




Ontology-based Textual Location Description Framework for Multidimensional Features

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Abstract. Textual location descriptions provide meaningful representations of spatial positions and are widely used to convey the locations of people and objects. Contemporary approaches for generating location descriptions focus mainly on point-based queries, such as reverse geocoding and human-based generators. In this study, an ontology-based textual location description framework that smoothly integrates spatial data, spatial cognition, and locational semantics is proposed. The aim is to generate automated natural-language location descriptions for multidimensional feature queries. Transportation scenarios are used as experimental cases. This method outperforms human-written and generative artificial intelligent (AI) descriptions by more than 30%. The proposed framework provides a new path for location description, supporting diverse spatial queries and contextual and spatial-cognitive applications.

Submission Type. Model.

BoK Concepts. [CF3] Cognitive, linguistic and social foundations, [CF6] Relationships, [AM2] Query operations and query languages.

Keywords. Ontology, textual location description, framework, multidimensional features, traffic.

1 Introduction

Textual location descriptions signify meaningful representations of natural language context, enabling not only the identification of one's position but also the generation of notifications where events or emergencies occur. Textual location descriptions are generally more efficient than coordinated values for localization in human communication. Common textual location descriptions often include place names, landmarks, points

of interest, addresses, and directions. An example is “in front of Taipei 101,” which illustrates the use of a landmark (Taipei 101) as the reference system for location identification, where the subject is situated in front of the landmark.

Textual location descriptions can be taken as the results of well-received reverse geocoding processes, which allow users to obtain structured textual information from spatial queries for localization and communication (Google, 2026; Mapbox, 2026; OpenStreetMap, 2026). Hall and Jones (2022) proposed a toponym-driven algorithm with spatial templates for location description generation. However, contemporary approaches to reverse geocoding can afford point-based queries only, which leaves room for more flexible requests involving multidimensional features, such as lines and polygons, to support spatial positing applications. Stock et al. (2022) proposed a spatial semantic pyramid framework to review and investigate a wide range of spatial language research. Previous studies focus only on generating textual guidance for vehicle and pedestrian navigation systems. A research gap occurs in answering diverse user demands with appropriate responses in a range of scenarios for stable and convinced textual location descriptions.

When ontologies enable the presentation of domain knowledge (Gruber, 1995; Noy, 2004), which formalizes the terminology, structures, attributes, and interrelations of domain-specific objects, they can also bridge existing gaps in the expression of location semantics within spatial data. In this study, an ontology-based framework is used to generate textual location descriptions for multidimensional feature queries. The following questions are addressed:

1. How can an ontology-based framework be designed to integrate spatial queries, geodata, and spatial

knowledge to generate textual location descriptions for multidimensional features?

2. How are textual location descriptions constructed via contextual and spatial-cognitive processes?

2 Methods

An ontology-based textual location description (O-TLD) framework is proposed to integrate spatial data with the semantic knowledge of location descriptions for natural language representation. Section 2.1 presents the O-TLD framework, which comprises spatial data, locational semantics, and textual representations. Section 2.2 presents the structure of the location description ontology (LocD ontology), which supports the modeling of multidimensional features' spatially semantic relationships. Section 2.3 describes the design criteria for semantic rules and the inference mechanism that enables the dynamic generation of location descriptions.

2.1 O-TLD Framework

Three layers of the O-TLD framework are shown in Fig. 1: the *data layer*, the *semantic layer*, and the *natural language layer*. This framework is designed to address the cognitive requirements of human spatial understanding regarding spatial data and the challenges of representing the semantics of location descriptions. These layers are connected through a top-down semantic mapping relationship, corresponding to spatial data, the ontology, and linguistic expressions. Semantic rules based on Semantic Web Rule Language (SWRL) (Horrocks et al., 2004) are applied to bridge the three layers, forming an integrated semantic inference mechanism.

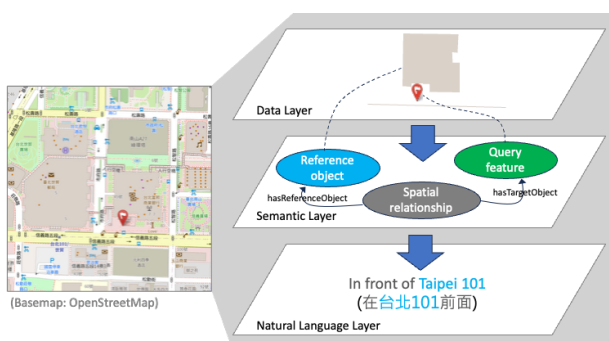


Figure 1. O-TLD three-layer framework.

