International Cartographic Association
Association Cartographique Internationale

Automating construction of cartographic ontology for transparent map-making decisions

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Keywords: cartographic ontology, transparent cartographic decision-making, trust in maps

Abstract:

Maps are not just objective representations of reality, but the outcome of a series of complex and often subjective cartographic decisions (Monmonier, 2018). However, the logic behind map production remains a “black box” to end users. Most users see only the final map output and do not understand the underlying design decisions (Gartner, 2022). Users know what a map contains, but not why specific features are selected, simplified, or emphasized. This lack of transparency becomes more critical in the era of automated and AI-assisted cartography (Gartner, 2025), where decision processes are further decoupled from human interpretation. Map production is no longer limited to professional cartographers. It is increasingly carried out by non-expert users (Yan et al., 2024) and AI systems (Zhang et al., 2025). This raises new challenges for map trustworthiness (Prestby, 2025). Therefore, improving the transparency in the cartographic process is essential for ensuring map trustworthiness. This calls for a formal and automated approach to document and communicate the logic behind map-making decisions.

Ontologies, defined as explicit specifications of shared conceptualization (Gruber, 1993), provide a framework for knowledge representation. Applying this framework to the cartographic domain leads to a cartographic ontology, which defines the objects, relationships, and rules of map-making (Duchesne et al., 2014). However, most existing cartographic ontologies focus on what is on the map (i.e. geographic features), such as roads, or buildings (Carral et al., 2013). These feature-based models describe what is on a map, but they cannot explain how and why the map was made. Thus, a cartographic ontology is needed to explain the decision-making processes behind map-making, focusing on how and why decisions are made. This type of ontology records the design logic and expert knowledge in a machine-readable format. By structuring these decisions into a traceable format, the logic of map production becomes easier to query and interpret. Consequently, such an ontology provides a formal way to document and communicate the reasoning behind cartographic decisions, which transforms the "black box" into a transparent pathway.

Achieving this transparency requires the formal construction of the ontology to document the cartographic decision-making process. Traditionally, building an ontology is a manual task that requires significant human effort (Noy & McGuinness, 2001), creating a bottleneck when documenting complex cartographic logic. Manual entry cannot capture the thousands of granular decisions made during map production. For example, in cartographic generalization, a cartographer must decide the displacement distance and direction for hundreds of individual buildings to avoid overlaps. Each adjustment represents a deliberate decision. Beyond generalization, the entire cartographic pipeline (including data reduction, projection, feature simplification, and so on.) involves a large number of detailed decisions. This makes manual documentation impractical. AI-driven systems further intensify this challenge by making thousands of decisions in milliseconds. Therefore, automating the construction of the cartographic ontology is essential to capture these decision parameters from the cartographic workflow. This process populates the ontology with real-time metadata, ensuring that the documented logic remains accurate, consistent, and free from human errors caused by fatigue or oversight. By embedding this process into map-production, recording decisions becomes the mechanism for achieving transparency.

The research follows the METHONTOLOGY framework to construct a formal cartographic decision ontology. The process synthesizes established cartographic principles from literature and refines them through expert consultations to elicit a taxonomy of map-making decisions (e.g., selection, generalization). These concepts are formalized into a machine-readable semantic model using OWL/RDF. The ontology schema is structured around core classes including DecisionEvent, Constraint, Operator, and Rationale, encoding the causal links of cartographic actions. To achieve automation, a decision-tracking tool is developed to log metadata from the cartographic workflow from GIS software API (e.g. QGIS) in real-time. These data are converted into RDF triples via a JSON-LD interface and integrated into a

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knowledge graph (KG) implemented in a scalable triple-store. This infrastructure ensures that the logic behind each map-making action is explicitly structured and traceable.

The framework is implemented using OSM-based building generalization in Vienna's Inner City as a case study. The system's technical validity is verified by evaluating the retrieval accuracy of decision rationales via SPARQL queries. Subsequently, a controlled experiment is designed to assess decision transparency; we measure whether the explicit logic provided by the ontology allows users to correctly identify the underlying rules of map changes. Additionally, the impact of this transparency on map trustworthiness is measured using the MAPTRUST scale. This setup evaluates whether the automated ontology-KG framework effectively transforms the cartographic "black box" into a transparent and interpretable experience.

The automated construction of a cartographic ontology provides a structured way to document the complex logic of map production. By making these previously hidden decisions explicit, the ontology makes the reasoning behind the map visible to the end-user. As the decision-making path becomes visible and traceable, the cartographic process becomes more transparent. Ultimately, when the map-making process is transparent and open to inspection, map trustworthiness improves and users can make more informed judgments.

Acknowledgements

The authors thank the EuroCarto 2026 organizing committee and the anonymous reviewers for their valuable feedback on the formatting and content of this abstract.

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