Modelling and Utilizing Human Knowledge from Everyday Place Descriptions Using Graph Database

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Abstract: Place descriptions in everyday communication or in online text provide a rich source of knowledge about places. This research proposes an extended place graph model for modeling spatial, non-spatial, and contextual information from place descriptions. The model overcomes limitations of an original, i.e., unextended, place graph, and three experimental tasks, namely georeferencing, reasoning, and querying, are tested to demonstrated the superiority of the new model in these tasks. We implemented the model using Neo4j graph database, and a management system has also been developed that allows operations including querying, mapping, and visualizing the stored knowledge in an extended place graph.

Keywords: place, spatial property graph, place graph, graph database, natural language place description

1. Introduction

Place descriptions occur in everyday verbal communication as a way of encoding and transmitting spatial and semantic knowledge about place between individuals [1]. They also occur in written forms such as news articles, social media texts, trip guides, and tourism articles, and the web provides a plethora of place descriptions as online texts. Knowledge conveyed by place descriptions can be used for the development of a platial information system [2]. Three relevant research problems are identified, accordingly: information extraction through natural language (NL) processing, information modelling, and knowledge creation and utilisation. For the first task, techniques such as gazetteered place name identification (e.g., [3–5]) and spatial relationship extraction (e.g., [6–8]) from texts have been developed. This research focuses on the second and third tasks, i.e., modeling and utilizing knowledge extracted from place descriptions.

Place descriptions typically provide a qualitative reference system for describing geographic locations, and consist essentially of references to places and their qualitative spatial relationships. Information extracted from place descriptions is used to construct place graphs [1], which consist of places as nodes and spatial relationships as edges. For example, the description ‘The courtyard is on the campus, beside the clocktower’ describes the location of the courtyard in relation to two other places, the campus (as a container) and the clocktower (as a neighbour). This information can be modelled in the form of triplets of a locatum L—the reference to a place that is to be located, a relatum R—the reference to a place that is already located, and a spatial relationship r between the two: <L: courtyard, r: on, R: campus> and <L: courtyard, r: beside, R: clocktower>. The two triplets are used in a simple place graph, as shown in Figure 1.

Though place graphs are place knowledge bases [9,10] the triplets that build them are stripped off of much of their conversational contexts. It is, therefore, possible to find incompatible
Figure 1. Place graph consisting of the two example triplets: <courtyard, on, campus> and <courtyard, beside, clocktower> with edges directed from locatum (L) to relatum (R).

information especially in graphs constructed from combining multiple place descriptions that were provided under potentially different contexts. For example, it is perfectly possible to collect seemingly contradicting triplets such as <Melbourne, near, Sydney> and <Melbourne, far, Sydney> where the use of the different distance prepositions is context-dependent. Storing such triplets in a place graph without further capturing their original contexts could result in loss of information and misinterpretation. Moreover, the interpretation of spatial relations found in NL place description often relies on information that has to be inferred, such the reference frame of relative direction relations, as in <courtyard, left of, clocktower> (egocentric, intrinsic, or allocentric). While people are often capable of such inferences, a place graph only stores explicit extracted information. Place graphs also do not consider place semantics or place-related human-activities, which are valuable for a platial information system truly capable of spatial reasoning and query answering.

Consequently, the usefulness of the original place graph model from a knowledge base perspective is restricted. Currently, query answers are provided by matching the values of certain property keys and by graph traversing, without filtering for context, inferences, or semantics, while the interpretation of spatial relationships such as relative directions or distance is limited.

This work reorganizes, revises and extends the original place graph model. The goal is to capture information from place descriptions that is useful, but lost during the triplet extraction. The hypothesis of this research is that, the extended place graph overcomes the limitations of the original model in georeferencing, reasoning, and querying tasks. Specifically, the extended model can be used to derive more constrained locations of places for georeferencing, captures additional information such as reference frames to be used in relational consistency, and is capable of answering additional spatial queries. Accordingly, the contributions of this research include:

1. The identification of eight types of information that are either embedded in place descriptions or in external context and have not been captured by the original place graph model.
2. An extended place graph that represents such information and enables future tracing as well as querying.
3. The implementation of the extended place graph into a graph database management system, which allows operations including querying, visualizing, and mapping.
4. The demonstration of how the extended model overcomes the limitations of the original place graph in georeferencing, reasoning, and querying tasks based on three experiments.

The remainder of this paper is structured as follows: In Section 2 related work on place, place models, place descriptions, and place graphs is provided. Section 3 identifies the information not captured in the original place graph model, and introduces the extended model. Section 4 looks at the extended model’s implementation and three experiments demonstrating its superiority. In Section 5 the experimental results are discussed, and the highlights of this work are presented in the concluding Section 6.

2. Related Work

Place based research is an emerging field in GIScience with importance widely acknowledged (e.g., [11–13]). The purpose is to smooth and simplify human-computer interaction by capturing, modelling, and utilizing place-related information. For example, Egenhofer and Mark suggested Naive Geography in order to capture and reflect the way that non-experts think and reason about space and time [14]. In this section, related work about how places are conceptualized, modelled in information systems, and communicated in descriptions is discussed.
2.1. Place as a cognitive concept

Space and place are two fundamental concepts in geography, and more broadly in social sciences, humanities, and information science [15]. Although the concept of place has existed for long in philosophy and psychology [16], it is relatively new in the geographic information domain. People talk about space by referring to places [17], and the definition of place has been discussed extensively (e.g., [18,19]). Compared to a space-based perspective of geography, place is regarded as space infused with human meaning and experience, and thus, enables conversations [20]. Place is also regarded by some as the prototypical spatial reference in human, economic, and culture geography [21].

Place, as a cognitive concept, is inherently vague, and this vagueness is evident in human cognition, perception, as well as natural language descriptions [22]. Some researchers believe the concept of place may be too vague to be formalized, except in narrow circumstances [12]. It has been argued that places do not have any natural boundaries, and are locations that have been given shape and form by people [19,23]. Agnew [24] suggests thinking of place in relation to other places, instead of as bounded and isolated. In contrast, most geographic information systems (GIS) and services are developed on unambiguous, crisp, and metric geometries removed from human concepts [25], and has, thus, not been much success in modeling and utilizing place information using current GIS models [26]. In short, place, while fundamental to human cognition and communication, is still well beyond the reach of current information systems.

2.2. Place models from an information system perspective

Several models have been proposed to capture the footprints of, as well as other non-spatial knowledge about places. Typically, a GIS represents geographic-related information in one of two ways: object and field [27,28], and places in these models need to be represented in either way.