The *data layer* records potential spatial data, including query features and reference features, that are being processed. All the features can be points, lines, or polygons. The *semantic layer* serves as the core in the framework and is responsible for semantic representation and knowledge integration with the use of ontologies. When the formal characteristics of ontological modeling are leveraged, this layer can integrate locational

knowledge from various domains, including spatial information, spatial cognition, and linguistics, to support the construction of location semantics and the generation of location descriptions. The ontology designed in this layer is highly extensible and can be expanded according to specific research objectives to enrich domain-specific content. The *natural language layer* transforms the semantic representations and reasoning results in the semantic layer into human-readable natural language texts. Language templates and structural configurations are employed to formally present the generated location descriptions.

2.2 Location Description Ontology

The spatial semantics of multidimensional features are aligned. So, the location description (LocD) ontology comprises top-level ontologies and two subclasses, “Feature Concept” and “Spatial Concept and Location Description Concept”, related to spatial objects and location descriptions, respectively. Top-level ontologies provide a foundational semantic structure for integration and interoperability within the domain, whereas subclasses represent concepts of transformation for semantically feature properties and textual location descriptions.

2.2.1 Upper part of the LocD

The semantic representation requirements of spatial cognition and natural language-based location descriptions are considered in this study. Three top-level ontologies, namely, Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) (Borgo et al., 2022), GeoSPARQL (Battle & Kolas, 2011), and Extended-HowNet Ontology (E-HowNet) (Huang et al., 2008), are integrated to form the foundation of the proposed LocD ontology. When DOLCE is adopted to distinguish different stages of spatial cognition, including the representation of spatial concepts, features, and location descriptions, GeoSPARQL serves as the semantic interface for the data layer, facilitating the representation and retrieval of features and their spatial operations within the ontology-based framework. E-HowNet is adopted as a Chinese lexicon resource, supporting the mapping between Chinese lexical items and semantic concepts by providing a predefined lexicon–concept structure as E-HowNet expression. Integration aims to achieve semantic interoperability across conceptual, spatial, and linguistic domains.

The three top-level ontologies form the upper part of the LocD ontology (Fig. 2). The *dul:Feature* from DOLCE is adopted to present spatial objects from the data layer. The *locd:SpatialConcept* and *locd:LocationDescription* (the *locd* prefix indicates the LocD ontology) are designed to

2.2.3 Spatial Concept and Location Description Concept

Location descriptions formally follow a triplet pattern, consisting of a place name, a spatial preposition, and a localizer structurally. In terms of supporting the semantic interpretation and generation of natural language-based location descriptions, the *locd: SpatialConcept* and the *locd: LocationDescription* are designed to record features' associated semantic concepts and lexical units (Fig. 4). E-HowNet classes related to Chinese directional or spatial lexical, denoted as *ehn* prefixes, are used to express spatial cognition. Three E-HowNet categories, *ehn: LocationFunction*, *ehn: DistanceValue*, and *ehn: AlterLocation*, are bridged to *locd: SpatialRelationship* to facilitate semantic-spatial integration.

While location descriptions are used to symbolize spatial concepts, the *locd: LocationDescription* is linked to its underlying *locd: SpatialConcept* via the property *locd: symbolize*. Analogous to the linguistic facet in the place facet framework, a location description is composed of three core elements: the figure feature (target place), the ground feature (reference place), and the spatial relationship between them. In linguistic form, the figure and ground are realized as place names, and the spatial relationship is encoded via spatial prepositions and localizers. Here, *locd: LocationDescription* is formally related to three key components via object properties: *locd: hasPlaceName* to *locd: PlaceName*, *locd: hasSpatialPreposition* to *locd: SpatialPreposition*, and *locd: hasLocalizer* to *locd: Localizer*.

2.3 Three-Stage Spatial Cognitive Rules

Three-stage spatial cognitive rules based on SWRL are proposed to enable the automated generation of location descriptions from spatial queries. The following rules are designed to bridge the O-TLD three-layer framework via the LocD ontology, thus supporting context-aware semantic reasoning and the generation of location descriptions:

1. Contextual influence on reference object selection,
2. Mapping data layer to semantic layer, and
3. Natural language layer transformation from the semantic layer.

Three stages form an extensible and semantically interpretable inference mechanism, which provides a knowledge foundation for the subsequent generation of locational lexical information.

