Speaking of Location: A Review of Spatial Language Research

Kristin Stock[a*], Christopher B. Jones[b] and Thora Tenbrink[c]

[a*]*Massey Geoinformatics Collaboratory, Massey University, Auckland, New Zealand;*

[b]*School of Computer Science and Informatics, Cardiff University, Wales, UK;*

[c]*Department of Linguistics, Bangor University, Wales, UK*

*Correspondence details: k.stock@massey.ac.nz

Abstract

Spatial language incorporates descriptions of locations, routes, and landscapes, and is used by humans daily. Research has addressed a wide range of aspects of spatial language, including its form; the ways in which it is selected and applied; and cognitive, geometric, and functional factors affecting its use. Furthermore, much work has been done on the automation of spatial language extraction, analysis, interpretation, and generation. To introduce the Special Issue on this broad topic, this paper reviews spatial language research framed by an extension to the well-known semantic triangle, the 'spatial semantic pyramid', which represents both human spatial language and relevant computational research. By introducing it, we hope to stimulate discussion about gaps and future directions in this important research field.

Keywords: spatial language; geospatial language; natural language; geographic information retrieval; spatial cognition; semantic triangle

1 Introduction

"*Spatial language* refers to the total set of linguistic expressions that denote aspects of space" (Carlson & van der Zee, 2005, p. 1). Such aspects may include "those words and simple phrases that encode objects and places" (Landau & Jackendoff, 1993, p. 218) and address the question: "How do people refer to places, describe spatial arrangements, say where someone is going, and so forth?" (Levinson, 1996, p. 355).

We use spatial language in everyday communication to refer to objects and events around us at varying scales, that range most commonly from the very local spaces of our own bodies, 'table-top' space and indoor space, to geographic and environmental spaces such as those of buildings, streets, cities, and objects within the natural landscape (mountains, rivers etc). These objects may be referred to using generic terms and descriptions (e.g. the *post office, the river*), official (e.g. *Waikato River*) or vernacular names (e.g. *North Auckland*). We use a mixture of different grammatical categories to describe location in natural language (e.g. prepositions, adverbs, verbs, adjectives) (Carlson & van der Zee, 2005), often in the form of relative expressions (e.g. *the house near the river*) as well as movement in the form of routes (e.g. *turn left at the traffic lights*).

The following is an example of spatial language:

> *The accident occurred in the left lane, on the bridge across the Waikato River, outside the northern suburbs of Hamilton, where the road curves past the gully.*

This expression includes a range of different types of information such as place names (*Waikato River, Hamilton*), landscape terms (*gully, river, bridge*), spatial relation prepositions (*across, in, outside*) and other terms that describe the location, configuration and shape of objects in space (*past, curves, northern*). In spatial language, not only are the form and semantics of the terms themselves important for understanding; the geometric configuration, characteristics and functionality of the environment referred to, along with underlying cognitive factors governing the way spatial terms are selected and applied are also key. All of these aspects are the subject matter of spatial language research.

The human use of spatial language has attracted considerable research interest for some decades, but the facility of computers to understand and generate spatial language is also of great potential value for the purposes of wayfinding and for extracting spatially-referenced facts from text and from speech about the location of phenomena. Such phenomena may include, for example, the location of injured people in emergency response; locations at which biological specimens were found; and parts of the body when conducting surgical procedures or describing injuries. Automated spatial language generation is already exploited in vehicle and pedestrian navigation systems that provide guidance as speech or text, but it remains a significant challenge to develop systems that can mimic and understand the inherent vagueness and frequent complexities of spoken and written spatial language.

The study of spatial language has been approached from many disciplinary perspectives, including linguistics, cognitive science, psychology, psycholinguistics, geographic information science and computer science, ranging widely in approach and theoretical underpinnings. The subject of these studies include the structure, semantics (meaning) and nature of location and motion-related language; cross-linguistic investigations that compare how location, path and orientation is described in different languages; investigations of spatial cognitive models and processes revealed through language; the nature of language used to describe landscape and place; and methods to enable computers to understand and generate spatial language. This Special Issue includes a set of articles that make significant advances in several of these areas[1].

Human language is not used in isolation. Specific terms are selected according to the objects in the world to which they refer, and both selection and interpretation of terms are mediated by the conceptualisations/thoughts of both sender (speaker/writer) and receiver (listener/reader). This interdependence of the world and human thought and symbols is known as the semantic triangle (and alternatively as the semiotic triangle, the triangle of reference or the triangle of meaning), and has been widely discussed by philosophers for centuries. Accordingly, any discussion of spatial language must consider all three of these aspects, and we therefore use the semantic triangle to frame our summary of research areas in the field of spatial language.

Furthermore, we recognise that automation of spatial language interpretation and generation is a key aspect of research in this area, and in order to fully represent the digital reflection and emulation of human language, we present an extension to the semantic triangle: **the semantic pyramid**, which distinguishes between:

- a *human face*, which corresponds to the semantic triangle and
- a *digital face*, which reflects the digital representation of human language and cognition.

We use the semantic pyramid to highlight the range and scope of contributions in a variety of areas related to spatial language. The pyramid structures our discussion of the spatial language literature, including that addressing: human aspects of spatial language, including

---

[1] It should be noted that while spatial language includes the description of entity properties such as shape, form and size, these are not addressed in detail in this review.

form, structure, meaning and connection to human thought (spatial cognition) and objects in the world (covered by the human face); digital aspects of spatial language, including automation and computational analysis of human language (covered by the digital face); and the connections between the two faces, relating particularly to the conversion between human and digital representations.

The paper is structured as follows. In Section 2, we describe the semantic triangle and introduce our own semantic pyramid. In Section 3, we map aspects of spatial language research to the human face of the pyramid, summarising basic principles and providing examples of research on the use of spatial language by humans. Then we turn to the digital face of the pyramid, addressing the ways in which spatial language is represented and used in digital systems. Finally, we discuss the ways in which the digital and human faces of spatial language are connected. In Section 4, we discuss the papers presented in this Special Issue, including their relationship to the wider field of research and to the pyramid. We do not attempt to review all literature within the field, but aim to highlight some of the key areas of contemporary spatial language research by offering the pyramid as a new model of understanding the field, as a basis for future discussion.

2 The Semantic Pyramid

The relationship between language, the things it describes, and human thought have been heavily studied, widely debated, and described by many authors in the form of a triangle (Almeida et al., 2011; Dahlberg, 1978; Kuhn, 2009; Nirenburg & Raskin, 2001; Peirce, 1965; Ranganathan, 1937; Saussure, 1967; Steinbring, 1998; Tichy, 1988). We adopt and extend Ogden and Richards' (1923) version of the triangle, as shown in Figure 1, as a framework for our review of research into spatial language[2]. At one vertex of the triangle are the *symbols* that "direct and organize, record and communicate" (p.9). In Ogden and Richards' treatise, and for our purposes, these *symbols* take the form of human language, although other forms of symbol (e.g. gestures, signs) are also possible. In the context of modern information systems, *symbols* might include many different kinds of languages (programming, schema, query, user interface, web service specification), vocabularies and lists (Kuhn, 2005). At another vertex are *thoughts*, or *references* which are represented by *symbols*. *Symbols* themselves are typically arbitrary but have meaning by attachment to a *reference*. At the third vertex of the triangle are *things* or *referents*, i.e., objects in the world that *symbols* stand for and that *thoughts* conceptualise.

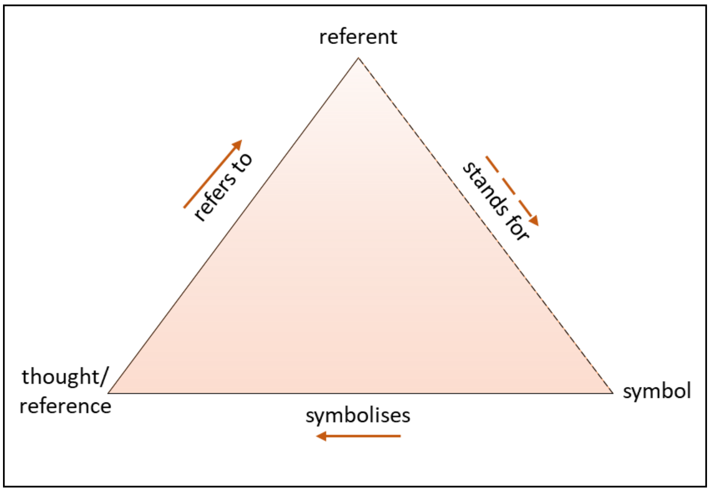

Figure 1: Ogden and Richards' Triangle (1923, p.11)

The sides of the triangle describe the relations between the vertices. The relation between a *symbol* and a *thought* is direct, in that the selection of language is determined by the thought we wish to convey, as well as contextual factors to do with the message we wish to communicate. The relation between a *thought* and a *referent* may have varying degrees of directness, depending on how abstract or complex the link. The relation between *symbol* and *referent* is indirect (and hence shown with a dashed line) as it is always mediated by *thought* – by our conceptualisation of the *referent* (Ogden & Richards, 1923), and this point is key to the

[2] For presentation reasons, we reorient the pyramid relative to Ogden & Richards (1923), to position the spatial world (equivalent to the *referent* in their terminology) at the top of the pyramid.

interpretation of the semantic triangle (Jackendoff, 1983; Langacker, 1986).

In this paper, we use the semantic triangle as a framework to discuss the research on spatial language. However, a substantial part of the current research addresses the digital representation of that language, and the human conceptualisations that underlie it. We therefore propose a *semantic pyramid*, with two additional vertices to depict the digital representations of language and thought respectively (Figure 2). The semantic pyramid supports the explicit description of not only human (the back face of the pyramid in Figure 2) and digital representations (the front face of the pyramid in Figure 2, facing the observer) of language and thought (including computerised methods for emulating human thought), but also the relations between them in a way that is not possible with the triangle alone, or by other extensions to the semantic triangle that have been proposed. For example, Peirce's (1880) stacked triangles (Figure 3) enable *thoughts/concepts* in one triangle to become *referents* in another, so for example the *symbol* for an actual mountain can be represented, as well as the *symbol* for the *concept* of a mountain, which is the *referent* in the next tier (Peirce, 1880; Sowa, 2000). However, this model does not represent the relation between symbols at different levels as is possible with the semantic pyramid.

Alternatively, in Sowa's (2000) connected triangles, the *symbol* vertex in one triangle becomes the *referent* in the next. Thus in a series of triangles the following three symbols become connected: the name of an object; the quoted string of the name; and the bit string encoding of the name. However, this model does not represent the relation between concepts at different levels. Another, more specialised approach extends the triangle into a tetrahedron with the additional vertex to represent the definition of a term in an ontology (Kudashev et al., 2010), but this is also unable to represent the relations between digital and human knowledge and language representations adequately for our purposes. In contrast, our semantic pyramid represents the relations between all three vertices, including those from both Sowa's (2000) and Peirce's (Peirce, 1880) extensions to the semantic triangle. However, our pyramid does not support multiple tiers of representation, as for our purposes (digital representation of human language and cognition), a single tier of abstraction is sufficient.