Existing web-based place services are typically based on gazetteers and treat places as objects. A gazetteer, which is often regarded as a geospatial dictionary of geographic names, contains three core components: place names, feature types, and footprints [29,30]. A place name, sometimes also stored together with alternative names, is what people usually search for; i.e., ‘the official name’. A place type is a category from a feature-type thesaurus for classifying places according to their semantics, and is often biased towards political or commercial entities and geographic features with large extents. A footprint represents the location of a place, typically by a single coordinate pair as an estimated center of an extended object, which is often inappropriately precise [19]. Gazetteers have been widely utilized for both enterprise and academic purposes such as geographic information retrieval (GIR) [31–33], navigation services, and web-mapping applications.

Vague places, also known as cognitive places, such as ‘the South of France’ have been modelled using field models in some studies to represent the degrees to which any location belongs to these places. Montello and Goodchild conducted a study to determine the footprint of downtown Santa Barbara by asking participants to draw the boundary of it and aggregating the results [34]. Later, data-driven methods were proposed using techniques such as density analysis and clustering, based on geotagged social media content of place names or tags [35–38]. Other studies focus on deriving continuous surfaces to represent places [39,40]. Such field-based representations computationally characterize the inherent uncertainty of the extent of vague places, and enable approximate crisp boundaries to be derived for place-based applications.

Winter and Freksa argue that the spatial extent of a place reference, e.g., a place name, could vary in different contexts [19]. Places function as spatial anchors, and are determined by their affordances of human activities and relationships to other spatial objects in the context environment. This idea refers to a sense of distinctiveness [41] and wholeness. The authors suggest to capture the cognitive and linguistic nature of the notion of a place in contrast to other places that are relevant to the discourse. Such places as contrast sets can either be explicitly mentioned in the discourse, implied, or pre-exist as shared, default knowledge. Vasardani et al. provided a first conceptual model to interpret the region implied by preposition at using contrast sets and Voronoi diagrams, and the results are context-aware [42].
Non-spatial place information such as place semantics, equipment, characteristics, and
affordance can also be useful in applications such as place searching and querying, and some
of them have already been studied. For example, it has been argued that place affordance is a
core component for defining place and designing ontologies, and several works have attempted
to formalize it [43–45]. Semantical categories used in gazetteers can be regarded as taxonomies
according to place affordance, although sometimes lack flexibility and interoperability [46].

2.3. Modelling place descriptions

The structure of place descriptions has been studied in linguistics and spatial cognition
research (e.g., [47,48]), and recently in the domain of geographic information science as well. For
example, Richter et al. found that place descriptions typically apply hierarchical structures when
describing places from different granularity levels [49]. Place descriptions provide a qualitative
reference system for describing geographic locations using references to places (often as place
names) and spatial relationships. Computers have difficulty understanding such structures, often
due to vernacular place references and flexible relationship expressions [17].

Bateman et al. developed a comprehensive linguistic ontology for processing spatial language
[50]. Some parsers for annotating references to places (or spatial objects in some studies) and
spatial relationships in natural language text have already been developed [6,8,51]. Vasardani
et al. study place references and spatial relationships embedded in locative expressions, which
can be extracted by a parser in the form of triplets [1]. A place reference can be a place name
(also called a toponym, e.g., ‘Paris’) or a count noun (typically a place category, e.g., ‘the library’)
[18]. It can also be in other vernacular forms (e.g., ‘the meeting place’). References that are
not officially stored place names are more challenging to locate and typically require considering
conversational contexts. A locative expression provides location information of a place by giving
relationships to other places as anchors or landmarks, e.g., ‘the café is in front of the library’, in
order to locate the locatum. The spatial relationship expressed in a locative expression is often a
preposition (e.g., on), but can also be a verb (e.g., surrounding), a phrase, or even implicit.

Place graphs are constructed from triplets [1,52]. Each triplet is stored as two nodes, one
each for the locatum and the relatum, and a directed edge in between for the spatial relationship.
Between each pair of nodes there can be multiple edges, representing different spatial relationships
between the two places. A place graph can be constructed from multiple descriptions, and the
same place may be referred to by several references in different discourses (sometimes even
within the same discourse). Thus, nodes referring to identical places should be identified and
merged. For this purpose, a graph-merging approach considering reference string and semantic
similarity, as well as similarity of spatial relationships to other places has been developed [9]. An
example of a merged place graph is shown in Figure 2, constructed from multiple descriptions of
the same environment. Place graphs have been leveraged to locate non-gazetteered references to
places [53], create sketch maps [52], and identify landmarks within some environments [10].

3. Extending the Place Graph Model

This section first analyzes types of information that is not captured in the original place graph
model, as well as the tasks for which they matter. Then, an extended place graph model that caters
for this information is introduced.

3.1. Information not captured in the original place graph model

The types of information identified below were not considered when the original model was
initially designed. Most of them provide contextual knowledge, which could affect the interpretation
of other information communicated in place descriptions (e.g., spatial relations), and, thus, should
ideally be captured. Contextual knowledge in the domain of spatial cognition has been argued
to be task-specific; in this research we adopt the categorization proposed by Wolter and Yousaf
[54]: description-, environment-, and human-dependent contexts, as shown in Figure 3. For
instance, near can refer different distances according to other places relevant to the discourse,
based on the theory of contrast sets [19] (description-dependent context). Certain relations require
Figure 2. An example of a merged place graph constructed from descriptions of the University of Melbourne campus environment, with node size and color corresponding to node degree, and edge size and color corresponding to number of edges between nodes (left side), and details of a zoomed-in sub-graph (right side).

information from the environment in order to be interpreted, e.g., ‘two blocks down the street’ (environment-dependent context). Places and spatial relations can also have different semantics and meanings for different individuals (human-dependent context).

Figure 3. Contextual factors that affect the interpretation of spatial information in place descriptions.

Figure 4 shows the UML of the original place graph model. In the early related work, each place node is associated with one reference [1,52]. With the later developed merging approach, a place node can be linked to one or more references [9]. For each type of relationship, e.g., near, north of, inside, at most one instance is stored between any pair of nodes as an edge, and additional instances will be regarded as duplications and discarded.

3.1.1. Place semantics and characteristics

Place descriptions sometimes contain non-spatial information about places, such as their types (e.g., ‘the room is a lecture theater’), the activities they afford (e.g., ‘having seminars and lectures’), the things they equip (e.g., ‘a projector’), as well as their characteristics (e.g., ‘old, large’) [55,56].