The purpose of the first stage is to automatically filter spatial objects that are contextually relevant and assign them appropriate semantic roles. Numerous features may serve as reference objects, but not all are semantically valuable for location descriptions in specific contexts. For

example, in a traffic-related context, the mechanism prioritizes road-related features while ignoring irrelevant features, such as natural geographic entities. For example,

$$\text{Traffic}(\text{?ctx}) \wedge \text{Road}(\text{?ref}) \wedge \text{SpatialOperation}(\text{?rel}) \rightarrow \text{GroundFeature}(\text{?ref}), \text{hasGroundFeature}(\text{?rel}, \text{?ref})$$

This rule indicates that in a traffic context (*Traffic*), a *Road* is treated as a *GroundFeature*.

In addition to context-specific rules, general rules not bound to specific contexts can be defined. For example:

$$\text{GeneralContext}(\text{?ctx}) \wedge \text{Feature}(\text{?ref}) \wedge \text{SpatialOperation}(\text{?rel}) \rightarrow \text{GroundFeature}(\text{?ref}), \text{hasGroundFeature}(\text{?rel}, \text{?ref})$$

This rule states that any feature can be treated as a *GroundFeature* in a general context.

The second stage emphasizes spatial semantic inference, which involves mapping spatial operations between features to corresponding semantic spatial relationships to ensure context-sensitive semantic interpretation. For example,

$$\text{Within}(\text{?rel}) \wedge \text{FigureFeature}(\text{?tar}) \wedge \text{hasFigureFeature}(\text{?rel}, \text{?tar}) \wedge \text{GroundFeature}(\text{?ref}) \wedge \text{hasGroundFeature}(\text{?rel}, \text{?ref}) \rightarrow \text{OnSite}(\text{?rel})$$

This rule states that if a spatial operation *Within* holds between the figure and ground, then it can be semantically interpreted as *OnSite*.

Moreover, rules may incorporate feature qualities (e.g., geometry, type, or elevation) to derive more nuanced semantic relations that cannot be inferred from spatial relations alone. For example, the semantic relation *Upper* may vary depending on the type of reference feature. If the reference object is a building, then *Upper* may denote a position above the rooftop. However, if the reference is a park, then such usage would be semantically odd.

$$\text{Within}(\text{?rel}) \wedge \text{FigureFeature}(\text{?tar}) \wedge \text{hasFigureFeature}(\text{?rel}, \text{?tar}) \wedge \text{GroundFeature}(\text{?ref}) \wedge \text{hasGroundFeature}(\text{?rel}, \text{?ref}) \wedge \text{hasQuality}(\text{?ref}, \text{?form}) \wedge \text{StyleandForm}(\text{?form}) \wedge \text{qualityValue}(\text{?form}, \text{"elevated"}) \rightarrow \text{Upper}(\text{?rel})$$

This rule expresses that when a figure lies within a reference feature and the reference is characterized by an elevated form (e.g., elevated structures), the semantic relation *Upper* can be inferred.

The third stage focuses on generating natural language location descriptions from the semantic layer. A template-based natural language generation approach is used to achieve flexible and context-aware generation. SWRL rules are mapped to language templates according to semantic relations. For example,

OnSite(?rel), *LocationDescription(?locad)*, *symbolize(?rel, ?locad)*, *AtSpatialPreposition(?word)* → *hasSpatialPreposition(?locad, ?word)*

This rule indicates that if the inferred spatial relation is *OnSite*, then the corresponding spatial preposition “At” (e.g., “在” [zai] in Chinese) is associated with the *LocationDescription*.

The rules allow spatial queries to be systematically transformed into natural language expressions, further allowing users to receive interpretable and accurate descriptions for position identification.

2.4 Data and Software Availability

The demo data and code that support the findings of this study are available at <https://gitops.tw/conference/locd>.

3 Implementation

A transportation scenario is selected as the case study, as traffic conditions are among the major concerns in daily life. The real-time traffic Chinese reports from the Police Broadcasting Service (PBS) (National Police Agency, 2026) are selected as the study materials, which presents formal announcements with manual editing. The results of multidimensional spatial queries based on the proposed method are provided in Section 3.1, and an evaluation and discussion are given in Section 3.2. All the raw and generated descriptions were originally presented in Chinese and subsequently translated into English by the author for presentation and evaluation purposes.

3.1 Results of the Multidimensional Spatial Query

Case 1 performs a point query on a national highway (Fig. 5). The generated location description is “near the 12.1 km mark of the Sun Yat-sen Freeway (the Xizhi System Interchange)”. The proposed method successfully captured the highway name and its nearby interchange.