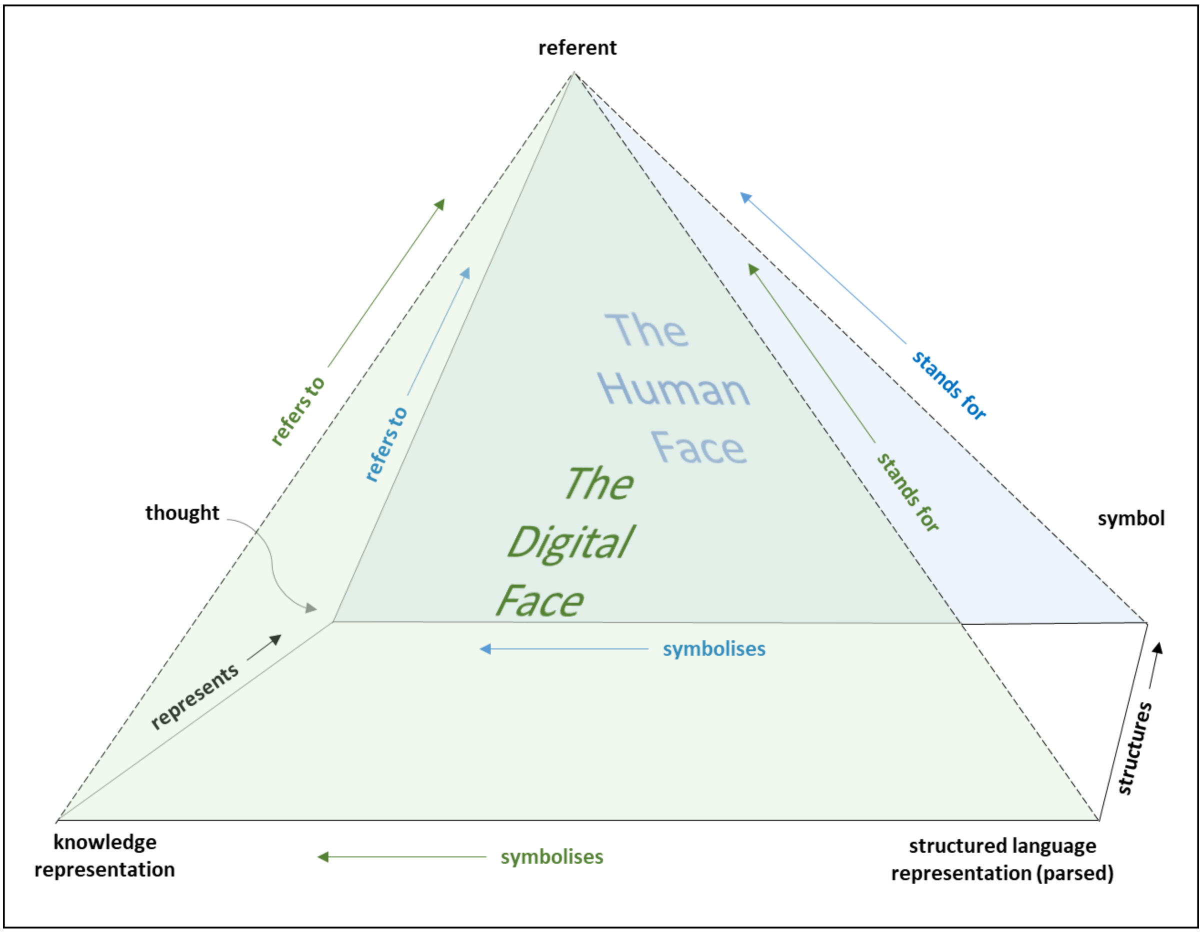

Figure 2: The Semantic Pyramid

We do not include a separate digital representation of the *spatial world* vertex of the semantic triangle in our semantic pyramid as we do for the *spatial cognition* and *spatial language* vertices since we consider that the real world represented by human thought is the same as that represented by digital systems. This is because, in the same way that the real world cannot be represented directly by language except through thought, it also cannot be directly represented digitally except through thought. Many of the debates in the geospatial sciences over the last few decades provide evidence to support this view, including difficulties in defining ontologies for geographic domains that are independent of context, purpose, human language and information community (Kuhn, 2005; Mark & Turk, 2003; Montello, 2009), and the rise of informal ontologies/folksonomies (H. Du et al., 2013); notions of vagueness in the definitions of geographic concepts (e.g. *How tall does a mountain have to be to qualify as a mountain? Where is downtown?*) (Bennett, 2001; Hollenstein & Purves, 2010; Montello et al., 2003) and issues of vague boundaries (e.g. *At what point does a mountain become a valley?*) (Bittner & Stell, 2002; Burrough et al., 1997; Yu et al., 2014).

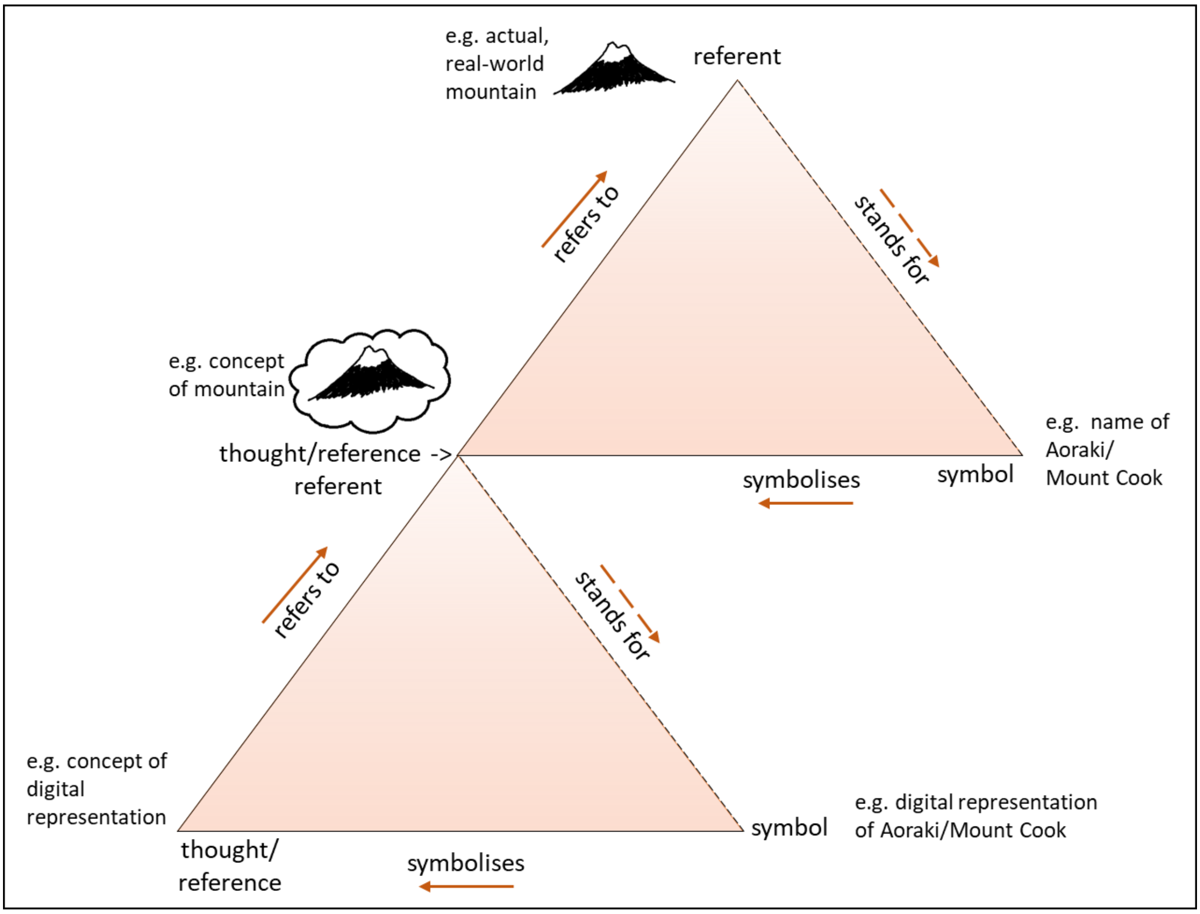

Figure 3: Peirce's (1880) Stacked Triangles

3 The Spatial Semantic Pyramid

Having described the semantic pyramid in general terms, we now apply the pyramid in the context of spatial language research, using it as a framework for a discussion of the different research areas within the field, which spans a number of disciplines, as illustrated in Figure 4. In this Section, we first describe the human face of the pyramid and summarise the research that aligns with each of its vertices and edges. We then turn to the digital face, and finally, to the edges and faces that connect the digital and human faces. We focus particularly on the parts of the triangle that are most relevant for spatial language research, and hope that the spatial semantic pyramid will provide a basis for further discussion, and for consideration of research gaps, future directions and potential.

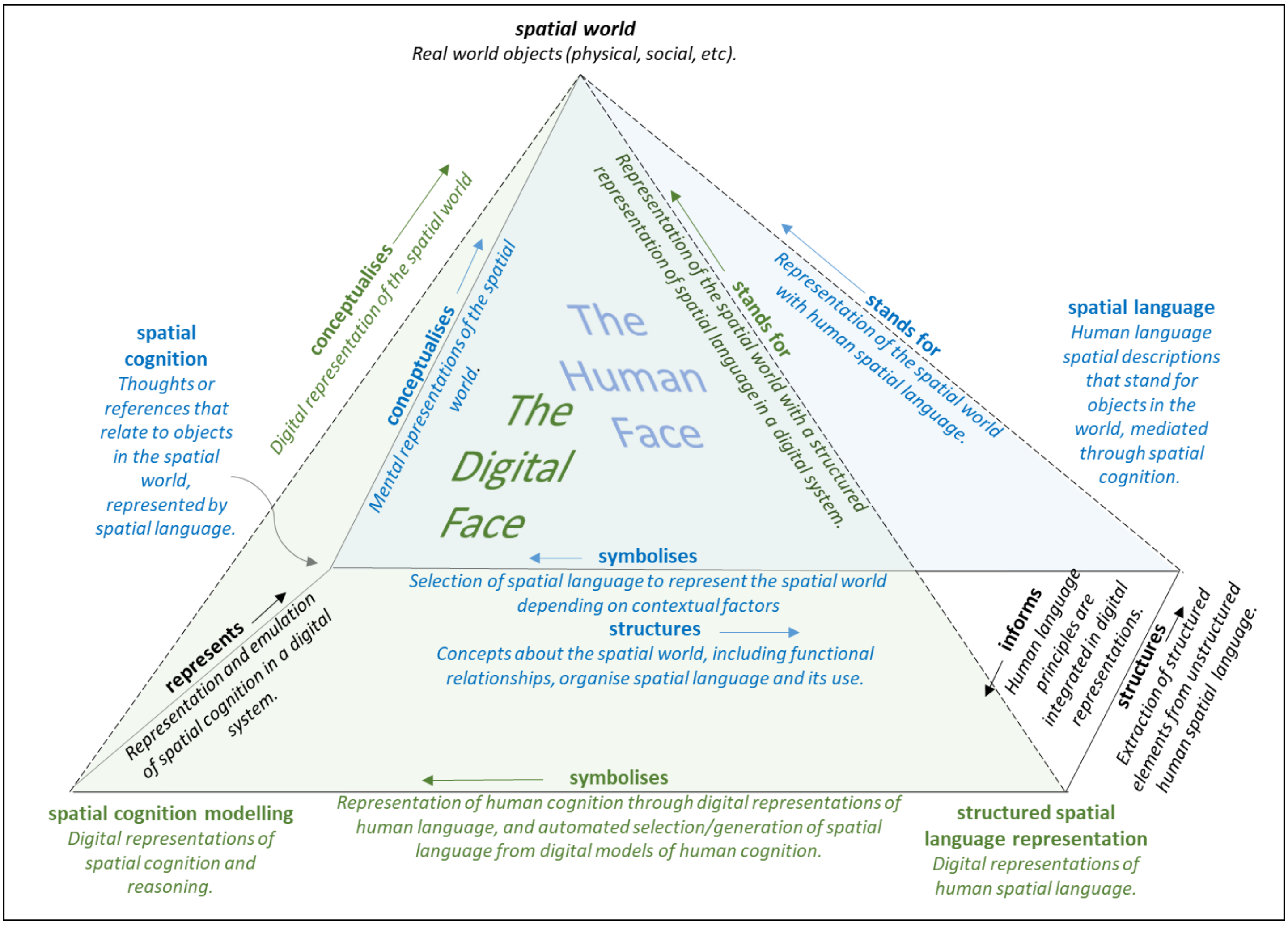

Figure 4: Spatial Semantic Pyramid

3.1 *The Human Face*

The *human face* of the semantic pyramid corresponds to the semantic triangle (Ogden & Richards, 1923), and in the following sections, we discuss basic principles and concepts of spatial language research relevant to each of the vertices and edges in turn. Table 1 provides examples of research areas that align with each part of the pyramid together with example references, listing first the three vertices, followed by the edges, and aligning the human and digital faces side by side in order to highlight parallels across the two faces. Table 2 separately addresses the edges that connect the human and digital faces (discussed in Section 3.3). It should be noted that nearly all spatial language research incorporates some combination of language, cognition and the world, and thus when we discuss research under each vertex, we mean research that relates predominantly to the vertex concerned, even though it may incorporate elements of the others, and similarly for the edges.

3.1.1 Vertices of the Human Face

The top of the pyramid corresponds to the *referent* vertex of the semantic triangle and, in our application of the pyramid, represents the *spatial world*, which contains physical, geographic objects and phenomena such as rivers, mountains, cities, winds and climatic zones; smaller scale objects such as a person, books and tables, or microscopic objects such as cells; and less tangible social and economic concepts such as poverty and social class. The spatial world is important for the discussion of spatial language, as it represents the objects that spatial language describes, that act as reference points for spatial descriptions of location, or that are of research interest in their own right. Maps are a common method for depicting the characteristics of the spatial world at geographic scales, displaying the terms used, geometry types, distribution and configuration of objects relative to another.