Place semantics and affordances have been used for characterizing places and enabling spatial search as well as analysis [40,56,57]. Different places may have the same affordances, and one place may have multiple types of affordances according to individuals or time periods. The way that a gazetteer categorizes places does not always align with the way people regard these
places, despite that such categorization is useful in many applications. Capturing semantics and characteristics of places in a place graph could provide additional dimensions for tasks such as georeferencing, identical-place matching, and querying.

In place descriptions, these types of information are often expressed in certain patterns, e.g., as adjectives, nouns followed by words such as ‘is’ and ‘has’, or as verb phrases. Such patterns can be recognized using a trained parser, and the feasibility of creating such a parser has been demonstrated in previous research (e.g., [56,58]).

3.1.2. Places and relationships from discourse and their sequential order of appearance

Places referred to in different discourse provide contextual knowledge for interpreting spatial relations and locating places. For instance, near in the description ‘the building is near the Flinder Street Station’ can be interpreted differently in terms of distance, depending on the spatial context (the geographic extent the description is embedded in), e.g., the limited area around the station, or the whole Melbourne CBD. Such a spatial context can be inferred by looking at the places mentioned in the same discourse.

Other than places, spatial relationships from the same discourse provide contextual knowledge as well. For example, relative direction relationships can be used to infer the reference direction used by the descriptor, especially when using local landmarks as relata. The inferred reference directions can help with interpreting other relative direction relationships in the discourse, and thus be used to locate places as locata of these relationships.

The order of appearance of places and relationships in a place description should also be preserved. For example, descriptors often switch the level of spatial granularity monotonically e.g., changing from city-level to district-level [49]. Such changes in context cannot be detected without recording the order of appearance of place references and spatial relationships. Similarly, reference directions can also change within a description, for example at turns, and affect the interpretation of subsequent relations.

Storing sequential order also helps linking different place references that are referring to the same place. Definite references such as ‘the building’, which refers to a building described previously in the discourse, can be ambiguous without sequential appearance information, if there were multiple buildings mentioned in the discourse.

Information about places and relationships from the same discourse, as well as their sequential order of appearance is not modelled in the original place graph model. Triplets from different descriptions are merged without any indexing mechanisms for future separation. The two types of information can be obtained directly without requiring an additional parser; the challenge is how to modify the place graph model in order to store this knowledge.

3.1.3. Reference frame and direction

The original place graph does not capture spatial reference frame and reference direction information [59,60]. Anchoring relative direction relations is, thus, problematic, as it is unknown which directions are being referred to. It is also difficult to perform qualitative spatial reasoning (QSR) [61,62] or to interpret seemingly contradicting direction relations, as in the example <the Arts Faculty Building, left, the Old Quad> and <the Arts Faculty Building, right, the Old Quad>, without knowing the reference directions used in both situations.

Reference frames in natural language have been classified in the literature [60]. In this research, a relative direction reference frame is defined to be either intrinsic or relative. For
example, the expression ‘the café is in front of the library’ is likely to be interpreted by a human
as having an intrinsic reference frame, while ‘you will find the library to the left side of the
lawn if you continue walking’ is likely to be applying a relative reference frame. Currently, a
parser for identifying the reference frame and direction used in place descriptions is unavailable.
Nevertheless, we will demonstrate how these two types of information can be modeled in an
extended place graph once extracted, as well as how they can be leveraged in application scenarios.

3.1.4. Non-binary relationships

Non-binary spatial relationships, e.g., across, between, around, and among, involve more than
two places thus cannot be represented by the aforementioned triplet structure. Vasardani et al.
suggested that between and across can be modeled by two edges linking two relata nodes to the
same locatum node in the original place graph [1]. However, these edges are not indexed hence
cannot be retrieved in the future, since it is unknown which edges labeled by between or across
are associated with each other. Furthermore, for the relationship across, representing ‘A is across
B from C’ as <A, across, B> and <A, across, C> causes ambiguity, as the two extracted triplets
can be interpreted as ‘A is across C from B’ as well. For non-binary relationships, the task in this
research is how to properly model them in order to preserve the original semantics and to allow
future tracking.

3.1.5. Number of occurrences of place references and spatial relationships

The original place graph does not store the number of times each place reference is used
to refer to a place, and thus, the information of which references are better-known ones for a
place is lost. Storing the number of occurrences for place references can distinguish between
common (popular) names and references only sub-communities are using. It also enables analyzing
which references are more often used in certain conversational contexts, description themes, or by
certain people.

The number of occurrences of each relation being used between two places is not recorded in
the original model either, as only one instance for each relation can exist between any two nodes.
As a result, if two contradicting relations north of and south of between two places have both
been stored in a place graph, it is impossible to determine which one is more likely to be the true,
according to relevant frequencies. By preserving the number of occurrences for each relation, the
one that occurs more often can be regarded as a better-agreed upon assertion and, thus, more
likely to be true.

3.1.6. Conceptualization of places

According to Lynch’s classification [63], a place from an urban environment can be
conceptualized as a node (a strategic spot that is accessible), a path (a channel that affords
movement of the observer), a district (an accessible and identifiable area), a landmark (an
inaccessible place typically for spatial referencing), or an edge (an inaccessible boundary), as a
0D, 1D, or 2D object. The classification has been adopted in geographic information science, such
as for describing the functional spatial structure of urban environments using graphs [64].

The sense of place emerges as it is functionally different from its surrounding environment and,
thus, becomes distinguishable. The functional difference between places is sometimes revealed
by place conceptualization in descriptions, and such difference is context-dependent. The same
place can be conceptualized differently in different description contexts or even within the same
description [19], depending on what information the descriptor wishes to convey. For example, a
district can be regarded as a 2D container for describing places within it, or being regarded as a
0D landmark for locating other nearby places, either from the same granularity level or not. The
conceptualization of places reveals the spatial mental representation [65] of the descriptor.

We argue that capturing the conceptualization of places in descriptions allows for better
interpretation of the information communicated. For example, the same expression north of
can either be interpreted as an external cardinal direction relationship (mapped as north and
disjoint) or an internal one (mapped as north and inside), depending on the conceptualization of
the relatum. Similarly, *at* can be interpreted as *disjoint* (near the relatum as a container), *inside*, or not specified (both are possible). In the examples, the conceptualization of a place can be regarded as a variable that affects the mapping of vernacular spatial relationship expressions to formal relations. Without capturing place conceptualizations, the mapping process becomes either risky or unrestrictive.

