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From Maps to Geospatial Knowledge Graph: Geospatial Knowledge Representation and Reasoning

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Abstract:

Geospatial knowledge is the result of spatial thinking and reasoning about natural and human phenomena (Golledge 2002), playing an important role in urban planning, land management, and environmental protection. Digital vector maps are important sources of geospatial knowledge such as topographic maps, land cover maps, traffic maps, city maps, etc. Maps, distinguished by spatial cognition expression symbols, are regarded as the second language of geoscience research. Maps are not only a means for humans to explain geographical phenomena, but they are also a significant instrument for gaining spatial information. Humans get spatial knowledge about geographic objects' location, shape, size, spatial pattern, etc. from maps via intuitive visual perception, computational geometry, spatial statistics, and other spatial operation methods. Driven by data collection technologies, artificial intelligence, and network technology, map audiences are shifting from human-oriented services to intelligent machine-oriented services. Map service has encountered new challenges in intelligent machine application fields (e.g., spatial scene perception for autonomous driving, semantic navigation of indoor robots, etc.)—heterogeneous spatial semantics, insufficient representation of spatial knowledge, and inadequate knowledge reasoning ability (Zhang et al. 2022). Traditional spatial representation with geometric symbols benefits human visual perception, geometric operations, and statistical analysis, but it is unsuitable for machine-oriented services. To expand geospatial knowledge services and promote the development of knowledge-driven research, a geographic knowledge representation model that can be interpreted and calculated by machines is required.

Knowledge representation creates an abstract model of reality and is a crucial medium for intelligent reasoning and efficient knowledge computing (Davis et al. 1993). From expert systems in the 1970s to rule-based reasoning framework languages in the 1980s, any knowledge representation approach necessitates a specific form for knowledge storage. The knowledge graph is the latest research outcome in the field of knowledge representation. Because of its benefits in structured knowledge representation and intelligent reasoning, it is widely utilized in intelligent question answering and intelligent recommendation. Inspired by the knowledge graph, geographic entities, geographic concepts (concept "river", "country", "forest", etc.), places and locations can be abstracted into nodes, and relations (spatial relationship, spatial process, spatio-temporal association, etc.) can be abstracted into edges, i.e., the geospatial knowledge graph (GKG). The combination of knowledge graph with geographical knowledge has piqued the interest of the GIS community. Geographic Knowledge Graph, for example, is a knowledge system that describes geographic concepts, geographic phenomena, geographic processes, and man-land relationships (Wang et al. 2019). GEKG (Geographic Evolutionary Knowledge Graph) focuses on conveying geologic evolution event knowledge and provides support for disclosing the formation process (Zheng et al. 2022). Furthermore, huge general knowledge graphs such as YAGO2 (Hoffart et al. 2013) and Dbpedia (Bizer et al. 2009) have extended predicate descriptions of spatio-temporal information. Although substantial progress has been achieved in the representation of geographic knowledge, some issues remain: (1) At present, most general knowledge graphs treat spatial knowledge as general attributes, ignoring spatio-temporal characteristics. Meanwhile, they are primarily extracted from Internet text data, with limited spatial entity coverage and insufficient spatial knowledge. (2) Existing geographic knowledge graphs summarize geographic links (e.g., topological relations, directional relations, etc.) but lack high-level geographic information, such as spatial patterns. Furthermore, knowledge graphs in geographic fields lack a summary of the geographic knowledge system, the framework for extracting spatial knowledge from vector maps, and the knowledge reasoning methods.

Concerning the aforementioned challenges, this study outlines the relevant theories and methodologies for constructing GKG from maps, covering three perspectives: knowledge representation, knowledge extraction, and knowledge reasoning. To begin, the geospatial knowledge system is divided into micro, meso, and macro levels, and the fundamental elements

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of knowledge representation are presented. Second, a technical framework for extracting spatial knowledge from maps (see Figure 1) is given, which is divided into two parts: initial knowledge graph construction and spatial knowledge enrichment. Finally, several methods of spatial knowledge reasoning are discussed.

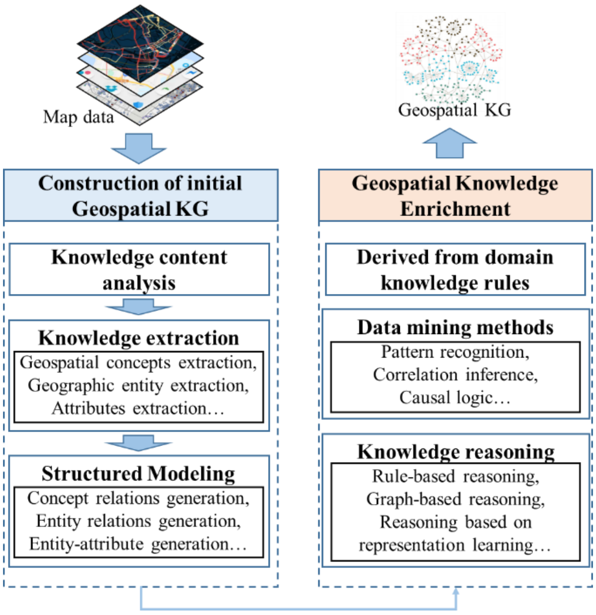

Figure 1. Geospatial knowledge extraction framework from vector maps.

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