Another vertex of the human face, corresponding to the *thoughts* vertex on the semantic triangle, represents *spatial cognition*. Thus while the spatial world consists of objects in the world (e.g. *mountain*), this vertex concerns the mental construction of the world in an individual's mind, mediated by their experience, world view or perspective. This is the realm of spatial cognition research that is not primarily focused on language or on real-world properties. Research in this area addresses the conceptualisations and perceived affordances held by an individual of the spatial world, and may include physical, social, functional or emotional concepts together with reasoning about them, with consideration of aspects such as scale or human perception, and their influence on the way people think about space. It addresses questions that include the way human cognitive models of the physical environment, known as mental maps, are determined by and support wayfinding. Mental maps can be regarded as expressing human perception of the form and configuration of spatial world features and hence include the spatial expression of vernacular place names that associate spatial language with the perceived places in the spatial world (and are therefore placed in an adjacent region of the pyramid's human face). Research in spatial cognition also addresses the mental associations, values and feelings attached to the landscape and to specific places (known as sense of place, or cultural ecosystem services), and reasoning about the spatial relationships (or relations) between objects in the world (for example, mental models of containment or proximity), independent of language.

At the third vertex of the human face (corresponding to *symbols* in the traditional triangle) is *spatial language*. *Spatial language* only gains meaning through its attachment to the *spatial world*, via *spatial cognition*. The field of cognitive semantics deals with the ways in which such meaning attachment is achieved (Talmy, 2000). This vertex of the triangle represents research investigating spatial language where the primary focus is language itself, rather than cognition or real-world properties, for instance its form, syntactic variants, and differences across languages, dialects, contexts etc. Human language that describes relative location (also known as locative expressions) is an important and widely researched type of spatial language, in which the location of an object is described by reference to some other object. The latter is known as the reference object, relatum, landmark or ground, while the object whose location is being described is known as the locatum, trajector or figure (Lehmann, 1983). The specific location of the located object in space relative to the reference object, is described using a *spatial relation term*. Spatial relation terms are commonly prepositions in English (e.g. *I live **in** Orewa; the house is **beside** the river, turn left **at** the intersection*), but may also be verbs (particularly commonly in verb-framed languages such as Spanish) (*the road **crosses** the park*) or adverbs (*the road extends **uphill***), or consist of multiword phrases (*the road extends **in line with** the Waikato River*) (Papafragou et al., 2002). The most basic form of spatial location description consists of three elements: located object, spatial relation term and reference object, but many other forms of expression are also used regularly, and may include adjectives that indicate location (*the **seaside** village*) or parthood (*the **central** part of the city*), adverbs that indicate location (*the river runs **northward*** or *the road runs **uphill***) or degree (***directly** across the road, **just** beside the church*) or deictic spatial relation terms (expressions whose interpretation depends on context, usually the current location of the observer), such as (*she sat on **this** side and he was in **that** corner*, *she saw cows over **there**, but donkeys **here***) (Stock et al., 2021). Research that aligns with this vertex addresses the syntax, frequency and nature of spatial language.

3.1.2 Edges of the Human Face

Much research addressing spatial language involves not only the language itself, but also aspects of spatial cognition, since the two are so closely entwined (Whorf, 2012), and this is represented in the semantic pyramid by the *spatial language-spatial cognition* edge. This edge may be read in both directions: it represents the process of selection of language to describe the spatial world, according to spatial cognition; as well as the influence of spatial cognition on the organisation and use of spatial language. The selection of language that describes spatial location (especially spatial relation terms) has been shown to be organised according to several underlying cognitive factors, including:

- the influence of metaphors on the language used to describe the location of objects in the spatial world, known as image schemata (for example, cities are conceptualised as containers, as is evident in phrases such as *I live in the city*, while islands are seen as platforms as in the phrase *I live on an island*) (Lakoff & Johnson, 2008; Mark, 1989);
- the perspective of the observer when describing a scene from either a survey (from above, bird's eye view, as in "*houses in the valley"*) or route (moving through the landscape as in *"a house every now and then through the valley"*) (Talmy, 2000, p. 71) and
- the spatial reference frame used for particular spatial relation terms, known as projective spatial relations (e.g. *left, right, in front of*) which depend on the observation frame of the observer, with the intrinsic reference frame describing location relative to the axes of the object (*the lamp post in front of the shop*), the relative reference frame relative to the observer (*he stood to the left of the postbox*) and the absolute reference frame using cardinal directions (*the house to the west of the city*)[3] (Levinson, 2003; Shusterman & Li, 2016; Tenbrink, 2011).

Similarly, cognitive factors influence the selection of spatial language that is used to describe routes, including aspects such as:

- the tendency to select landmarks with certain properties (e.g. prominence, size, type) when providing route descriptions, known as landmark salience and
- the influence on the quality of route descriptions on people's ability to successfully navigate.

[3] Reference frames have also been classified as egocentric and allocentric, among other schemes; Levinson (2003) described how these different classifications relate to each other, precluding a direct 'translation' of terminologies.

In the reverse direction, regarding the influence of language on spatial cognition, it has been argued that the dominant linguistic use in some communities of a particular form of spatial reference, notably an absolute (cardinal direction) reference system, can result in the necessity for members of that community to think in that particular way (Levinson, 1997).

Studies of the acquisition of spatial language, both in childhood and by second language learners also sit along the *spatial cognition-spatial language* edge and have been widely studied following seminal work by Piaget and Inhelder (Piaget & Inhelder, 1956). Children learn spatial language gradually as they grow, with spatial oppositions (e.g. up/down, in/out, on/off) emerging earlier than other spatial prepositions (e.g. at, with, by) (Tomasello, 1987), with variations in attainment of terms and concepts varying with the language (Choi et al., 1999); and difficulties in attaining complex frames of reference (Shusterman & Li, 2016). Studies of spatial language learning among second language learners have shown commonalities in the basic system for expression of spatial relations across languages (Becker & Carroll, 1997).

One of the challenges of research that addresses the relationship between spatial language and spatial cognition is the development of appropriate experimental methods, with methods based on detailed analysis of language use. For instance, cognitive discourse analysis (CODA) (Tenbrink, 2020, p. 2) may be most appropriate for identifying principles governing unconstrained language use, protocol analysis (Ericsson & Simon, 1984) for identifying thought processes during problem solving (including spatial contexts) and psycholinguistic methodologies (Cutler et al., 2005) for addressing specific factors in highly controlled language elicitation scenarios.

The edge that connects the *spatial cognition* vertex to the *spatial world* vertex, describes the ways in which individuals conceptualise objects in their minds. While there is much research addressing human conceptualisations of the spatial world, one particularly relevant topic is human conceptualisations of landscape, investigation of which goes beyond linguistic studies of the language used to describe landscape (see below, when we discuss research on the edge connecting spatial language with the spatial world), and attempts to discover underlying insights into human conceptualisations. For example, the study of Australian Aboriginal Yindjibarndi landscape language led to speculation that Indigenous Australians may be more inclined to view the landscape as a continuous field rather than a collection of objects (Mark & Turk, 2003).

The third edge on the human face of the pyramid represents the relationship between *spatial language* and the *spatial world*. As with the other edges, spatial language research is influenced by all three areas, but on this edge of the pyramid sits research that is most focussed on language as a description of the world, with a lesser (though still present) cognitive component than research areas aligned with the other edges.

Several researchers have investigated the properties of the located and reference objects in spatial location descriptions, highlighting the typical asynchronicity between the two objects (reference objects are usually larger, more permanently located, more geometrically complex and more independent than the object whose location is being described) (Talmy, 2000). For example, the *post box is by the post office* is a much more usual expression than *the post office is by the post box*, because the post office is larger and more permanent than the post box, so makes a more natural reference object, although there are exceptions to this if the smaller object is more prominent (e.g. *the post office by the traffic lights*).

The problem of identifying the precise boundaries of objects referenced in spatial language descriptions (i.e. which part of the *spatial world*) has prompted studies of vague and fuzzy boundaries, exploring for example the extents of areas described as 'downtown' (Montello et al., 2003); named geographic places like Mount Everest (Varzi, 2001) and generic areas such as mountains and forests, whose boundaries are influenced by the properties of the landscape (Bennett, 2001). Researchers have identified wide variations in the way different languages divide up the landscape into categories of geographic features such as rivers, streams, hills etc. (known as ethnophysiography), identifying the importance of aspects such as metaphors relating to kinship and body parts; basic element or material (earth, water, etc.); motion and different kinds of spatial relationships in some cultures (Burenhult & Levinson, 2008). Languages have also been shown to vary in membership of classes of landscape features (e.g. *hill, mountain*) by size, shape, substance and boundedness (e.g. some languages may require an object to be much larger than others to be considered a mountain) (Mark et al., 2011a). While classical models of these categories used sets of criteria to define the meaning and membership of geographic object types (e.g. rivers must have a certain width to be considered rivers), other models proposed prototypical exemplars as the way in which people define categories in their minds (e.g. a snow-capped mountain is a 'better' member of the class of mountains than some other alternatives) (Jackendoff, 2002; M. Johnson, 2013; Lakoff, 2008; Rosch, 1975).

In addition to the cross-linguistic studies of the way languages categorise landscape; cross-linguistic studies of location encoding in different languages, and what that might tell us about underlying cognitive approaches of speakers, is a wide field of study, involving studies of variations in the spatial relation terms available in different languages, the semantics of apparently similar spatial relation terms and comparisons of spatial reference frames (e.g. the dominance of absolute *vs* relative frames in different languages) (Feist, 2008; Frawley, 1992; Palmer et al., 2017).

The spatial world has also been studied via language through place names (also known as toponyms), with the names used for places, including vernacular names (place names in common, colloquial usage, that might not be officially assigned), revealing the meaning of the landscape as well as the cultural practices and stories associated with places (Gudde & Bright, 2010; Riley, 1994).

In addition to the cognitive factors that influence location language discussed above (e.g. image schema, spatial reference frame), the selection of spatial relation terms used in location descriptions depends on the physical configuration and characteristics of the spatial world. It has been recognised that this relationship is complex, and that the use of spatial relation terms cannot be determined simply by using geometric rules. Coventry and Garrod's (2004) framework discusses the interplay between the geometric relationship between reference object and located object, and force dynamics. For example, the use of the preposition *on* depends not only on physical location, but also on support, as in *the cup on the table*, *the key on the chain*, while the preposition *in* implies location control, even if an object is not entirely physically enclosed, as in *the apple in the bowl*). Talmy (2000) further describes a range of factors that influence the selection of spatial prepositions, including plexity (indicating quantity or amount of constituent elements or actions) , boundedness (clearly delineated as an individual item), dividedness (composite or continuous), extension (physical extents/geometry type) and axiality (position on a conceptual axis between extremes, which can influence the use of adjectives of degree) of located and reference objects; and Lautenschütz et al. (2006) explore the influence of scale and object type.

Alongside the geometric and cognitive aspects, the influence of functional aspects on the selection and application of spatial language has also been studied, with the function, the context and the goals of the sender and recipient of spatial language being important (Carlson & van der Zee, 2005). Together, cognitive, geometric and functional factors affect how a spatial scene is conceptualised and hence how it is described by selecting the best available preposition, or preposition sense out of multiple options (for example: senses of the preposition *across* include coverage, as in *there are buildings all across the country* and an 'other side' relation, as in *she lives across the road*) (Tenbrink, 2020). Furthermore, studies of the semantics of individual senses of spatial relation terms have suggested an ideal, core, primary or prototypical meaning, from which varying senses may be derived (Tyler & Evans, 2003) on the basis of wider discourse, scene or object characteristics (Tenbrink, 2007), adopted conventions or pragmatic processes (Herskovits, 1986; Langacker, 1987).

3.2 The Digital Face

The digital face of our spatial semantic pyramid (Figure 4) reflects digital representations of spatial language and thought. The two faces are connected via two edges, connecting spatial language and its digital representation, and spatial cognition and its digital representation respectively, as discussed in Section 3.3 below. The digital face adds two additional vertices to the semantic triangle: the *structured spatial language representation* vertex to characterise digital representations of human natural language, and the *spatial cognition modelling* vertex to characterise digital representations of human thought (i.e. computational procedures and reasoning methods). The pyramid is motivated by the fact that digital representations of human spatial language and cognition are an important, fruitful and growing area of research in spatial language.

In the following sections, we describe each vertex and then each edge of the digital face, and corresponding examples of research in each area are shown in Table 1, beside their parallel on the human face. Research on digital aspects of spatial language has been boosted in recent years by the availability of massive amounts of digital text data, not least through social media and crowdsourcing, which has enabled the application of machine learning approaches, including deep learning and its associated use of embeddings[4], more recently extended through transformer-based methods such as BERT (Devlin et al., 2019) which are able to take advantage of embeddings that are pre-trained from large data sets, using smaller training sets to adapt them to a specific problem (for example, generic corpora created through web crawling or from Wikipedia can be combined with smaller, spatially specific training sets). Machine learning and more traditional rule-based methods have been applied to multiple spatial language research tasks, including place name extraction, document georeferencing and the analysis and classification of landscape terms, as discussed below.