3.1.7. Route and accessibility

Some place descriptions contain description of routes, which are often associated with reference directions and accessibility information for navigation purposes. For a triplet, the accessibility from the relatum to the locatum is usually implied by the spatial relationship expression used, as well as the conversational context. Accessibility also determines whether the triplet belongs to the part of a route or not. For example, Moncla *et al.* use motion expressions to distinguish places that are only seen and places that can actually be reached from hiking route descriptions, in order to reconstruct itineraries [66]. In the GUM ontology, a relationship indicating accessibility is classified as a *GeneralizedRoute*, and is distinguished from a *GeneralizedLocation* which does not belong to a route [50].

Tracking places and relationships originally from routes in an extended place graph enables querying of path knowledge for purposes such as navigational direction. Moreover, as the number of occurrence of relationships is also preserved in an extended place graph, it is also possible to identify prominent routes that are described more often by people.

3.1.8. Description- and human-level context

Some contextual knowledge is embedded at description level instead of in locative expressions. For example, Yao and Thill identified several contextual variables that determine the metrical meaning of qualitative distance relationships, e.g., type of activity and transportation model [67], which may or may not be extracted from place descriptions. Places chosen to be mentioned in the discourse of a description are also related to the purpose or theme of the description. Therefore, information of the theme of a description is useful for place analysis. For example, Kim *et al.* identified landmarks using the original place graph model, and observed the differences of place occurrences in descriptions of four themes: environment, business, travel, and other [10]. Since the experiment is based on the original place graph, places are pre-processed to re-link to their original place description. Identifying thematic topics of textual documents can be done using existing techniques such as topic modelling [39,40].

From a database perspective, the metadata of a place description, e.g., its source and timestamp, should also be preserved, if available. Such knowledge can be useful when determining the reliability or time validity of the extracted knowledge.

The descriptors and the recipients of place descriptions provide another dimension of contextual information. Individuals may describe the same environment differently, in terms of the selection of place and place semantics, spatial relations, reference frame, and conceptualization. The intention of giving a description to a recipient (or recipients) may also influence how a description will be organized [54]. Human-level factors such as age, gender, ethnicity, and degree of familiarity with the environment have also been identified as being influential on the meaning of the spatial relationships communicated [67]. In addition, the affordance of a place also varies among individuals. For instance, a supermarket may afford for some people shopping, and for others (or at other times) work.

Linking descriptions with people allows richer types of queries and analysis to be performed on an extended place graph, e.g., what places are more frequently mentioned by whom. As another example, an extended place graph database supporting an autonomous vehicle can be used to establish links between passengers’ accounts and the place where each one of them calls *my home*, instead of treating it as an official place name. Currently, such human-related information is often unavailable or limited when descriptions are collected, as the main source is online documents.
3.2. The extended place graph database model

The extended place graph database model is illustrated below by a UML diagram shown in Figure 5. The model preserves the information described in the last subsection and is designed to support efficient querying through graph traversal. Each class in the diagram represents a node type in an extended place graph, and each relationship represents an edge type. All node types and some edge types are associated with properties. Values of some of the properties will be set to null if the corresponding information is not (or not yet) available. For example, properties such as footprint of a place node cannot be obtained directly from place descriptions, and must be derived using georeferencing techniques [53].

![Figure 5. UML diagram illustrating the extended place graph database model, with seven types of classes (nodes) and nine types of relationships (edges).](image)

A n-plet is an extension of a triplet, and each place reference that occurs in a place description is regarded as being embedded in a n-plet. A n-plet is often a triplet representing a binary relationship locative expression; however, it can also represent a non-binary relationship, e.g., between, around and across, having multiple locata and relata based on the sequential order of appearance in the description. A n-plet can also consist of only one locatum without any relatum, as a place reference may not be embedded in any locative expressions in a description, e.g., ‘Melbourne is a populous city’. Thus, a n-plet must have at least one locatum, and any non-negative number of relata. In the remaining part of the section, each type of node, edge, and the associated properties are discussed.

3.2.1. Place reference node

A place_reference node represents a reference to a place from a n-plet in a description, either as a locatum or a relatum. Each place reference node must have one and only referred_by incoming edge from a place node. Between place nodes and place reference nodes are n:1 relationships, i.e., a place may be referred to by one or more different place references, while the same place reference may be used to describe different places in different contexts (but modelled by distinct place reference nodes). For example, two references ‘Flinders Street Railway Station’ (an official place name) and ‘the train station’ (a non-gazetteered reference) come from conversational contexts where they refer to the same place (Flinders Street Railway Station). In a different context, the reference ‘the train station’ may refer to another train station.
A place reference node, when created, is by default linked to a new place node instance through a referred_by edge. A merging algorithm [9] can then modify the correspondence by removing the newly created edge and place node instance, and establishing another referred_by edge between the place reference node and a pre-existing place node, if it is determined so.

Since place references are embedded in n-plets extracted from place descriptions, each place reference node has one and only outgoing edge in to a n_plet node. An in edge has two mandatory properties: pos and as. The value of as can either be locatum or relatum, representing whether the place reference is corresponding to the locatum or the relatum of the n-plet. The property pos is an positive integer denoting the index of the occurrence of the place reference, as it is possible that a n-plet has multiple locata or relata. For a triplet, the value of pos is 1 for either of the two place reference nodes it links to.

Thus, a place reference node is defined by Axiom 1 below:

\[ \text{Place_reference} \sqsubseteq \exists \text{referred_by}. \text{Place} \sqcap \exists \text{in}. \text{N_plet} \quad (1) \]

A place reference node has six properties: place_reference, conceptualization, place_type, equipment, characteristic, and affordance. Among the properties only place_reference is mandatory. The value of conceptualization is one of the categories based on Lynch’s classification: node, path, district, landmark, or edge. Values for the remaining four properties are unrestricted, and some examples are given in Section 3.1.1. The data type of these four properties is string list, as multiple values of each of these properties can be described. These properties are not stored under place nodes in order to preserve the context of where and by whom these values are given.

3.2.2. N-plet node

A n-plet node is defined by Axiom 2 below. Other than in as already explained, each n-plet node has one and only edge from as an outgoing edge, denoting the description from which this n-plet is extracted. The edge from has the same property pos as in, showing the sequential order of appearance of a n-plet in the description. A n-plet node can have one or more in and map edges, depending on the number of locata and relata, and the number of mapped formal spatial relations mapped respectively.

\[ \text{N_plet} \sqsubseteq \exists \text{in}^{-}. \text{Place_reference} \sqcap \exists \text{from}. \text{Description} \sqcap \exists \text{map}. \text{Spatial_relation} \quad (2) \]

A n-plet node has two properties: spatial_relation_expression and reference_frame. The first one stores the original spatial relationship expression used for the n-plet in the description. In an original place graph, such expressions are formalized by a controlled vocabulary before graph construction [52], yet it is quite often that the same spatial relationship expression can be mapped to different formal relations depending on the context. Therefore, in an extended graph, the original spatial relationship expressions are kept, and the mapped relationships will be stored separately as spatial_relation nodes linked by outgoing edges map from n-plet nodes.

