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MapMate: A Framework Bridging Natural Language Interaction and Map Design Through Large Language Models

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Abstract: Map design represents a critical interface between geographic data and human decision-making, yet it remains constrained by expertise barriers that limit its accessibility across diverse application domains. As geographic information systems (GIS) increasingly integrate with simulation environments—from urban planning scenarios to environmental modeling workflows—the need for intuitive, adaptable map design capabilities becomes paramount. This study introduces MapMate, a large language model (LLM)-based framework that transforms map design from a technical, procedure-intensive task into an accessible, natural language-driven process, thereby enhancing the integration of cartographic visualization within modeling and simulation ecosystems.

Traditional map design workflows require specialized knowledge of cartographic principles, software-specific operations, and complex parameter configurations. These barriers become particularly problematic in simulation contexts where rapid visualization iteration is essential for model validation, scenario comparison, and stakeholder communication. MapMate addresses this challenge by modeling the map design process as a goal-oriented task decomposition problem, leveraging LLMs to translate high-level design intentions into executable technical operations while maintaining cartographic integrity.

The framework architecture comprises four interconnected components that collectively model the human-AI collaborative design process. First, a request validator ensures that natural language inputs align with established cartographic principles and technical constraints, effectively simulating expert review processes. Second, a map design task planner decomposes complex, goal-oriented requirements into sequences of atomic operations, modeling the cognitive workflow of experienced cartographers. Third, a context information retriever maintains project coherence across multi-round interactions by tracking design history and current map states, simulating the contextual awareness essential to iterative design processes. Fourth, a map design tool router orchestrates platform-specific functions, abstracting technical implementation details while preserving operational precision.

A key innovation in MapMate is its hierarchical knowledge base that bridges abstract cartographic concepts with platform-specific implementations. This knowledge structure models the semantic relationships between design goals, cartographic principles, and technical parameters, enabling the framework to reason about design decisions across multiple abstraction levels. To address the inherent memory limitations of LLMs in extended interaction sessions—critical for complex simulation-driven design scenarios—MapMate implements a persistence strategy that maintains comprehensive records of operational history and evolving design states, effectively modeling the design process as a stateful system.

Three case studies validate MapMate's effectiveness across representative simulation-relevant scenarios: single-layer design refinement (modeling iterative improvement of individual thematic elements), cross-layer design coordination (simulating the integration of multiple geographic data layers), and context-aware design adaptation (demonstrating responsive modification based on accumulated design history). These studies reveal that MapMate successfully models the complex interplay between user intentions, cartographic constraints, and technical implementations, reducing design cycle time while maintaining quality standards comparable to expert-produced outputs.

The implications for modeling and simulation communities are substantial. MapMate provides a framework for integrating adaptive visualization capabilities into simulation workflows, enabling non-specialist users to generate publication-quality cartographic outputs that accurately represent model results. By modeling map design as a natural language-driven, AI-mediated process, this framework reduces technical barriers that currently limit effective communication of simulation outputs to stakeholders and decision-makers.

Keywords: *Cartography; Large language model; GIS; Human-AI collaboration*

