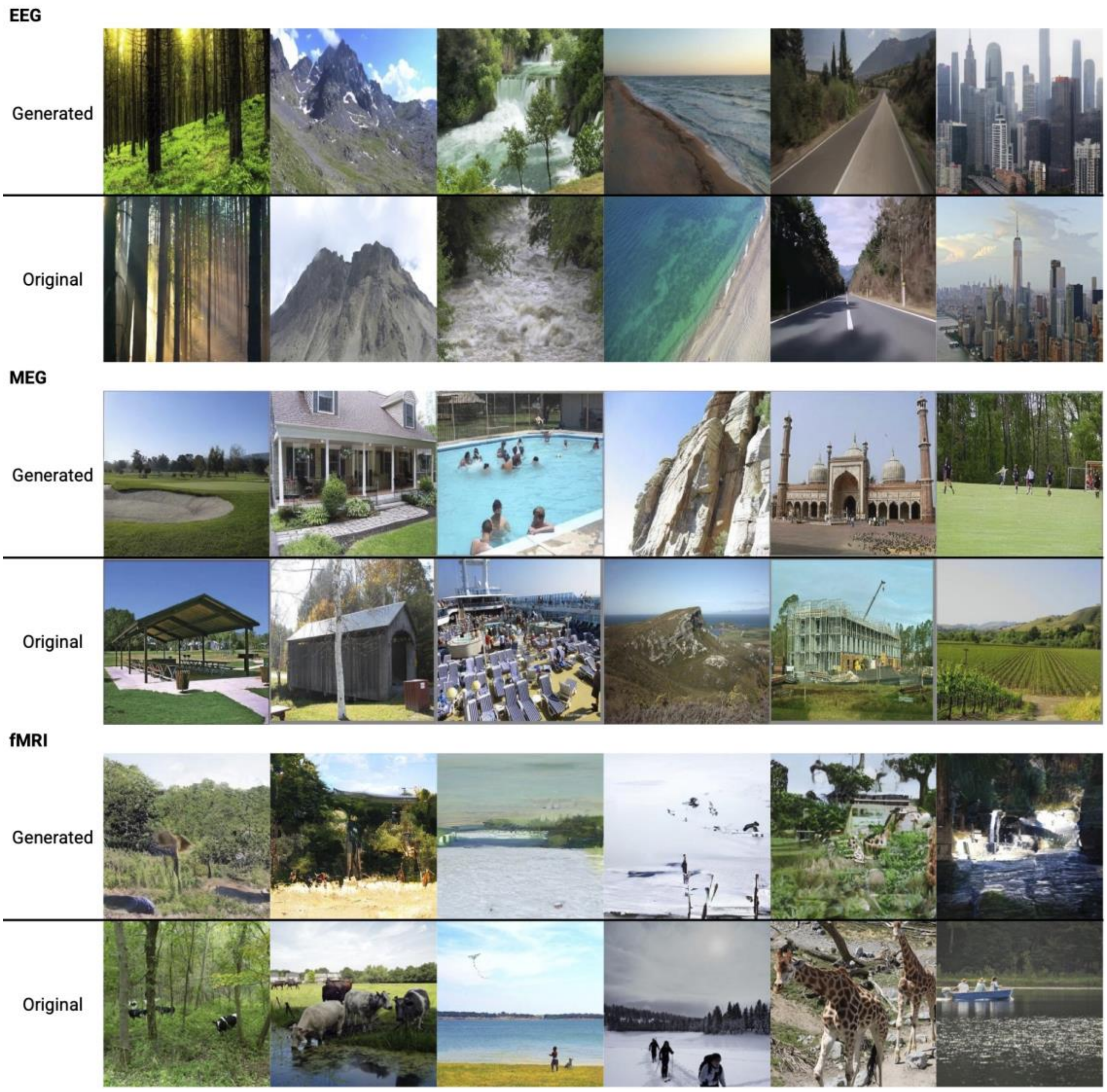

Figure 2: EEG, MEG, fMRI results

Quantitative results partially support these observations (Table 1). While MEG achieves the best performance in general metrics such as FID, EEG shows the highest scores in place-level evaluation, particularly in PSS. This suggests that general image quality metrics do not fully capture reconstruction performance for geographic scenes. In contrast, PSS better reflects the qualitative results, as it evaluates scene-level and semantic consistency. Across all modalities, strict scene matching remains challenging, but Top-5 results indicate that reconstructed images capture plausible geographic categories even when exact matches are not achieved. This further supports the idea that reconstruction operates at the level of semantic interpretation rather than exact visual replication. Overall, the discrepancy between general metrics and PSS indicates that place-level evaluation is more appropriate for assessing geographic scene reconstruction. Interestingly, EEG-based reconstruction outperforms MEG and fMRI in visual quality, suggesting that temporal resolution may play a more important role than spatial resolution in capturing geographic imagination.

	General Metrics		Place Similarity Score (PSS)		
Modality	FID ↓	IIS ↑	Element ↑	Scene ↑	Text ↑
EEG	195	0.480	0.265	0.052 (Top1) 0.244 (Top5)	0.724
MEG	96	0.490	0.256	0.015 (Top1) 0.104 (Top5)	0.678
fMRI	160	0.515	0.214	0.012 (Top1) 0.164 (Top5)	0.644

Table 1: Evaluation metrics

Discussion and Conclusion

This study demonstrates that geographic imagination can be reconstructed from brain activity using a diffusion-based Mind2Place GeoAI framework. The results show that neural signals encode place-level meaning, including distinctions between natural and built environments, rather than only low-level visual features.

Compared to traditional methods such as interviews and surveys, this approach may provide a direct and data-driven way to examine internal spatial cognition. By using brain activity as a measurable representation of how individuals perceive and interpret environments, this study offers a new empirical pathway for studying human–environment relationships.

The results also reveal important differences across evaluation metrics. While general image metrics such as FID favor MEG, place-level evaluation using PSS aligns more closely with qualitative reconstruction results, where EEG shows the strongest performance. This suggests that traditional image-based metrics may not fully capture reconstruction quality for geographic scenes, and that place-level metrics are more appropriate for evaluating geographic imagination.

Interestingly, EEG-based reconstruction outperforms MEG and fMRI in visual quality, suggesting that temporal resolution may play an important role in capturing dynamic aspects of geographic imagination. Differences across EEG, MEG, and fMRI further indicate that geographic imagination is supported by multiple neural processes, highlighting the value of a multimodal approach.

From a GeoAI perspective, this study emphasizes the importance of human-centered approaches in which human cognition becomes an integral part of the modeling process. Rather than relying solely on external data, incorporating neural signals enables a deeper understanding of how environments are internally represented.

In conclusion, this study introduces a new framework that connects human geography, neuroscience, and generative AI, and suggests that human cognition can serve as a new form of geospatial data.

Acknowledgements:

This work was supported by the University of Texas at Austin Office of the Vice President for Research (OVPR).

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