If the spatial relation expression of a n-plet is mapped to a relative direction relation, the value for the property reference_frame can either be intrinsic, relative, or null (undetermined). The intrinsic value means the relative direction is based on the intrinsic direction of the relatum (e.g., ‘in front of the building’), while the relative value means a non-intrinsic reference direction is adopted. If the value relative is used, the n-plet node will have an additional outgoing edge has_reference_direction to a place node referred in the discourse, anchoring the reference direction used for the n-plet. A has_reference_direction edge has a property as, and the value is one from \{front, back, left, right, left front, right front, left back, right back\}. An example is given in Figure 6, with description:

"... coming from the **Main South Entry**, the **Baillieu Library** will be on the left hand side of the **South Lawn** ..."
3.2.3. Place node

Each place node represents a place. In an extended place graph, a place is identified from one or more place descriptions by place references embedded in n-plets. A place node does not have any place references stored; however, all the references used for referring to it (as well as the number of occurrence for each reference) can be obtained easily from all the place reference nodes it is connected to through outgoing referred_by edges. A place node is defined by Axiom 3:

\[
\text{Place} \sqsubseteq \exists \text{referred}_by.\text{Place}_{\text{reference}}
\]

A place node has three derived properties. The value of footprint represents the location of the place, and can be either a point, a polyline, a polygon, or an approximate location region (ALR) [53]. An ALR is a region derived using spatial relation search space models (including formal and probabilistic models) for georeferencing places without gazetteered references. The value of property type denotes the data type of the footprint, e.g., polygon. The property spatial granularity is a classification of the spatial granularity of the place based on the categories found in [68]: {furniture, room, building, street, district, city, country}.

3.2.4. Route node

Places referred to as part of a route are grouped by linking their corresponding place nodes to a route node through part_of edges. The property pos of a part_of edge records the position of the place reference in the route by sequential order of appearance, and the value is a positive integer.

3.2.5. Spatial relation node

Each spatial relation node represents a formal spatial relation. Unlike a value of the property spatial_relation_expression stored in a n-plet node, which can be expressed in flexible ways, formal relations are from a controlled vocabulary. Binary formal relations from four families are considered, as listed in Table 1. The vocabulary of non-binary relations in not restricted, since non-binary relations have not yet been well defined in literature. Accordingly, the value of property family is from one of the five spatial relation families: {qualitative distance, cardinal direction, relative direction, topological, non-binary}. The property relation stores the name of the relation.

Mapping between spatial relation expressions and formal relations is a m:n relationship. A spatial_relation_expression value can be mapped to one or more formal relations from single or multiple families, and different spatial relation expressions could be mapped to the same formal relation. The mapping process is context-dependent. For example, a spatial relation expression ‘north’ can be mapped to either north, disjoint (external north) or north, inside (internal north),
depending on the original expression and place conceptualization. Compared to an original place graph, the extended model supports more flexible and context-aware reasoning of spatial relations.

Table 1. Formal binary spatial relations considered in this research.

<table>
<thead>
<tr>
<th>Spatial relation family</th>
<th>Spatial relation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardinal direction</td>
<td>north, south, east, west, northeast, southeast, northwest, southwest</td>
</tr>
<tr>
<td>Qualitative distance</td>
<td>near</td>
</tr>
<tr>
<td>Relative direction</td>
<td>front, back, left, right, left front, right front, left back, right back</td>
</tr>
<tr>
<td>Topological</td>
<td>inside, covered by, overlap, meet, disjoint, cover, contain, equal</td>
</tr>
</tbody>
</table>

3.2.6. Description node

A *description* node represents a description document as a single discourse. It is used to store the global-level context variables of the descriptions from which n-plets were extracted. The four properties of a description node, i.e., *theme*, *transportation_mode*, *source*, and *timestamp*, have already been explained in Section 3.1.8.

A description node has at least one instance of an incoming edge *from* from a n-plet node. The property *pos* of *from* is the position of the linked n-plet in the description by appearance, and the value is a positive integer. The property *spatial_context* is a derived one, representing the geographic extent a description is embedded in, using the approach developed in [53]. For example, if the extracted places are landmarks in the Melbourne CBD as a suburb, the context of the original description is likely to be about Melbourne CBD. Finally, a description node can also have outgoing edges *created_by* and *given_to* to a user node, if such information is available.

3.2.7. User node

A user node either represents a describer (connected by a *created_by* edge from a description node) or a recipient (connected by a *given_to* edge). The same user node can be connected to multiple description edges by either roles. The property *info* of a person node is not restricted in this research, as what information is useful for the application of an extended place graph is domain- and task-dependent. Examples have been given in Section 3.1.8. The property value is defined in the format of JSON as key-value pairs.

3.3. Summary

The purpose of the extended place graph model is to capture information ignored in the original place graph, in order to overcome the graph’s limitations. The extended place graph captures the five core concepts of spatial information proposed by Kuhn [69]: *location*, *field*, *object*, *network*, and *event*. The graph stores the *location* of a place, and the probabilistic ALR derived using the approach in [53] represents the approximate location of the place as a *field*, based on its relationships to other places from the discourse. Different places are modeled as node *objects* in a place graph, characterized by information including place references and semantics. An extended place graph also forms a *network* by representing the links not only between places, but also between places and descriptions, as well as between places and people. Such links can be strengthened given additional descriptions, as their times of co-occurrence are captured as well. Finally, an *event* involves aspects of people, time, location, and activity, and these aspects are covered by node properties *info* (of user nodes), *timestamp* (of description nodes), *footprint* (of place nodes), and *affordance* (of place reference nodes) respectively.

4. Implementation and Experiments

This section describes the implementation of the extended place graph model, as well as three experiments to demonstrate how an extended place graph outperforms the corresponding original one. We do not use all the identified information in Section 3.1 in the experiments, since the goal
is not to provide a comprehensive evaluation, but rather to demonstrate the superiority of the extended model. We also discuss additional challenges and insights.