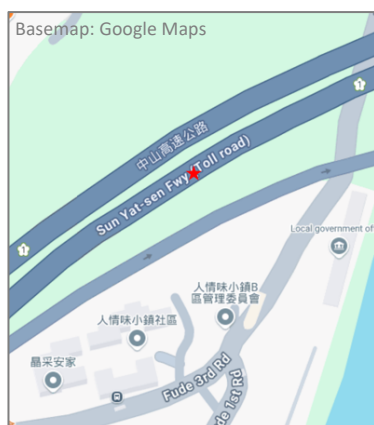


Figure 5. Point query case (on a national highway).

Case 2 presents a line query on an elevated expressway (Fig. 6). In this example, a linear feature, such as driver movement trajectory, was used to indicate that the system can interpret linear spatial relations. The generated location description is “On Jianguo Expressway in Daan District, Taipei City (above Section 3, Zhongxiao East Road)”. The proposed method successfully captured the road name and elevation information.

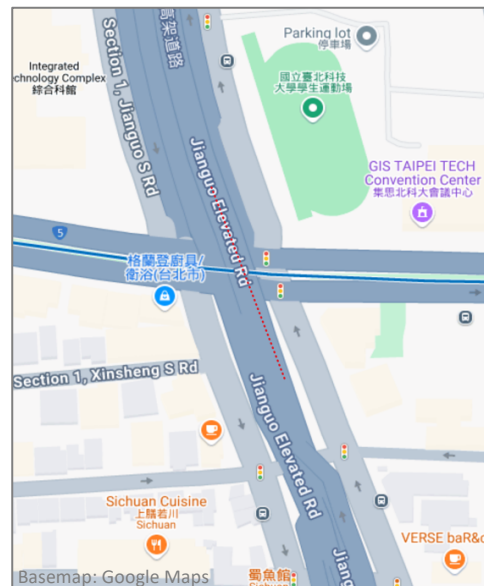


Figure 6. Line query case (at an elevated expressway).

Case 3 involves a polygon query at a road intersection (Fig. 7). The generated location description is “at the Minquan West Road intersection in Datong District, Taipei City (near the MRT Minquan West Road Station)”. The environmental surroundings are successfully captured for spatial recognition.



Figure 7. Polygon query case (at a road intersection).

3.2 Evaluation and Discussion

Human-written PBS and the GPT-4o, a large-language model, are selected for comparison in the experiments. The former represents formal announcements with a human-written approach, and the latter are AI-based solutions.

Semantic Propositional Image Caption Evaluation (SPICE) is used as the evaluation metric for assessing the semantic alignment between the results and the ground-truth descriptions (Anderson et al., 2016). SPICE is considered equivalent to the F1 score, which integrates the precision and recall of semantic units. Semantic units refer to sets of triples derived from descriptions into semantic scene graphs. The triples can take the form of (*object*), (*object, attribute*), or (*object, relation, object*). The evaluation protocols are defined by Eqs. (1)–(3). P denotes precision, R denotes recall, c represents the generated candidate description, S is the ground truth reference description, T(G(c)) is the set of triples extracted from the candidate, T(G(S)) is the set of triples extracted from the reference, and the operator \otimes denotes set-level matching.

$$P(c, S) = \frac{|T(G(c)) \otimes T(G(S))|}{|T(G(c))|} \quad (1)$$

$$R(c, S) = \frac{|T(G(c)) \otimes T(G(S))|}{|T(G(S))|} \quad (2)$$

$$SPICE(c, S) = F_1(c, S) = \frac{2 \cdot P(c, S) \cdot R(c, S)}{P(c, S) + R(c, S)} \quad (3)$$

Table 1 shows the evaluation results, supplemented by ground truth data and detailed description results (Appendices A and B). The proposed method outperforms the other approaches because of its better alignment with the ground truth in terms of semantic content and more appropriate textual location presentation among all dimensions. Human-written PBS has high-precision performance, especially when working on line and polygon features, with convincing descriptions provided for localization. However, human-written PBS may be suitable only for domain experts because of their simplified descriptions, thus leading to low recall. Compared with GPT-4o, the understanding of geographic entities is more limited. As a result, its overall scores are consistently low and show a notable gap in AI-based location descriptions.

Table 1. Evaluation results.