<Tables 1 and 2 to be located approximately here>

3.2.1 Vertices of the Digital Face

The digital and human faces share the same *spatial world* vertex, as the spatial world is the referent for the other vertices on both of the other faces. However, the relations between both the *structured representation of language* and *spatial cognition modelling* vertices on the digital face with the *spatial world* vertex are both indirect (shown as dashed lines in Figure 4), as they are mediated by their equivalent vertices on the human face, since human thought is instrumental in the design and use of all digital systems and artefacts.

The *spatial world* is represented by various types of digital models, one of which is digital mapping. In digital maps the locations on the earth of physical and social phenomena are commonly represented quantitatively in vector map models in which discrete entities such as

---

[4] The embedding of a word is a multidimensional vector, intended to represent its meaning, based on a dimensionality reduction procedure applied to words that represent the context of the word, derived for example from data co-occurrence statistics.

buildings, roads, rivers and socio-economic regions are modelled with geometry objects, primarily of either points, lines or areas that are defined by geographical (latitude and longitude or map grid) coordinates. The geometry objects are associated with semantic categories and statistics of the phenomena they represent. Digital mapping plays a key role in digital studies of spatial language, since spatial language references objects in the *spatial world*. For example, methods for automated georeferencing of spatial language rely on digital representations, including coordinated location, of places and feature types referenced in spatial language descriptions and their surroundings. Thus to georeference *the accident on the Auckland Harbour Bridge*, we need to know the location of the bridge, and to make useful recommendations to emergency services, we need to know about the surrounding area, including access routes etc. At more localised scales a digital map might also be used or created to represent the environment of a robot that was controlled by or generated spatial language.

Digital representations of human *spatial cognition* are represented by the *spatial cognition modelling* vertex. Examples include the large body of qualitative spatial reasoning (QSR) work, which is intended to more accurately reflect the way that humans reason about space than quantitative handling of spatial data (e.g. through standard Geographic Information Systems). QSR focusses on representation and reasoning about spatial relations (including those describing topology, proximity, orientation, and cardinal directions) rather than natural language terms, and develops methods for representation of spatial knowledge using different forms of logic, and inference of spatial relations between objects (for example, based on knowledge of the relations between other objects). Computational models of mental maps and wayfinding have aimed to emulate some of the navigation tasks that humans regularly perform, including aspects such as the selection of objects to reference when giving route descriptions, with studies of landmark salience exploring a range of possible contributing factors.

In addition to digital models of spatial cognition, digital methods have been used to capture values and feelings attached to the landscape and to specific places (sense of place), including through crowdsourcing from social media (for example, the tags and, less reliably photo density in photo sharing platforms have been used as an indications of attractiveness), and using Public Participation GIS.

Digital representations of human spatial language are reflected in the *structured spatial language representation* vertex. These representations are extracted (see Section 3.3) from spatial language, and are intended to capture the relevant content expressed in human spatial language in a way that is suitable for computational processing. Spatial language representation schemes have varying degrees of abstraction from the structure of natural language to include aspects of human cognitive models of spatial location, and varying levels of detail. Typically they represent the key elements of spatial relation term, relatum and locatum, with additions including spatial verbs, adverbs and adjectives; direction and distance information; implicit places; motion; events and start, end and intermediate points of routes.

3.2.2 Edges of the Digital Face

Research that combines aspects of both language and cognition in a digital context fits on the edge between the *structured spatial language representation* and *spatial cognition modelling* vertices, and represents many important current topics of research on digital aspects of spatial language. The accurate interpretation of spatial relation terms (for example, if *the accident occurred next to, outside, near* or *opposite the post office*, where exactly is meant?) is important for multiple purposes, including georeferencing of text (e.g. for mapping social media content and of records of biological specimens), human language communication with robots and image retrieval (e.g. *show me photos of boys on horses*). While multiple automated methods have been developed to address this research problem, most interpret spatial relation terms using purely geometric means (the physical arrangement, see below), with very few capturing the cognitive aspects that have been investigated in studies of human spatial cognition, with the exception of automated models that incorporate image-schemata (Stock & Yousaf, 2018). Also combining cognition and language, are digital methods for mapping to human language the QSR approaches (discussed under the *spatial cognition modelling* vertex) that intend to model spatial relations qualitatively rather than quantitatively, and in so doing better reflect human spatial cognition.

The combined consideration of spatial language and spatial cognition is required in automated spatial dialogue systems (Cuayáhuitl et al., 2010; Kruijff et al., 2007). Geospatial question-answering systems in particular attempt to provide appropriate answers to spatial questions using methods such as knowledge graphs and geospatial analysis, and conversational geospatial interfaces address the broader challenge of automated dialogue with the geographic information user.

Another fruitful research area has addressed automated spatial reasoning for navigation, focussing on methods for generating or following natural language navigation instructions, with robotics and autonomous vehicles being important application areas for these techniques.

The edge that connects *spatial cognition modelling* and the *spatial world* reflects the digital representation of conceptualisations of the world in digital systems. Formally-specified ontologies[5] are an example of a model of classes of objects (e.g. rivers, towns, forests) in the spatial world that are commonly referenced in spatial language (via the labels given to classes and the relations between them). Formally-specified ontologies describe the semantics of classes of objects using a formal language such as Web Ontology Language (OWL) in terms of their attributes (the characteristics they must have in order to be considered a member of the class), and their relations to other classes, and representing a shared conceptualisation of the world (Dimitrova et al., 2008; Gruber, 1995; Guarino et al., 2009; Studer et al., 1998). Such ontologies and thesauri (a simplified form of ontologies with less formally specified semantics) can be used for various tasks including identification of landscape features in natural language; automated ontology mapping; cross-linguistic data integration and translation using multilingual thesauri (Kavouras et al., 2005; Stock & Cialone, 2011a). Kuhn (2009) identifies the need for the classes in formally-specified ontologies to be grounded in physical properties, and proposes the idea of semantic reference systems to avoid formally-specified ontologies being "islands in a sea of different conceptualisations" (Kuhn, 2005, p. 15).

In recent years, the use of ontologies has been less popular, due to the large amount of effort required to create them, the difficulty in defining ontologies that are sufficiently generic to be used across a range of applications and the challenges in formalising domain expertise (Claramunt, 2020; Stock et al., 2012). While some thesauri are in common use (e.g. GEMET[6]), another development is the use of informal tagging schemes (sometimes known as

[5] We use the term formally-specified ontologies to refer to the kind of ontologies described in the computer science discipline as a formal specification of a shared conceptualisation (Gruber, 1995), in contrast to the more general use of the word ontology as a study of the nature of being.

[6] https://www.eionet.europa.eu/gemet/en/themes/

folksonomies). Many crowdsourcing/social media applications (e.g. OpenStreetMap[7]) allow users to add any tags that they consider appropriate (Mocnik et al., 2017). However, this approach can cause significant challenges, as identification and retrieval of particular types of landscape features can be inconsistent (Ballatore, 2016; Hall & Jones, 2021).

As for the relationship between *spatial language* and the *spatial world*, the relationship between *structured spatial language representation* and the *spatial world* on the digital face is mediated by human thought, specifically the ways in which system designers and users (e.g. those who capture data, design data models and interpret data) understand and interpret the world. Research that aligns with this edge of the pyramid includes development of automated methods for place name extraction or toponym recognition (given that place names refer to real world places), building on methods for named entity recognition (NER), a task that has been widely addressed in the natural language processing (NLP) and that identifies particular types of named entities, including locations, people, and organisations. Once identified, place names must be matched to a coordinated location in a gazetteer, requiring disambiguation due to different locations being referred to by the same place name (Purves et al., 2018). Additional information is used to disambiguate, including population; associated place names and other concepts mentioned in surrounding text; feature types and language models (Ju et al., 2016; Speriosu & Baldridge, 2013). Related to this challenge is research in modelling the geographic extents of regions referred to by place names, particularly vernacular names that reflect colloquial usage of place name terminology. Text sources such as social media and web sites have been used to identify the areas referred to by the general population with vernacular place names.

Also along this edge is work that uses language (specifically text sources, particularly social

[7] https://www.openstreetmap.org/

media) to study sense of place and other cultural ecosystem services (see Section 3.1.1), as well as conceptualisation of land of different cultures through automated analysis or classification of landscape terms. Methods applied in these studies include extraction of words that commonly co-occur with landscape terms, and the comparison of words used in text descriptions to identify landscapes that are semantically similar.

Work on automated document georeferencing has aimed to determine the footprint of the area or areas referenced in a document, based variously on the coordinates of named places identified within a document using NER; the use of all the document's text with language modelling approaches that associate sets of words with locations (Melo & Martins, 2017)); or on the locations of objects (such as biological species or disaster impacts) mentioned in text. The focus of this latter task then becomes one of relation extraction: identifying related place names and objects. Relation extraction is a generic task addressed in the NLP field, but successful extraction of objects referenced by places in text documents in still limited by the complexity of language and the common use of co-references (e.g. pronouns that refer to objects referenced earlier in a document).

The task of automated georeferencing, interpretation and generation of spatial relation expressions has a number of applications, including the accurate mapping of specific phenomena mentioned in text (e.g. *samples were collected in and around the north-eastern corner of Lake Vanda*); communication with robots or driverless vehicles (e.g. enabling users for giving directions about movement (*turn left at the next corner*) or actions such as *put the book on the bookshelf/in the bookshelf*) and photo retrieval (*find me photos of boys on horses*) or question answering (*what is the name of the building next to the river?*). Older models for interpretation of spatial relation terms have focussed on the rules that describe the geometric arrangement between the relatum and locatum that corresponds to a particular spatial relation term, but the inability of such approaches to accurately reflect the vague, under-specified and context sensitive way that humans describe space has led to probabilistic (including density fields in the form of spatial templates) and machine learning approaches, which learn from a range of previous experiences with different contexts.

3.3 Edges Connecting the Human and Digital Faces

Table 2 summarises the research areas that correspond to the two edges connecting the digital and human faces, and provides examples of relevant research.

The edge that connects the *structured spatial language representation* vertex with the *spatial language* vertex on the human face describes the transformation from human language to a structured representation of language through parsing, extraction and abstraction. Natural language descriptions of location form only a very small part of the entire body of human language, and methods for automated detection of spatial and geospatial (e.g. in geographic, outdoor environments) expressions have been developed to extract relevant location content (e.g. to identify social media descriptions of damage following a disaster in social media among the multitude of posts that are not about location).

Natural language spatial descriptions can vary enormously, due to the range of vocabulary that can be used, nuances in expression and their relationship to context and purpose of communication, and differences in grammatical structure (e.g. *near the house is a bridge; the bridge is near the house; there is a bridge near the house*). This complexity and variability is very difficult for automated systems to deal with, and one approach to address this has been the definition of constrained spatial languages. Another approach is the automated parsing of spatial language to identify important elements. Attention thus far has focussed on extraction of relatum, locatum and spatial relation term (usually preposition). There is much potential for further advances to achieve this task for more complex location descriptions.

The final edge of the pyramid connects the ***spatial cognition modelling*** vertex on the digital face to the ***spatial cognition*** vertex on the human face, representing the process of development/extraction of models of spatial cognition from human models. The Sapir-Whorf (linguistic relativity) hypothesis considers that people's ways of thinking are determined (strong linguistic relativism) or influenced (weak linguistic relativism) by the language they use (Whorf, 2012), and accordingly, spatial language has been used to extract digital models of spatial cognition, since human cognitive models can be difficult to access directly.

4 Papers in the Special Issue

The Special Issue that this paper introduces includes four additional papers on the topic of spatial language, situated at a variety of locations on the semantic pyramid, including both the human and digital faces.

The paper by Yousaf and Wolter titled "A Reasoning Model for Geo-Referencing Named and Unnamed Spatial Entities in Natural Language Place Descriptions" is concerned with the task of detecting and georeferencing words that refer to places, where the words may or may not be place names. This mix of detecting and georeferencing place references along with a concern for identifying relations within text, places the work in a broad region of the pyramid that is close to the *structured spatial language representation* corner but extending towards all three connected vertices of that corner. The work aims to advance on current approaches, in analysing the often complex spatial language of locative descriptions to identify the primary location that is described (as opposed to other places that might be referenced indirectly). For example, in the expression *post office near Bamberg main station,* the phrase *post office*, which in this case is an unnamed entity, would be the target for georeferencing. Pointing out the limitations of standard dependency parsers, the authors start from part of speech tagged text and adopt an inference-based approach that initially identifies candidate entities and relations (both semantic and spatial) before generating further categorisations based on adjacency between entities where one of the entities is a category. OpenStreetMap (OSM) is then used to match the candidate entities to actual places, using a procedure that avoids generating excess possible matches by limiting the OSM queries to particular combinations of named entities or entity types and a containing region. Benefits of their method relative to several current systems for entity recognition are demonstrated in an experimental evaluation.