4.1. Data overview and construction of the test place graph database

The description dataset used in this research are place descriptions submitted by 42 graduate students about the University of Melbourne campus environment. The data set consists of over 9000 words, 726 n-plets, and a total of 241 distinct places being mentioned. A place can be referred to by multiple place references in different descriptions, or even within the same description. Some places are not referred to by any gazetteered names due to two reasons: the place itself is not captured in the gazetteer, possibly due to granularity (e.g., ‘the small courtyard’, ‘the dean’s office’); or the place is only referred to by synonyms or other vernacular names as commonly-used references (e.g., ‘the mathematics department building’). A part of a description is shown below:

"... If you go into the Old Quad, you will reach a square courtyard and at the back of the courtyard. You can either turn left to go to the Arts Faculty Building, or turn right into the John Medley Building and Wilson Hall. Raymond Priestly Building is the open aired ground area which is in front of Wilson Hall that is adjacent to it. Towards North, which is when you turn left when exiting the Old Quad, you will see Union House where there are shops selling foods. If you continue walk along the road on the right side where you’re facing Union House, you can see the Beaurepaire and Swimming Pool. There will also be a sport tracks and university oval behind it ...")

A parser was used in previous studies to extract triplets from the dataset [8]. The extracted triplets are stored in a csv file with three columns: locatum place reference, spatial relation, and relatum place reference. However, such a csv file does not preserve the necessary information for constructing an extended place graph. Therefore, we create a JSON file in order to capture additional information. For the following experiments, the information of reference direction is required as well. Due to lack of a parser capable of extracting this information, a graduate student was asked for manual annotations to obtain the information. To minimize the influence of pre-existing local knowledge on the annotation process, all place references were replaced by five place types: building, spot (any place finer than a building), area, alley, and street. For example, the first building name that occurs in a description is anonymized as Building_1. The task of the student was to assign each relative direction relationship three property values: reference frame (intrinsic or relative), the anonymized reference of the place indicating the reference direction (e.g., ‘Main South Entry’ in Figure 6), and the reference direction (value of property as for edge has_reference_direction). The structure of the final input JSON file for creating the test place graph database is shown below:

```json
{"descriptions": [
  {...
  "did": 2,
  "n_plets":
  [{nid: 4,
    "locatum_reference": "Baillieu Library",
    "spatial_relation_expression": "on the left hand side",
    "relatum_reference": "South Lawn",
    "reference_frame": "relative",
    "reference_direction": ["Main South Entry", "back"]
    "relation_map": ["left"]
  },
  {...}, ...
  }],
  {...}, ...
]}
```

A place graph database management system interface has been implemented using Neo4j and Python, as shown in Figure 7. The system is able to perform tasks including description parsing, graph creation from JSON, graph visualization, georeferencing, qualitative reasoning, querying, and mapping. Some functions are necessary for the following experiments and will be explained in detail in the remaining part of this section.
4.2. Experiment I: locating places without gazetteered references

An approach has been developed previously to georeference places in an original place graph [53]. The approach first identifies and disambiguates places with gazetteered, i.e., well known references, called anchor places, based on gazetteer look-up and a clustering-based disambiguation approach. Then, the anchor places are used to derive the spatial context of the graph. Next, an ALR is derived for each remaining place node by intersecting the spatial context, as well as the search spaces for the spatial relationships between this place and the anchor places. Search spaces can either be based on formal or probabilistic models. An illustration is provided in Figure 8 based on formal search space models. The location of place b: Federation Square is represented by the shaded region, which is derived by intersecting the search spaces of the three relationships: east of a, south of c, and near c.

Figure 8. An example of deriving the ALR for place b through intersection of search spaces.

In this experiment, three ALR refinements are possible, leveraging two of the newly captured information: identifying places from the same discourse, and reference direction. The first refinement is by separating spatial contexts for individual descriptions. The original place graph
merged from different descriptions has only one spatial context. As shown in Figure 9 (left), for places from different descriptions, only one spatial context will be derived. Consequently, the ALRs generated for places in the first description will be inappropriately large. However, separate spatial contexts regarding each description can now be derived (Figure 9, right), since the link between descriptions and place references is preserved in the extended place graph.

The second refinement is by anchoring relative direction relations using the newly captured reference direction information. Search spaces for relative direction relations can only be defined as buffered regions similar to near information, as shown in Figure 10 (left). The reference direction of a relative direction relation can only be anchored, if the locations of the relatum and the place indicating reference direction (i.e., the place linked by the has_reference_direction edge) are available. The proposed refined search search is illustrated in Figure 10 (right), with front indicating the reference direction, and the shaded regions representing search spaces.

Third, the interpretation of qualitative distance relationships, such as near, can be contextualized by considering other relevant places mentioned in the discourse, based on the theory of contrast sets [19]. An example is given in Section 3.1.2. In this experiment, the contrast set of a relatum based on a qualitative distance relationship is defined as places that: 1. are of the same granularity level as the relatum, and 2. have been used as relata in the same description. The underlying assumption is that when a descriptor says ‘A is near B’, it is often implied that A is closer to B than any of the other places used as relata in the discourse, and are of the same granularity as B. Vasardani et al. provided a first interpretation of the preposition at by contrast sets using their Voronoi diagrams [42]. In this research a similar approach is adopted, as illustrated in Figure 11. The shaded region indicates the search space derived based on a contrast set, and which is intersected with other search spaces to derive the ALR of the locatum in the georeferencing process.

4.3. Experiment II: relational consistency reasoning using reference direction information

This experiment aims at leveraging reference direction information to determine the relational consistency of relative and cardinal direction relations stored in an extended place graph, e.g., determining whether the two relationships <the Arts Faculty Building, left, the Old Quad> and <the Arts Faculty Building, right, the Old Quad> are contradicting, or not. This experiment is not about checking global, but rather local consistency. Relational composition is also not considered.
Two complementary reasoning approaches are suggested in this work. One is based on search space intersection, and the other relies on reference direction transformation. A illustration of the first approach is given in Figure 12, where the shaded regions are search spaces as explained in the previous experiment. The approach first finds all directional relationships between two places in an extended place graph, and derives their search spaces. If any pair of these search spaces does not intersect, an inconsistency is flagged.

However, deriving such search spaces requires the location information of the relata as well as the places indicating the reference directions, which may not always be available. Therefore, a complementary qualitative reasoning approach is proposed using reference direction translation rules. An illustration is provided in Figure 13. Given the knowledge in (a), consistent relationships can be inferred as shown in (b) and (c), through translations of the reference direction. Thus, given another relationship ‘A is right of B with C as back’, it can be identified as inconsistent with (a), (b), or (c). The drawback of this approach is that it is only applicable to scenarios with up to three places, while the previous approach does not have this limitation. The full reasoning procedure of this experiment is described in Algorithm 1.