ID	Ours			PBS			GPT-4o		
	P	R	F1	P	R	F1	P	R	F1
1	0.67	0.50	0.57	0.20	0.25	0.22	0.20	0.25	0.22
2	1.00	0.80	0.89	1.00	0.40	0.57	0.25	0.40	0.31
3	1.00	0.57	0.73	1.00	0.29	0.44	0.17	0.14	0.15

4 Conclusions and Future Works

An O-TLD framework using ontology engineering for highly automated generation of textual location descriptions is proposed in this study. The framework not only enables multidimensional feature queries, exceeding contemporary reverse geocoding services but also outperforms human-written and generative AI solutions when locational semantics are captured with domain cognition. Traffic scenarios based on point, line, and polygon queries are exemplified to highlight the dominant surroundings and elevation conditions. The outcome can facilitate natural language-based communication tasks, such as alert reporting and location positioning. Future work may incorporate real-time users' cognitive characteristics from profiles or interactions to adapt location descriptions to personal preference. In addition, exploring ontology-based agents with question-answering procedures for textual location descriptions is valuable.

Acknowledgments

This research is supported by the National Science and Technology Council, Taiwan (Grant No. NSTC 114-2121-M-001-003).

Declaration of Generative AI in writing

The authors declare that they have not used Generative AI tools in the preparation of this manuscript. All intellectual and creative work, including the analysis and interpretation of data, is original and has been conducted by the authors without AI assistance.

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Appendix A. Ground Truth Data

ID	Labeled Ground Truth
1	(None, None, "北上"), ("在", "中山高速公路", "上"), (None, "10.5 公里", "處"), (None, "汐止交流道", None) (Northbound) (at) (Sun Yat-sen Freeway) (on) (km) (Xizhi System Interchange)
2	("在", "臺北市", None), (None, "大安區", None), (None, "建國南北快速道路", None), (None, "忠孝東路三段", "上方"), (at) (Taipei City) (Da'an District) (Jianguo Expressway) (Section 3, Zhongxiao East Road) (above) ("鄰近", "臺北科技大學", None) (near) (National Taipei University of Technology)
3	("在", "臺北市", None), (None, "大同區", None), (None, "民權西路", "路口"), (None, "承德路二段", "路口"), (at) (Taipei City) (Datong District) (Minquan W. Rd.) (intersection) (Section 2, Chengde Rd.) (intersection) (None, "捷運民權西路站", "附近"), (None, "台灣銀行", "附近"), (None, "台北大橋", "前") (MRT Minquan W. Rd. Station) (near) (Bank of Taiwan) (near) (Taipei Bridge) (in front of)

Appendix B. Experimental Results

ID	Output
1	Ours: Near the 12.1 km mark of the Sun Yat-sen Freeway (the Xizhi System Interchange) (中山高速公路 12.1 公里附近 (汐止系統交流道)) Human-written PBS: Northbound between kilometer markers 12 and 7, from before the Xizhi System Interchange to Wudu. Const. the inner lane. (北上在 12 公里到 7 公里之間. 汐止系統前~五堵. 內線.) GPT-4o: Located in Xizhi District, New Taipei City, approximately 10 kilometers northeast of Taipei 101, near the Xizhi Interchange of National Freeway No. 1. The area is close to the Keelung River and is primarily a residential zone. (位於新北市汐止區, 鄰近台北 101 東北約 10 公里, 靠近國道一號汐止交流道, 附近有基隆河, 屬於住宅區。)
2	Ours: On Jianguo Expressway in Da'an District, Taipei City (above Section 3, Zhongxiao East Road) (在臺北市大安區建國南北快速道路上 (忠孝東路三段上方)) Human-written PBS: Northbound on Jianguo Expressway, above Zhongxiao East Road (建高往北. 忠孝東路上方) GPT-4o: Located in Daan District, Taipei City, approximately 1 kilometer northeast of Taipei 101, near the intersection of Xinyi Road and Fuxing South Road, close to Daan Forest Park, and situated in a commercial district. (位於台北市大安區, 鄰近台北 101 東北約 1 公里, 靠近信義路和復興南路交會處, 接近大安森林公園, 屬於商業區。)
3	Ours: At the Minquan W. Rd. intersection in Datong District, Taipei City (near MRT Minquan W. Rd. Station) (在臺北市大同區民權西路路口 (捷運民權西路站附近)) Human-written PBS: At the intersection of Section 2, Chengde Rd. and Minquan W. Rd. (承德路二段+民權西路路口) GPT-4o: Located in Zhongzheng Dist., Taipei City, approximately 300 meters southeast of Taipei Main Station, near the intersection of Zhongxiao W. Rd. and Guanqian Rd., in the center of a commercial district. (位於台北市中正區, 靠近台北車站東南約 300 公尺, 鄰近忠孝西路與館前路交會處, 周圍為商業區中心。)