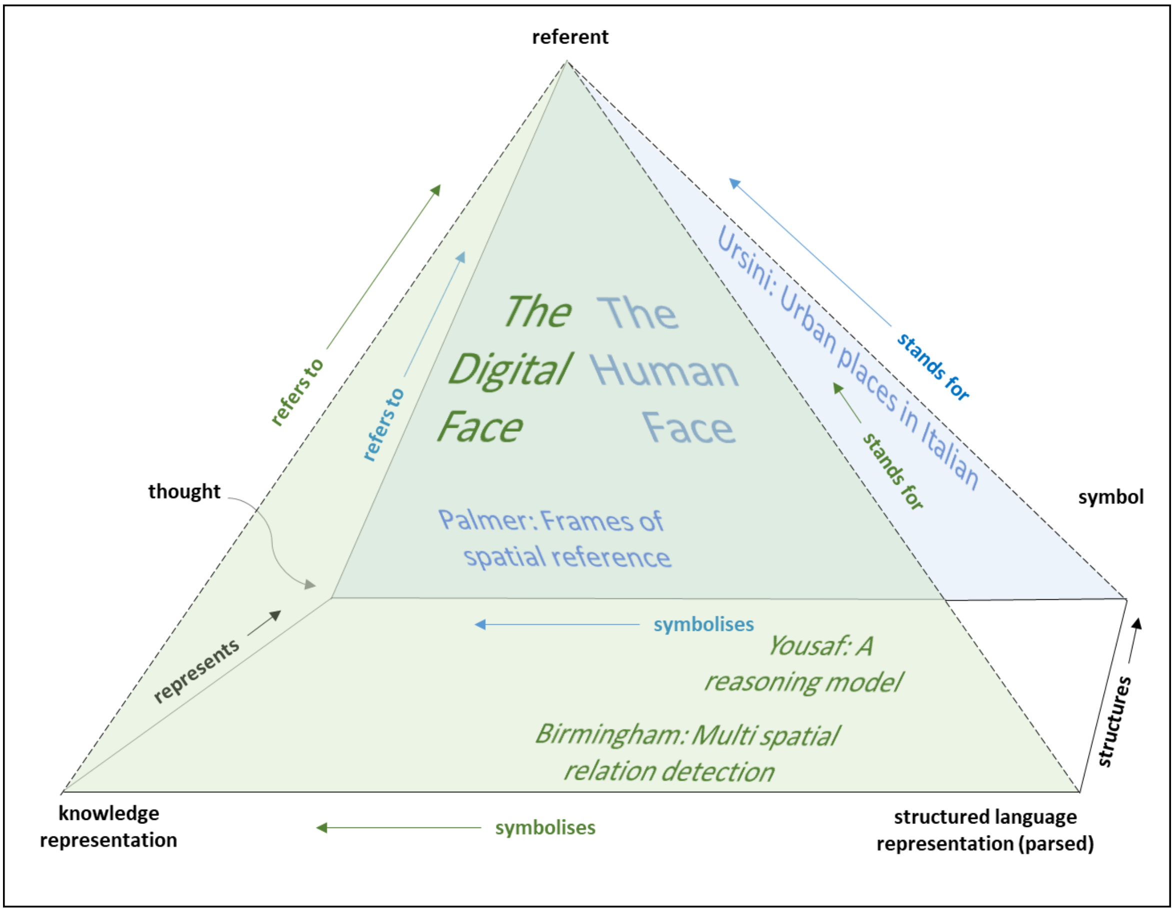

Figure 5: The Special Issue papers in the context of the Semantic Pyramid

The paper “Multi Spatial Relation Detection in Images” by Birmingham and Muscat addresses the problem of allocating prepositional spatial relation terms to the spatial relationship between a pair of objects in an image, where the ground truth indicates that more than one preposition is usually applicable. The aspect of selecting spatial relational terms places the paper in the semantic pyramid near the edge of *structured spatial language representation symbolises spatial cognition modelling* between the two vertices. The authors work from data in the French language that has been manually annotated with the class and text description of each object, their bounding boxes in the image, and spatial relation terms that have been assigned to describe the relation. The task is to predict the manually assigned spatial relation terms. They use a machine learning approach with various classifiers in combination with a variety of machine learning features that are classed as linguistic, geometric or depth. The classifiers include nearest neighbour, k-means clustering, agglomerative hierarchical clustering, and a multi-label neural network. The linguistic features include the class and text descriptors of the respective objects and word embeddings of those terms. The geometric features include measures of distance between and overlap and orientation of the pairs of bounding boxes. The depth features were obtained from human annotators' estimation of depths of the individual object pairs and the derived depth difference. Of their classifiers, the multi-label neural network gave the best overall performance, though some of the other classifiers displayed individual strengths: for example the k-means clustering classifier, while overall relatively poor, was successful in predicting less frequent prepositions.

In addition to testing on the ground truth of an external dataset, the authors conducted their own human subjects experiments that indicated some though not large disagreement with the ground truth data, reflecting the subjectivity of allocating particular preposition terms, some of which might be essentially interchangeable in some situations.

The paper "Names for Urban Places and Conceptual Taxonomies: The View from Italian" by Ursini and Samo presents an analysis of the characteristics of urban place names in Italian cities, with particular regard to the communication of distinctive facets of place that reflect geographic variation in dialect and culture. In its concern for place taxonomy (or ontology) and the link between terminology (in this case place names) and the referent of the physical and cultural worlds, it is located on the structured *spatial language stands for spatial world* edge of the semantic pyramid. The authors focus on the place type components of the names that include generic types such as (translated to English) street, square, avenue, park, alley etc, of which there are 218. The authors organise the terms into a hierarchical taxonomy that includes is-a and part-of relations. The highest level of the taxonomy distinguishes between connecting places (streets of various form) and gathering places such as squares and parks. Lower levels distinguish between degrees of artificiality and between different types of places with respect to social function and spatial form and structure. The lowest levels distinguish subtypes of the features with further levels reflecting the geographic differences that relate particularly to regional dialect or local physical characteristics. Many terms are found to be unique to one or a few particular cities, for example *sotoportego* (under-porch) in Venice, and *alzaia* (a tow path) in Milan. Other more internationally generic terms such as *via* do not have such geographic distinctions. The paper presents maps to illustrate regional and local variation in the use of groups of terms in the taxonomy.

The paper 'Frames of spatial reference in five Australian languages' by Palmer et al. presents a study that challenges the widely held view that the spatial aspects of Australian indigenous languages are characterised by the use of absolute, cardinal direction-based frames of reference (FoR), with little use of relative or egocentric frames of reference. The paper falls near the *spatial cognition* corner of the human face of our semantic pyramid, as it makes a valuable contribution to the use of frames of reference in Australian languages but does not present computational methods. Their study analyses sources from five distinct languages and finds that cardinal directions were not used at all. Rather there was common use of front-back (sagittal) and to lesser extent left-right (transverse) in intrinsic and relative frames of reference, as well as 'geomorphic' frames of reference, in which the spatial language uses natural features of the environment for orientation, such the path and direction of rivers, elevation (distinguishing between going up or down) and the direction of seasonal winds. The geomorphic frame of reference falls within the class of geocentric FoR (Bohnemeyer & O'Meara, 2012; Carlson-Radvansky et al., 1999) to which (absolute) cardinal directions also belong. Palmer *et al*. refer to a lack of agreement on the use of the term absolute, pointing out that in some interpretations, e.g. (Danziger, 2010), all allocentric and extrinsic relations[8] (such as geomorphic) can be regarded as absolute, whereas most such FoR are insufficiently abstract in the sense of Levinson (Levinson, 2003) to be regarded as absolute. Usage of intrinsic frames of reference was dominated by the front-back axis, with less common use of left-right. A further finding concerned previously less well documented use of an egocentric and extrinsic nearside-farside FoR (referring to the near or far side of objects relative to the observer).

5 Conclusions

This paper has provided a review of some of the key areas of research addressing spatial language in recent decades, viewed within the framework of the spatial semantic pyramid. We have considered a range of areas addressing human spatial language, as represented by the human face, including those that are primarily linguistically focussed, those that address spatial cognition, and those that consider the spatial world that is referenced by language. We have then addressed the digital representation or emulation of human spatial language,

---

[8] An allocentric FoR is centred on objects other than the observer (in contrast to egocentric), while the distinction between extrinsic and intrinsic FoR refers to whether the FoR orientation is determined by intrinsic features of the reference object or person (as opposed to by an external perspective or other external factors, such a cardinal directions or direction of flow of a river).

summarising the research that has described spatial language, and attempted to interpret or generate the ways in which spatial language is used by humans. The spatial semantic pyramid reflects the way in which research areas addressing digital aspects of spatial language reflect human language.

While all areas of spatial language research incorporate all three elements of the spatial semantic triangle (in the case of computational research this occurs through the relevant parts of the digital face and its associations with the human face), the framing of research in the light of these three areas can be useful for clarifying the picture of research in the field, which is highly multi-disciplinary, and for identifying potential areas for new attention. For example, current spatial language representation schemes (Section 3.2.1) often combine linguistic, cognitive and geometric (spatial world) factors, but as methods for the representation of all three aspects of spatial language become richer (see below), a greater separation of these areas may be useful for creating functional knowledge representation systems.

The pyramid is also useful for identifying areas of research into human language that are as yet poorly addressed in digital systems. For example, cross-linguistic aspects of spatial language have been studied comprehensively for decades, but computational cross-linguistic spatial language work is more scarce. Furthermore, the computational work on cognitive aspects of spatial location descriptions (Section 3.2.2) has lagged behind the understanding that has been gained in the linguistics and cognitive science fields, with automated methods to deal with spatial deixis, or many cognitive aspects of language like frames of reference being as yet undeveloped, and ripe for attention given the rapid advances in data mining and machine learning methods, together with an ever-increasing availability of text data. A major challenge in this field lies in establishing sufficient world knowledge to enable context-specific adaptations – a well-known obstacle across AI efforts; here, the idea of 'strong spatial cognition' (Freksa, 2015) is pertinent, paralleling 'strong AI' (Searle, 1980). Also providing great potential for the future of the automation of spatial language are recent and quickly developing advances in generic NLP research (e.g. in the areas of fine-grained entity typing, relationship extraction and co-reference resolution), to enable more sophisticated processing of spatial language to further the goal of more closely emulating human language selection, application and understanding. While some of these methods currently lack accuracy, future improvements are likely, with the opportunity for increased exploitation for spatial language research.

Language is fundamental to human relationships, and spatial language is grounded within our everyday experience of the world. The research reviewed in this paper illustrates some of the vast range of achievements that have been made in the field, as well as the challenges going forward. It also demonstrates our significant potential for better understanding of the way that humans use spatial language, and for the development of computational processes to imitate that use across a range of application areas.

References

Acheson, E., & Purves, R. S. (2021). Extracting and modeling geographic information from scientific articles. *Plos One*, *16*(1), e0244918.

Alazzawi, A. N., Abdelmoty, A. I., & Jones, C. B. (2012). What can I do there? Towards the automatic discovery of place-related services and activities. *International Journal of Geographical Information Science*, *26*(2), 345–364. https://doi.org/10.1080/13658816.2011.595954

Almeida, M., Souza, R., & Fonseca, F. (2011). Semantics in the Semantic Web: A Critical Evaluation. *KNOWLEDGE ORGANIZATION*, *38*(3), 187–203. https://doi.org/10.5771/0943-7444-2011-3-187

Arampatzis, A., Kreveld, M. van, Reinbacher, I., Jones, C. B., Vaid, S., Clough, P. D., Joho, H., & Sanderson, M. (2006). Web-Based Delineation of Imprecise Regions. *Computers Environment and Urban Systems*, *30*(4), 436–459. https://doi.org/10.1016/j.compenvurbsys.2005.08.001

Auer, P., Schmidt, J. E., & Lameli, A. (2010). *Language and Space: An International Handbook of Linguistic Variation*. Walter de Gruyter.

Ballatore, A. (2016). Semantic challenges for volunteered geographic information. *European Handbook of Crowdsourced Geographic Information*, 87.

Bartie, P., Reitsma, F., Clementini, E., & Kingham, S. (2011). Referring Expressions in Location Based Services: The Case of the 'Opposite' Relation. In O. De Troyer, C. Bauzer Medeiros, R. Billen, P. Hallot, A. Simitsis, & H. Van Mingroot (Eds.), *Advances in Conceptual Modeling. Recent Developments and New Directions* (pp. 231–240). Springer. https://doi.org/10.1007/978-3-642-24574-9_30

Bateman, J. A., Hois, J., Ross, R., & Tenbrink, T. (2010). A Linguistic Ontology of Space for Natural Language Processing. *Artif. Intell.*, *174*(14), 1027–1071. https://doi.org/10.1016/j.artint.2010.05.008

Beaudoin, J. (2007). Folksonomies: Flickr image tagging: Patterns made visible. *Bulletin of the American Society for Information Science and Technology*, *34*(1), 26–29.

Becker, A., & Carroll, M. (1997). *The acquisition of spatial relations in a second language* (Vol. 11). John Benjamins Publishing.