---

**Figure 11.** The search space of a qualitative distance relationship with contrast set information, represented by the shaded region.

**Figure 12.** Determining consistency of directional relationships between a locatum B and a relatum A by search spaces.

**Figure 13.** Consistency reasoning through reference direction translation.
Algorithm 1 Consistency reasoning of directional relationships.

**Input:** place_graph

**Output:** inconsistent_pairs

1: inconsistent_pairs := ∅
2: for relationship in getDirectionalRelations(place_graph) do
3:    search_space = computeSearchSpace(relationship)
4:    locatum, relatum, reference direction_place = getPlaces(relationship)
5:    others = getDirectionalRelationsBetween(locatum, relatum)
6:    for new_relationhip in others do
7:       new_search_space = computeSearchSpace(new_relationhip)
8:       if intersect(search_space, new_search_space) == False then
9:          inconsistent_pairs ← (relationship, new_relationhip)
10:     end if
11:    end for
12: end for
13: others = getDirectionalRelationsWith(locatum, relatum, reference direction_place)
14: for new_relationhip in others do
15:     if new_relationhip not in transformation(relationship) then
16:        inconsistent_pairs ← (relationship, new_relationhip)
17:     end if
18: end for
19: inconsistent_pairs.removeDuplications()
20: return inconsistent_pairs

4.4. Experiment III: spatial knowledge querying

All the queries that were previously answered from the original place graph can still be performed, e.g., ‘find the relationships between two places’, or ‘find places that have relationships to a particular place.’ An extended place graph additionally supports queries complex queries, such as finding in which descriptions a particular place occurred, as well as other places mentioned in the same descriptions ranked by their co-occurrence frequency.

Cypher queries are used in an extended place graph. For example, the corresponding Cypher query for the NL query ‘find computer labs that are inside the University of Melbourne’ is shown below. A Cypher query is a graph traversal algorithm that attempts to find nodes or edges that match certain label (place and edge type) and properties values. In this research, results are returned simply by criteria string matching.

```cypher
MATCH {p:place}-->(a:place_reference)-[:in {as: 'locatum'}]->(b:n_plet),
     (c:place_reference)-[:in {as: 'relatum'}]->(b:n_plet)-->(d:spatial_relation)
WHERE a.place_type = 'computer lab'
    AND c.place_reference = 'the University of Melbourne'
    AND d.relation = 'inside'
RETURN p
```

Three query examples that cannot be answered with the original place graph are selected:

- Find the most frequently referred to relatum (landmarks).
- Find places that are most frequently linked to a specific place by spatial relations (place relevance by co-occurrence).
- Find the most frequent paths of length three, consisting of only directional relationships, i.e., place A-relation a->place B-relation b->place C (prominent routes)

5. Results and Discussion

This section discusses the results of the three experiments. In Experiment I, places without gazetted references have been georeferenced using five methods, namely baseline (without using any refinement approaches), SC (applying only the spatial context separation refinement), RF (applying only the reference direction refinement), CS (applying only the contrast set refinement), and Hybrid (all of the three refinements are applied). Refinement methods can only reduce the size of the ALR derived for a place. Thus, for each of the latter four refined georeferencing methods, four results are possible when georeferencing a place:
• The size of the ALR is reduced compared to the one from the baseline, but both ALRs capture the ground-truth location of the place (Case 1).
• There is no change in the ALR’s size (Case 2).
• The ground-truth location is not captured in the either ALR (Case 3).
• The ground-truth location is captured by the ALR of the baseline method, but not in the reduced-size ALR (Case 4).

Figure 14 shows the percentages of places that belong to each of the four cases, grouped by the four georeferencing methods. Places from Case 1 are regarded as better-georeferenced, while places from Case 2 and 3 are considered as equally georeferenced, and those from Case 3 are regarded as worse-georeferenced, when compared to the baseline. Among the first three methods, SC has the largest proportion of better georeferenced places, while for the RF and CS methods the percentages are much lower. In order to get refined ALRs for the latter two methods, relative direction relationships to some anchor places with reference direction information (for the RF method), or anchor places in the discourse as members of a contrast set (for the CS method) must be available. Since that is not always the case, only part of the places to be georeferenced can benefit from these two refinement methods.

Figure 14. Percentages of places from different ALR refinement situations compared to baseline.

When applying RF and CS methods, some places are worse-georeferenced (Case 4). For the RF method, this is because some relative direction relation information is incorrect, either due to mistakes made by descriptors, or the imperfection of the reference direction annotation procedure. For the CS method, the worse-georeferenced cases are because some ALRs are over-refined and, thus, not capturing the ground-truth locations of places anymore.

The Hybrid method has overall the largest improvement in terms of the proportion of better-georeferenced places. This is expected as the method requires only information that can be used in any one of the three previous methods in order to make refinements. One drawback is that the Hybrid method also has the largest worse-georeferenced place numbers due to error propagation. It is a trade-off problem between sizes of ALRs (the smaller the better as being more constraining) and having ALRs capturing the ground-truth location of places. A measure of the refinement in terms reduced ALRs is depicted in Figure 15, which shows the ALR remaining size percentage after refinement compared to the baseline, for individual places. A value of 0.6, for instance, means the refined ALR is 60% of the size it was in the baseline method. Only places with the available required information for refinement are included in the figure. For example, for the RF method, only places with relative direction relationships and reference direction information to some anchor places are included. The Hybrid method results in the most size reduced ALRs for
all places, which is also expected, given the method uses all the refining information available, combining the restrictions of the other three methods.

Figure 15. Refined ALR sizes as percentages of the original (baseline) ALR size.

Places to be georeferenced are matched to gazetteer entries that fall within their derived ALR, based on the method described in [53] considering string, semantic, and spatial similarity. For example, if there is a gazetteer entry named ‘University Square’ within the ALR derived for the place reference ‘the large square’, the two place references are likely to be matched. The distance errors between ground-truth and matched gazetteer locations for individual places are shown in Figure 16 for the baseline and the Hybrid method, sorted by error size in the baseline. Large distance errors in the baseline seem to be more likely to be reduced by the Hybrid refinement method. A possible explanation is that large distance errors usually correspond to large, less restricting ALRs, and in such situations a refinement is more effective. On the other hand, if an ALR derived in the baseline is already constraining enough, further refinement might have no, or
even negative effects. For example, the peak on the left side of the axis represents a place which
was correctly linked to its corresponding gazetteer entry in the baseline. In contrast, the refined
ALR leaves out the ground-truth location, and causes the place to be miss-matched, resulting in an
increased distance error.