Bennett, B. (2001). Application of Supervaluation Semantics to Vaguely Defined Spatial Concepts. In D. R. Montello (Ed.), *Spatial Information Theory* (pp. 108–123). Springer. https://doi.org/10.1007/3-540-45424-1_8

Bisk, Y., Shih, K., Choi, Y., & Marcu, D. (2018). Learning Interpretable Spatial Operations in a Rich 3D Blocks World. *Proceedings of the AAAI Conference on Artificial Intelligence*, *32*(1), Article 1. https://ojs.aaai.org/index.php/AAAI/article/view/12026

Bittner, T., & Stell, J. G. (2002). Vagueness and Rough Location. *GeoInformatica*, *6*(2), 99–121. https://doi.org/10.1023/A:1015291525685

Bohnemeyer, J. (2008). *MesoSpaceSpatial language and cognition in Mesoamerica*. https://www.acsu.buffalo.edu/~jb77/MesoSpaceManual2008.pdf

Bohnemeyer, J., & O'Meara, C. K. (2012). Vectors and frames of reference Evidence from Seri and Yucatec. In *Space and Time in Languages and Cultures: Language, culture, and cognition* (pp. 217–249). John Benjamins Publishing. https://benjamins.com/catalog/hcp.37.16boh

Brown, G., & Brabyn, L. (2012). An analysis of the relationships between multiple values and physical landscapes at a regional scale using public participation GIS and landscape character classification. *Landscape and Urban Planning*, *107*(3), 317–331. https://doi.org/10.1016/j.landurbplan.2012.06.007

Burenhult, N., & Levinson, S. C. (2008). Language and landscape: A cross-linguistic perspective. *Language Sciences*, *30*(2), 135–150. https://doi.org/10.1016/j.langsci.2006.12.028

Burrough, P. A., McDonnell, R. A., & Lloyd, C. D. (2015). *Principles of Geographical Information Systems* (Third Edition). Oxford University Press.

Burrough, P. A., van Gaans, P. F., & Hootsmans, R. (1997). Continuous classification in soil survey: Spatial correlation, confusion and boundaries. *Geoderma*, *77*(2–4), 115–135.

Caduff, D., & Timpf, S. (2008). On the assessment of landmark salience for human navigation. *Cognitive Processing*, *9*(4), 249–267.

Cai, G., Wang, H., MacEachren, A. M., & Fuhrmann, S. (2005). Natural Conversational Interfaces to Geospatial Databases. *Transactions in GIS*, *9*(2), 199–221. https://doi.org/10.1111/j.1467-9671.2005.00213.x

Canter, D. (1997). The Facets of Place. In G. T. Moore & R. W. Marans (Eds.), *Toward the Integration of Theory, Methods, Research, and Utilization* (pp. 109–147). Springer US. https://doi.org/10.1007/978-1-4757-4425-5_4

Carlson, L., & van der Zee, E. (Eds.). (2005). *Functional features in language and space: Insights from perception, categorization, and development* (pp. xiv, 386). Oxford University Press.

Carlson-Radvansky, L. A., Covey, E. S., & Lattanzi, K. M. (1999). “What” Effects on “Where”: Functional Influences on Spatial Relations. *Psychological Science*, *10*(6), 516–521. https://doi.org/10.1111/1467-9280.00198

Carlson-Radvansky, L. A., & Radvansky, G. A. (1996). The influence of functional relations on spatial term selection. *Psychological Science*, *7*(1), 56–60.

Chen, H., Winter, S., & Vasardani, M. (2018). Georeferencing places from collective human descriptions using place graphs. *Journal of Spatial Information Science*, *2018*(17), 31–62. https://doi.org/10.5311/JOSIS.2018.17.417

Choi, S., McDonough, L., Bowerman, M., & Mandler, J. M. (1999). Early Sensitivity to Language-Specific Spatial Categories in English and Korean. *Cognitive Development*, *14*(2), 241–268. https://doi.org/10.1016/S0885-2014(99)00004-0

Claramunt, C. (2020). Ontologies for geospatial information: Progress and challenges ahead. *Journal of Spatial Information Science*, *2020*(20), 35–41. https://doi.org/10.5311/JOSIS.2020.20.666

Cohn, A. G., Bennett, B., Gooday, J., & Gotts, N. M. (1997). Qualitative Spatial Representation and Reasoning with the Region Connection Calculus. *GeoInformatica*, *1*(3), 275–316. https://doi.org/10.1023/A:1009712514511

Cohn, A. G., & Hazarika, S. M. (2001). Qualitative spatial representation and reasoning: An overview. *Fundamenta Informaticae*, *46*(1–2), 1–29.

Collell, G., Gool, L. V., & Moens, M.-F. (2018, April 27). Acquiring Common Sense Spatial Knowledge Through Implicit Spatial Templates. *Thirty-Second AAAI Conference on Artificial Intelligence*. Thirty-Second AAAI Conference on Artificial Intelligence. https://www.aaai.org/ocs/index.php/AAAI/AAAI18/paper/view/16232

Coventry, K. R., & Garrod, S. C. (2004). *Saying, Seeing and Acting: The Psychological Semantics of Spatial Prepositions*. Psychology Press. https://doi.org/10.4324/9780203641521

Coventry, K. R., Lynott, D., Cangelosi, A., Monrouxe, L., Joyce, D., & Richardson, D. C. (2010). Spatial language, visual attention, and perceptual simulation. *Brain and Language*, *112*(3), 202–213. https://doi.org/10.1016/j.bandl.2009.06.001

Coventry, K. R., Tenbrink, T., & Bateman, J. (2009). *Spatial language and dialogue* (Vol. 3). OUP Oxford.

Cuayáhuitl, H., Dethlefs, N., Richter, K.-F., Tenbrink, T., & Bateman, J. (2010). A Dialogue System for Indoor Wayfinding Using Text-Based Natural Language. *International Journal of Computational Linguistics and Applications*, *1*(1–2), 285–304.

Cunha, E., & Martins, B. (2014). Using one-class classifiers and multiple kernel learning for defining imprecise geographic regions. *International Journal of Geographical Information Science*, *28*(11), 2220–2241. https://doi.org/10.1080/13658816.2014.916040

Cunninghan, W., & Cunningham, M. (2019). *Principles of Environmental Science*. McGraw Hill. https://www.mheducation.com/highered/product/principles-environmental-science-cunningham-cunningham/M9781260219715.html

Cutler, A., Klein, W., & Levinson, S. C. (2005). The cornerstones of twenty-first century psycholinguistics. In *Twenty-first century psycholinguistics: Four cornerstones* (pp. 1–20). Erlbaum.

Dahlberg, I. (1978). A referent-oriented, analytical concept theory for INTERCONCEPT. *Knowledge Organization*, *5*(3), 142–151. https://doi.org/10.5771/0943-7444-1978-3-142

Dale, R., Geldof, S., & Prost, J.-P. (2005). Using natural language generation in automatic route description. *Journal of Research and Practice in Information Technology*. http://search.informit.org/doi/abs/10.3316/ielapa.015346326352219

Daniel, M.-P., Carité, L., & Denis, M. (1996). Modes of Linearization in the Description of Spatial Configurations. In J. Portugali (Ed.), *The Construction of Cognitive Maps* (pp. 297–318). Springer Netherlands. https://doi.org/10.1007/978-0-585-33485-1_13

Daniel, M.-P., Tom, A., Manghi, E., & Denis, M. (2003). Testing the value of route directions through navigational performance. *Spatial Cognition and Computation*, *3*(4), 269–289.

Danziger, E. (2010). Deixis, gesture, and cognition in spatial Frame of Reference typology. *Studies in Language*, *34*, 167–185. https://doi.org/10.1075/sl.34.1.16dan

Davies, C., Holt, I., Green, J., Harding, J., & Diamond, L. (2009). User needs and implications for modelling vague named places. *Spatial Cognition & Computation*, *9*(3), 174–194.

Demeritt, D. (2002). What is the 'social construction of nature'? A typology and sympathetic critique. *Progress in Human Geography*, *26*(6), 767–790.

Denis, M. (2017). *Space and Spatial Cognition: A Multidisciplinary Perspective*. Routledge.

Derungs, C., & Purves, R. S. (2016). Characterising landscape variation through spatial folksonomies. *Applied Geography*, *75*, 60–70. https://doi.org/10.1016/j.apgeog.2016.08.005

Devlin, J., Chang, M.-W., Lee, K., & Toutanova, K. (2019). BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding. *Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long and Short Papers)*, 4171–4186. https://doi.org/10.18653/v1/N19-1423

Diessel, H., & Coventry, K. R. (2020). Demonstratives in Spatial Language and Social Interaction: An Interdisciplinary Review. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.555265

Dimitrova, V., Denaux, R., Hart, G., Dolbear, C., Holt, I., & Cohn, A. G. (2008). Involving Domain Experts in Authoring OWL Ontologies. In A. Sheth, S. Staab, M. Dean, M. Paolucci, D. Maynard, T. Finin, & K. Thirunarayan (Eds.), *The Semantic Web—ISWC 2008* (pp. 1–16). Springer. https://doi.org/10.1007/978-3-540-88564-1_1

Downs, R. M., & Stea, D. (1973). *Image and environment: Cognitive mapping and spatial behavior*. Aldine.

Du, H., Alechina, N., Jackson, M., & Hart, G. (2013). Matching Formal and Informal Geospatial Ontologies. In D. Vandenbroucke, B. Bucher, & J. Crompvoets (Eds.), *Geographic Information Science at the Heart of Europe* (pp. 155–171). Springer International Publishing. https://doi.org/10.1007/978-3-319-00615-4_9

Du, S., Wang, X., Feng, C.-C., & Zhang, X. (2017). Classifying natural-language spatial relation terms with random forest algorithm. *International Journal of Geographical Information Science*, *31*(3), 542–568. https://doi.org/10.1080/13658816.2016.1212356

Duckham, M., Winter, S., & Robinson, M. (2010). Including landmarks in routing instructions. *Journal of Location Based Services*, *4*(1), 28–52. https://doi.org/10.1080/17489721003785602

Egorova, E., Moncla, L., Gaio, M., Claramunt, C., & Purves, R. S. (2018). Fictive motion extraction and classification. *International Journal of Geographical Information Science*, *32*(11), 2247–2271. https://doi.org/10.1080/13658816.2018.1498503

Ericsson, K. A., & Simon, H. A. (1984). *Protocol analysis: Verbal reports as data* (p. 426). The MIT Press.

Feist, M. I. (2008). Space Between Languages. *Cognitive Science*, *32*(7), 1177–1199. https://doi.org/10.1080/03640210802152335

Fish, R., Church, A., & Winter, M. (2016). Conceptualising cultural ecosystem services: A novel framework for research and critical engagement. *Ecosystem Services*, *21*, 208–217. https://doi.org/10.1016/j.ecoser.2016.09.002

Frawley, W. (1992). *Linguistic Semantics*. Routledge. https://doi.org/10.4324/9781315044644

Freksa, C. (1992). Using orientation information for qualitative spatial reasoning. In A. U. Frank, I. Campari, & U. Formentini (Eds.), *Theories and Methods of Spatio-Temporal Reasoning in Geographic Space* (pp. 162–178). Springer. https://doi.org/10.1007/3-540-55966-3_10

Freksa, C. (2015). Strong Spatial Cognition. In S. I. Fabrikant, M. Raubal, M. Bertolotto, C. Davies, S. Freundschuh, & S. Bell (Eds.), *Spatial Information Theory* (pp. 65–86). Springer International Publishing. https://doi.org/10.1007/978-3-319-23374-1_4

Gapp, K.-P. (1995). Angle, Distance, Shape, and their Relationship to Projective Relations. *Proceedings of the 17th Annual Conference of the Cognitive Science Society*, 112–117. https://www.semanticscholar.org/paper/Angle%2C-Distance%2C-Shape%2C-and-their-Relationship-to-Gapp/e2175dc074d72a5cb99f38f2d5f2e8d29429b534

Gliozzo, G., Pettorelli, N., & Haklay, M. (2016). Using Crowdsourced imagery to detect cultural ecosystem services: A case study in South Wales, UK. *Ecology and Society*, *21*. http://dx.doi.org/10.5751/ES-08436-210306

Golledge, R. G. (1999). Human wayfinding and cognitive maps. *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*, 5–45.

Golledge, R. G., Smith, T. R., Pellegrino, J. W., Doherty, S., & Marshall, S. P. (1985). A conceptual model and empirical analysis of children's acquisition of spatial knowledge. *Journal of Environmental Psychology*, *5*(2), 125–152. https://doi.org/10.1016/S0272-4944(85)80014-1

Gruber, T. R. (1995). Toward principles for the design of ontologies used for knowledge sharing? *International Journal of Human-Computer Studies*, *43*(5), 907–928. https://doi.org/10.1006/ijhc.1995.1081

Guarino, N., Oberle, D., & Staab, S. (2009). What Is an Ontology? In S. Staab & R. Studer (Eds.), *Handbook on Ontologies* (pp. 1–17). Springer. https://doi.org/10.1007/978-3-540-92673-3_0

Gudde, E. G., & Bright, W. (2010). *California Place Names: The Origin and Etymology of Current Geographical Names*. Univ of California Press.