In Experiment II, directional relations in the extended place graph are checked for relational
inconsistency using Algorithm 1. Among the 43 directional relations (out of 726 in total) stored in
n-plets, 4 were identified as inconsistent with other relationships stored in the database. As an
example, consider the following two descriptions of the environment in Figure 17:

“... You’re now in the **Old Quad** ... Pass through the **Old Arts** building and
immediately look to your left - the tall building is the **Babel** building that, somewhat
ironically, houses the languages and linguistics departments ...”

“... From the **Old Quad**, you can go through the **Old Arts** building, and then turn
right and walk until you come to a building called the **Babel** building (a 1970s yellow
brick monolith) ...”

The two relationships between the Babel building and the Old Arts Building from the two
different descriptions are denoted here as ‘Babel *left of* Old Arts with Old Quad as *back*’ and
‘Babel *right of* Old Arts with Old Quad as *back*’, respectively. The first description is not true as
can be verified from the map in Figure 17. The algorithm developed successfully identified the two
relationships as being inconsistent. Note that this reasoning mechanism only flags inconsistent
relationship pairs, instead of deciding which one is true.

![Figure 17](image)

*Figure 17.* The locations of the three places mentioned in the descriptions above, with a red arrow
indicating the walking direction.

Table 2 shows results generated for the three selected queries, in Experiment III. The second
column ranks the most frequently mentioned relata in the test dataset, which can be regarded
as local landmarks considering their prominence in the descriptions. In the original place graph,
landmarks can only be identified by node degrees, as the number of occurrences of neither place
references, nor instances of the same spatial relation is preserved. For example, the relationship
<Old Arts, *right*, Baillieu Library> was described more than ten times in the dataset. The original
place graph stores the relationship once, which from a knowledge base perspective leads to loss of
information about frequently mentioned, prominent relationships.

The third column shows places that are most frequently linked to *Alice Hoy*, a place from
the test place graph being used here as an example. Again, such co-occurrence knowledge is not
captured in the original place graph. The last column shows the top five most frequent length-3
paths, which are actually all from route descriptions.
Table 2. Results for the three queries from the third experiment, with the second query using the place Alice Hoy as an example

<table>
<thead>
<tr>
<th>Rank</th>
<th>Most frequent relata</th>
<th>Places most frequently co-occurring with Alice Hoy</th>
<th>Most frequent length-3 paths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>University Of Melbourne</td>
<td>Monash Road</td>
<td>&lt;Old Arts, right, Baillieu Library, left, South Lawn&gt;</td>
</tr>
<tr>
<td>2</td>
<td>Union Building</td>
<td>Entrance</td>
<td>&lt;Baillieu Library, left, South Lawn, front, John Medley&gt;</td>
</tr>
<tr>
<td>3</td>
<td>Grattan Street</td>
<td>University of Melbourne</td>
<td>&lt;Royal Parade, left, Baillieu Library, left, South Lawn&gt;</td>
</tr>
<tr>
<td>4</td>
<td>South Lawn</td>
<td>Wilson Hall</td>
<td>&lt;Medical Building, left, Baillieu Library, left, South Lawn&gt;</td>
</tr>
<tr>
<td>5</td>
<td>Swanston Street</td>
<td>Peter Hall Building</td>
<td>&lt;Baillieu Library, left, South Lawn, left, Wilson Hall&gt;</td>
</tr>
</tbody>
</table>

6. Conclusions

Place descriptions occur in everyday communication as a way of conveying spatial information about place, and the web provides a plethora of such descriptions in text format. This research proposes a graph-based approach for modeling and utilizing information from place descriptions, including references to places, spatial relationships, place semantics, and various contextual knowledge. The model is an extension of the original place graph [1]. Place graphs are regarded as platial knowledge bases that can be used in reasoning, georeferencing, landmark identification, and sketch-map drawing. However, place graphs constructed from triplets stripped off of context and other useful spatial or non-spatial information, have restricted applications. This research proposes an extended model in order to overcome those limitations. We implement the model in a graph database and demonstrate its superiority over the original place graph in three experiments.

We identified eight types of information that is embedded in place descriptions and not captured in the original place graph model: place semantics and characteristics, places and spatial relations from the same discourse, as well as their sequential order of appearance, reference frame, non-binary relationships, co-occurrence of place references and spatial relations, place conceptualization, route and accessibility, and description- and human-level context. We then designed a graph database schema for modeling these types of information, allowing convenient and efficient query through graph traversal. We implemented the schema using the Neo4j graph database for three experiments, and developed a management system interface capable of multiple place graph operations.

To demonstrate the new model, three experiments were performed on an extended place graph created from descriptions about the University of Melbourne campus. The first experiment georeferences places without gazetteered matches, using their spatial relationships to anchor places (gazetteered places that are georeferenced first). We propose three refinement methods to reduce the areas of the approximate location regions generated for these places, when compared to the baseline method. More than 60% of the derived regions are reduced in size with a Hybrid approach that takes into consideration information information from all three refinement methods, all based on information newly captured in the extended graph. The second experiment leverages reference direction information for identifying contradicting directional knowledge in an extended place graph. The results show that the approach can identify inconsistent relationships based on both qualitative and quantitative data. In the third experiment, we demonstrate how the extended place graph is capable for answering queries that cannot be answered by the original place graph.

The three experiments utilize only some of the newly-captured information in the extended place graph model. In future work, additional information such as place semantics could also be used for ALR refinement for example, in defining search spaces for non-binary relationships. Also, query expansion (e.g., based on place semantic similarity and relational inference) and relevance-ranking (e.g., based on occurrence and description source) mechanisms can be further...
developed. Some of the identified information, however, requires new techniques or parsers to obtain automatically, which are not readily available.

The extended place graph model provides a complementary information system and can be used in applications requiring human spatial and non-spatial knowledge about places. The standard available geographic information systems or authoritative datasets may not be detailed enough, or even updated to capture the knowledge communicated in everyday place descriptions that people share. The implemented extended place graph management system supports Cypher queries and returns tabular results with high interoperability. Finally, the knowledge modeled in extended place graphs can help with better understanding human descriptions as input to spatial services and, thus, support intuitive and smooth human-computer interaction.

References

6. Kordjamshidi, P.; Van Otterlo, M.; Moens, M.F. Spatial role labeling: Towards extraction of spatial relations from natural language. ACM Transactions on Speech and Language Processing 2011, 8, 4.


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