Hall, M., & Jones, C. B. (2021). Generating geographical location descriptions with spatial templates: A salient toponym driven approach. : *: International Journal of Geographical Information Science*. https://doi.org/10.1080/13658816.2021.1913498

Hall, M., Jones, C. B., & Smart, P. (2015). Spatial Natural Language Generation for Location Description in Photo Captions. In S. I. Fabrikant, M. Raubal, M. Bertolotto, C. Davies, S. Freundschuh, & S. Bell (Eds.), *Spatial Information Theory* (pp. 196–223). Springer International Publishing.

Hall, M., Smart, P. D., & Jones, C. B. (2011). Interpreting spatial language in image captions. *Cognitive Processing*, *12*(1), 67–94. https://doi.org/10.1007/s10339-010-0385-5

Hannes, E., Kusumastuti, D., Espinosa, M. L., Janssens, D., Vanhoof, K., & Wets, G. (2012). Mental maps and travel behaviour: Meanings and models. *Journal of Geographical Systems*, *14*, 143–165. https://doi.org/10.1007/s10109-010-0144-2

Hassani, K., & Lee, W.-S. (2017). Disambiguating spatial prepositions using deep convolutional networks. *Proceedings of the Thirty-First AAAI Conference on Artificial Intelligence*, 3209–3215.

Hercus, L., Hodges, F., & Simpson, J. (Eds.). (2009). *The Land is a Map: Placenames of Indigenous Origin in Australia*. ANU Press. https://doi.org/10.26530/OAPEN_459353

Herskovits, A. (1986). *Language and Spatial Cognition*. Cambridge University Press.

Hois, J., & Kutz, O. (2008). Natural Language Meets Spatial Calculi. In C. Freksa, N. S. Newcombe, P. Gärdenfors, & S. Wölfl (Eds.), *Spatial Cognition VI. Learning, Reasoning, and Talking about Space* (pp. 266–282). Springer. https://doi.org/10.1007/978-3-540-87601-4_20

Hollenstein, L., & Purves, R. (2010). Exploring place through user-generated content: Using Flickr tags to describe city cores. *Journal of Spatial Information Science*, *2010*(1), 21–48. https://doi.org/10.5311/JOSIS.2010.1.13

Holton, G. (2011). Differing conceptualizations of the same landscape. *Landscape in Language. Transdisciplinary Perspectives. Amsterdam/Philadelphia: John Benjamins Publishing*, 225–237.

Huang, A. S., Tellex, S., Bachrach, A., Kollar, T., Roy, D., & Roy, N. (2010). Natural language command of an autonomous micro-air vehicle. *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2663–2669.

Inkpen, R., & Wilson, G. (2013). *Science, Philosophy and Physical Geography*. Routledge.

Jackendoff, R. (1983). *Semantics and cognition* (Vol. 8). MIT press.

Jackendoff, R. (2002). *Foundations of language: Brain, meaning, grammar, evolution*. Oxford University Press, USA.

Jeawak, S., Jones, C. B., & Schockaert, S. (2017). Using Flickr for characterizing the environment: An exploratory analysis. *13th International Conference on Spatial Information Theory (COSIT 2017)*, 21:1-21:13. https://doi.org/10.4230/LIPIcs.COSIT.2017.21

Jenkins, A., Croitoru, A., Crooks, A. T., & Stefanidis, A. (2016). Crowdsourcing a collective sense of place. *PloS One*, *11*(4), e0152932.

Johnson, L. M. (2010). *Trail of Story, Traveller's Path: Reflections on Ethnoecology and Landscape*. Athabasca University Press.

Johnson, L. M., & Hunn, E. S. (2010). *Landscape Ethnoecology: Concepts of Biotic and Physical Space*. Berghahn Books.

Johnson, M. (2013). *The body in the mind: The bodily basis of meaning, imagination, and reason*. University of Chicago Press.

Jones, C. B. (1997). *Geographical Information Systems and Computer Cartography*. Routledge. https://doi.org/10.4324/9781315846231

Jones, C. B., Alani, H., & Tudhope, D. (2001). Geographical Information Retrieval with Ontologies of Place. *COSIT 2001: Proceedings of the International Conference on Spatial Information Theory: Foundations of Geographic Information Science*, 322–335. https://doi.org/10.1007/3-540-45424-1_22

Jones, C. B., Purves, R. S., Clough, P. D., & Joho, H. (2008). Modelling vague places with knowledge from the Web. *International Journal of Geographical Information Science*, *22*(10), 1045–1065. https://doi.org/10.1080/13658810701850547

Jordan, T., Raubal, M., Gartrell, B., & Egenhofer, M. (1998). An affordance-based model of place in GIS. *8th Int. Symposium on Spatial Data Handling, SDH*, *98*, 98–109.

Ju, Y., Adams, B., Janowicz, K., Hu, Y., Yan, B., & McKenzie, G. (2016). Things and strings: Improving place name disambiguation from short texts by combining entity co-occurrence with topic modeling. *European Knowledge Acquisition Workshop*, 353–367.

Karimzadeh, M., Pezanowski, S., MacEachren, A. M., & Wallgrün, J. O. (2019). GeoTxt: A scalable geoparsing system for unstructured text geolocation. *Transactions in GIS*, *23*(1), 118–136. https://doi.org/10.1111/tgis.12510

Kavouras, M., Kokla, M., & Tomai, E. (2005). Comparing categories among geographic ontologies. *Computers & Geosciences*, *31*(2), 145–154. https://doi.org/10.1016/j.cageo.2004.07.010

Kelleher, J. D., & Costello, F. J. (2009). Applying Computational Models of Spatial Prepositions to Visually Situated Dialog. *Computational Linguistics*, *35*(2), 271–306. https://doi.org/10.1162/coli.06-78-prep14

Kenyon, D. (1991). *The origins of Lancashire*. Manchester University Press.

Khan, A., Vasardani, M., & Winter, S. (2013). Extracting Spatial Information From Place Descriptions. *Proceedings of The First ACM SIGSPATIAL International Workshop on Computational Models of Place*, 62:62-62:69. https://doi.org/10.1145/2534848.2534857

Klein, W. (1983). Deixis and Spatial Orientation in Route Directions. In H. L. Pick & L. P. Acredolo (Eds.), *Spatial Orientation* (pp. 283–311). Springer US. https://doi.org/10.1007/978-1-4615-9325-6_12

Klippel, A., Tappe, H., Kulik, L., & Lee, P. U. (2005). Wayfinding choremes—A language for modeling conceptual route knowledge. *Journal of Visual Languages & Computing*, *16*(4), 311–329. https://doi.org/10.1016/j.jvlc.2004.11.004

Kordjamshidi, P., Roth, D., & Moens, M.-F. (2015). Structured learning for spatial information extraction from biomedical text: Bacteria biotopes. *BMC Bioinformatics*, *16*(1), 129. https://doi.org/10.1186/s12859-015-0542-z

Kordjamshidi, P., Van Otterlo, M., & Moens, M.-F. (2011). Spatial Role Labeling: Towards Extraction of Spatial Relations from Natural Language. *ACM Trans. Speech Lang. Process.*, *8*(3), 4:1-4:36. https://doi.org/10.1145/2050104.2050105

Kruijff, G.-J. M., Zender, H., Jensfelt, P., & Christensen, H. I. (2007). Situated dialogue and spatial organization: What, where… and why? *International Journal of Advanced Robotic Systems*, *4*(1), 16.

Kudashev, I., Kudasheva, I., & others. (2010). Semiotic Triangle Revisited for the Purposes of Ontology-based Terminology Management. *TOTh 2010. Actes de La Quatrième Conférence TOTh-Annecy–3 & 4 Juin 2010*.

Kuhn, W. (2005). Geospatial Semantics: Why, of What, and How? In S. Spaccapietra & E. Zimányi (Eds.), *Journal on Data Semantics III* (pp. 1–24). Springer. https://doi.org/10.1007/11496168_1

Kuhn, W. (2009). Semantic Engineering. In G. Navratil (Ed.), *Research Trends in Geographic Information Science* (pp. 63–76). Springer. https://doi.org/10.1007/978-3-540-88244-2_5

Kuipers, B. (1978). Modeling spatial knowledge. *Cognitive Science*, *2*(2), 129–153. https://doi.org/10.1016/S0364-0213(78)80003-2

Lakoff, G. (2008). *Women, fire, and dangerous things: What categories reveal about the mind*. University of Chicago press.

Lakoff, G., & Johnson, M. (2008). *Metaphors we live by*. University of Chicago press.

Landau, B., & Jackendoff, R. (1993). "What" and "where" in spatial language and spatial cognition. *Behavioral and Brain Sciences*, *16*(2), 217–238.

Langacker, R. W. (1986). An Introduction to Cognitive Grammar. *Cognitive Science*, *10*(1), 1–40. https://doi.org/10.1016/S0364-0213(86)80007-6

Langacker, R. W. (1987). *Foundations of cognitive grammar: Theoretical prerequisites* (Vol. 1). Stanford university press.

Lautenschütz, A.-K., Davies, C., Raubal, M., Schwering, A., & Pederson, E. (2006). The influence of scale, context and spatial preposition in linguistic topology. *International Conference on Spatial Cognition*, 439–452.

Le Guen, O. (2011). Modes of pointing to existing spaces and the use of frames of reference. *Gesture*, *11*(3), 271–307.

Lee, K., Webster, J., & Fang, A. C. (2010). ESpatialML: an event-driven spatial annotation framework. *Proceedings of the 24th Pacific Asia Conference on Language, Information and Computation*, 223–232.

Lee, P. U., & Tversky, B. (2005). Interplay Between Visual and Spatial: The Effect of Landmark Descriptions on Comprehension of Route/Survey Spatial Descriptions. *Spatial Cognition & Computation*, *5*(2–3), 163–185. https://doi.org/10.1080/13875868.2005.9683802

Lehmann, C. (1983). Latin preverbs and cases. *Latin Linguistics and Linguistic Theory*, 145–161.

Levinson, S. C. (1996). Language and space. *Annual Review of Anthropology*, *25*(1), 353–382.

Levinson, S. C. (1997). Language and Cognition: The Cognitive Consequences of Spatial Description in Guugu Yimithirr. *Journal of Linguistic Anthropology*, *7*(1), 98–131. https://doi.org/10.1525/jlin.1997.7.1.98

Levinson, S. C. (2003). *Space in language and cognition: Explorations in cognitive diversity* (Vol. 5). Cambridge University Press.

Levinson, S. C., Kita, S., Haun, D. B. M., & Rasch, B. H. (2002). Returning the tables: Language affects spatial reasoning. *Cognition*, *84*(2), 155–188. https://doi.org/10.1016/S0010-0277(02)00045-8

Li, J., Sun, A., Han, J., & Li, C. (2020). A Survey on Deep Learning for Named Entity Recognition. *IEEE Transactions on Knowledge and Data Engineering*, 1–1. https://doi.org/10.1109/TKDE.2020.2981314

Li, P., & Gleitman, L. (2002). Turning the tables: Language and spatial reasoning. *Cognition*, *83*(3), 265–294. https://doi.org/10.1016/S0010-0277(02)00009-4

Logan, G. D., & Sadler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In *Language and space* (pp. 493–529). The MIT Press. https://doi.org/10.1146/annurev.anthro.25.1.353

Longley, P., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic Information Science and Systems, 4th Edition | Wiley*. Wiley.Com. https://www.wiley.com/en-gb/Geographic+Information+Science+and+Systems%2C+4th+Edition-p-9781118676950

Lopez, B., & Gwartney, D. (2011). *Home Ground A Guide to the American Landscape*. Trinity University Press. https://tupress.org/9781595341754/home-ground/

Lynch, K. (1960). *The image of the city* (Vol. 11). MIT press.

MacEachren, A. M. (2004). *How maps work: Representation, visualization, and design*. Guilford Press.

Mai, G., Janowicz, K., He, C., Liu, S., & Lao, N. (2018). POIReviewQA: A Semantically Enriched POI Retrieval and Question Answering Dataset. *Proceedings of the 12th Workshop on Geographic Information Retrieval*, 1–2. https://doi.org/10.1145/3281354.3281359

Majid, A., Bowerman, M., Kita, S., Haun, D. B. M., & Levinson, S. C. (2004). Can language restructure cognition? The case for space. *Trends in Cognitive Sciences*, *8*(3), 108–114. https://doi.org/10.1016/j.tics.2004.01.003

Malinowski, M., & Fritz, M. (2015). A Pooling Approach to Modelling Spatial Relations for Image Retrieval and Annotation. *ArXiv:1411.5190 [Cs]*. http://arxiv.org/abs/1411.5190

Mani, I. (2009). SpatialML: annotation scheme for marking spatial expression in natural language. *Technical Report Version 3.0*.

Mani, I., Doran, C., Harris, D., Hitzeman, J., Quimby, R., Richer, J., Wellner, B., Mardis, S., & Clancy, S. (2010). SpatialML: Annotation scheme, resources, and evaluation. *Language Resources and Evaluation*, *44*(3), 263–280. https://doi.org/10.1007/s10579-010-9121-0

Manzoor, U., & Kordjamshidi, P. (2018). Anaphora Resolution for Improving Spatial Relation Extraction from Text. *Proceedings of the First International Workshop on Spatial Language Understanding*, 53–62. https://doi.org/10.18653/v1/W18-1407

Marchi Fagundes, C. K., Stock, K., & Delazari, L. S. (n.d.). A cross-linguistic study of spatial location descriptions in New Zealand English and Brazilian Portuguese natural language. *Transactions in GIS*, *n/a*(n/a). https://doi.org/10.1111/tgis.12815

Mark, D. M. (1989). Cognitive image-schemata for geographic information: Relations to user views and GIS interfaces. *GIS/LIS*, *89*(2).

Mark, D. M., Comas, D., Egenhofer, M. J., Freundschuh, S. M., Gould, M. D., & Nunes, J. (1995). Evaluating and refining computational models of spatial relations through cross-linguistic human-subjects testing. In A. U. Frank & W. Kuhn (Eds.), *Spatial Information Theory A Theoretical Basis for GIS* (pp. 553–568). Springer. https://doi.org/10.1007/3-540-60392-1_36

Mark, D. M., & Csillag, F. (1989). The Nature Of Boundaries On 'Area-Class' Maps. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *26*(1), 65–78. https://doi.org/10.3138/D235-3262-062X-4472

Mark, D. M., & Egenhofer, M. J. (1994). Modeling Spatial Relations Between Lines and Regions: Combining Formal Mathematical Models and Human Subjects Testing. *Cartography and Geographic Information Systems*, *21*(4), 195–212. https://doi.org/10.1559/152304094782540637

Mark, D. M., & Egenhofer, M. J. (1995). Topology of prototypical spatial relations between lines and regions in English and Spanish. *AUTOCARTO-CONFERENCE-*, 245–254.

Mark, D. M., & Turk, A. G. (2003). Landscape Categories in Yindjibarndi: Ontology, Environment, and Language. In W. Kuhn, M. F. Worboys, & S. Timpf (Eds.), *Spatial Information Theory. Foundations of Geographic Information Science* (pp. 28–45). Springer. https://doi.org/10.1007/978-3-540-39923-0_3

Mark, D. M., Turk, A. G., Burenhult, N., & Stea, D. (2011a). Landscape in language: An Introduction. In D. M. Mark, A. G. Turk, N. Burenhult, & D. Stea (Eds.), *Landscape in language: Transdisciplinary perspectives* (Vol. 4, pp. 1–24). John Benjamins Publishing.

Mark, D. M., Turk, A. G., Burenhult, N., & Stea, D. (2011b). *Landscape in Language: Transdisciplinary perspectives*. John Benjamins Publishing.

Mazalov, A., Martins, B., & Matos, D. (2015). Spatial role labeling with convolutional neural networks. *Proceedings of the 9th Workshop on Geographic Information Retrieval*, 1–7. https://doi.org/10.1145/2837689.2837706

McDermott, D., & Davis, E. (1984). Planning routes through uncertain territory. *Artificial Intelligence*, *22*(2), 107–156. https://doi.org/10.1016/0004-3702(84)90045-6

Meilinger, T. (2008). The Network of Reference Frames Theory: A Synthesis of Graphs and Cognitive Maps. In C. Freksa, N. S. Newcombe, P. Gärdenfors, & S. Wölfl (Eds.), *Spatial*

Cognition VI. Learning, Reasoning, and Talking about Space (pp. 344–360). Springer. https://doi.org/10.1007/978-3-540-87601-4_25

Melo, F., & Martins, B. (2017). Automated Geocoding of Textual Documents: A Survey of Current Approaches. *Transactions in GIS*, *21*(1), 3–38. https://doi.org/10.1111/tgis.12212

Mocnik, F.-B., Zipf, A., & Raifer, M. (2017). The OpenStreetMap folksonomy and its evolution. *Geo-Spatial Information Science*, *20*(3), 219–230. https://doi.org/10.1080/10095020.2017.1368193

Montello, D. R. (2009). Cognitive Research in GIScience: Recent Achievements and Future Prospects. *Geography Compass*, *3*(5), 1824–1840. https://doi.org/10.1111/j.1749-8198.2009.00273.x

Montello, D. R., Goodchild, M. F., Gottsegen, J., & Fohl, P. (2003). Where's Downtown?: Behavioral Methods for Determining Referents of Vague Spatial Queries. *Spatial Cognition & Computation*, *3*(2–3), 185–204. https://doi.org/10.1080/13875868.2003.9683761

Nirenburg, S., & Raskin, V. (2001). Ontological semantics, formal ontology, and ambiguity. *Proceedings of the International Conference on Formal Ontology in Information Systems - Volume 2001*, 151–161. https://doi.org/10.1145/505168.505183

Nölle, J., Fusaroli, R., Mills, G. J., & Tylén, K. (2020). Language as shaped by the environment: Linguistic construal in a collaborative spatial task. *Palgrave Communications*, *6*(1), 1–10. https://doi.org/10.1057/s41599-020-0404-9

Ogden, C. K., & Richards, I. A. (1923). *The meaning of meaning*. Kegan Paul London.

O'Sullivan, D., & Unwin, D. J. (2010). *Geographic Information Analysis, 2nd Edition | Wiley*. Wiley.Com. https://www.wiley.com/en-us/Geographic+Information+Analysis%2C+2nd+Edition-p-9780470288573

Palmer, B., Lum, J., Schlossberg, J., & Gaby, A. (2017). How does the environment shape spatial language? Evidence for sociotopography. *Linguistic Typology*, *21*(3), 457–491. https://doi.org/10.1515/lingty-2017-0011

Papafragou, A., Massey, C., & Gleitman, L. (2002). Shake, rattle, 'n' roll: The representation of motion in language and cognition. *Cognition*, *84*(2), 189–219. https://doi.org/10.1016/S0010-0277(02)00046-X

Peirce, C. S. (1880). On the Algebra of Logic. *American Journal of Mathematics*, *3*(1), 15–57. JSTOR. https://doi.org/10.2307/2369442

Peirce, C. S. (1965). *The collected papers of Charles S. Peirce* (C. Hartshorne & P. Weiss, Eds.; Vols. 1 and 2). Belknap Press.

Piaget, Jean, & Inhelder, Barbel. (1956). *The child's conception of space / by Jean Piaget and Barbel Inhelder ; translated from the French by F.J. Langdon & J.L. Lunzer*. Routledge & Kegan Paul London.

Platonov, G., & Schubert, L. (2018). Computational Models for Spatial Prepositions. *Proceedings of the First International Workshop on Spatial Language Understanding*, 21–30. https://doi.org/10.18653/v1/W18-1403

Proulx, M. J., Todorov, O. S., Taylor Aiken, A., & de Sousa, A. A. (2016). Where am I? Who am I? The Relation Between Spatial Cognition, Social Cognition and Individual Differences in the Built Environment. *Frontiers in Psychology*, *7*, 64. https://doi.org/10.3389/fpsyg.2016.00064

Pruden, S. M., Levine, S. C., & Huttenlocher, J. (2011). Children's spatial thinking: Does talk about the spatial world matter? *Developmental Science*, *14*(6), 1417–1430. https://doi.org/10.1111/j.1467-7687.2011.01088.x

Purves, R. S., Clough, P., Jones, C. B., Hall, M. H., & Murdock, V. (2018). *Geographic Information Retrieval: Progress and Challenges in Spatial Search of Text*. now. https://ieeexplore.ieee.org/document/8311405

Pustejovsky, J., Moszkowicz, J. L., & Verhagen, M. (2011). ISO-Space: The annotation of spatial information in language. *Proceedings of the Sixth Joint ISO-ACL SIGSEM Workshop on Interoperable Semantic Annotation*, *6*, 1–9.

Quesnot, T., & Roche, S. (2015). Quantifying the Significance of Semantic Landmarks in Familiar and Unfamiliar Environments. In S. I. Fabrikant, M. Raubal, M. Bertolotto, C. Davies, S. Freundschuh, & S. Bell (Eds.), *Spatial Information Theory* (pp. 468–489). Springer International Publishing. https://doi.org/10.1007/978-3-319-23374-1_22

Radke, M., Das, P., Stock, K., & Jones, C. B. (2019). Detecting the Geospatialness of Prepositions from Natural Language Text (Short Paper). In S. Timpf, C. Schlieder, M. Kattenbeck, B. Ludwig, & K. Stewart (Eds.), *14th International Conference on Spatial Information Theory (COSIT 2019)* (Vol. 142, p. 11:1-11:8). Schloss Dagstuhl–Leibniz-Zentrum fuer Informatik. https://doi.org/10.4230/LIPIcs.COSIT.2019.11

Ranganathan, S. R. (1937). *Prolegomena to library classification*. Madras Library Association, Madras.

Reinecke, K., & Bernstein, A. (2013). Knowing What a User Likes: A Design Science Approach to Interfaces that Automatically Adapt to Culture. *MIS Quarterly*, *37*(2), 427–453.

Rickheit, G., & Wachsmuth, I. (2006). *Situated communication*. Mouton de Gruyter.

Riley, M. J. (1994). Constituting the Southwest Contesting the Southwest Re-Inventing the Southwest. *Journal of the Southwest*, *36*(3), 221–241.

Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General*, *104*(3), 192–233. https://doi.org/10.1037/0096-3445.104.3.192

Rose, J., & Lehmann, J. (2020). CASQAD – A New Dataset for Context-Aware Spatial Question Answering. In J. Z. Pan, V. Tamma, C. d'Amato, K. Janowicz, B. Fu, A. Polleres, O. Seneviratne, & L. Kagal (Eds.), *The Semantic Web – ISWC 2020* (pp. 3–17). Springer International Publishing. https://doi.org/10.1007/978-3-030-62466-8_1

Sadeghian, P., & Kantardzic, M. (2008). The New Generation of Automatic Landmark Detection Systems: Challenges and Guidelines. *Spatial Cognition & Computation*, *8*(3), 252–287. https://doi.org/10.1080/13875860802039257

Saussure, F. de. (1967). *Grundfragen der allgemeinen Sprachwissenschaft*. Walter de Gruyter.

Scheider, S., Nyamsuren, E., Kruiger, H., & Xu, H. (2021). Geo-analytical question-answering with GIS. *International Journal of Digital Earth*, *14*(1), 1–14. https://doi.org/10.1080/17538947.2020.1738568

Schirra, J. R. J. (1993). A contribution to reference semantics of spatial prepositions: The visualization problem and its solution in VITRA. *The Semantics of Prepositions*, 471–516. https://www.degruyter.com/document/doi/10.1515/9783110872576.471/html

Schober, M. F. (1995). Speakers, addressees, and frames of reference: Whose effort is minimized in conversations about locations? *Discourse Processes*, *20*(2), 219–247. https://doi.org/10.1080/01638539509544939

Schubert, C. (2006). The vertical axis in landscape description: Elaborations of the image schemas UP and DOWN. *Landscape and Englishness*, *1*, 47.

Schulz, R., Stockwell, P., Wakabayashi, M., & Wiles, J. (2006). Towards a spatial language for mobile robots. In *The Evolution of Language* (pp. 291–298). WORLD SCIENTIFIC. https://doi.org/10.1142/9789812774262_0037

Scott, J., Stock, K., Morgan, F., Whitehead, B., & Medyckyj-Scott, D. (2021). Automated Georeferencing of Antarctic Species. In K. Janowicz & J. A. Verstegen (Eds.), *11th*

International Conference on Geographic Information Science (GIScience 2021)—Part II (Vol. 208, p. 13:1-13:16). Schloss Dagstuhl – Leibniz-Zentrum für Informatik. https://doi.org/10.4230/LIPIcs.GIScience.2021.II.13

Searle, J. R. (1980). Minds, brains, and programs. *Behavioral and Brain Sciences*, *3*(3), 417–424. https://doi.org/10.1017/S0140525X00005756

Seresinhe, C. I., Moat, H. S., & Preis, T. (2018). Quantifying scenic areas using crowdsourced data. *Environment and Planning B: Urban Analytics and City Science*, *45*(3), 567–582. https://doi.org/10.1177/0265813516687302

Shamai, S., & Ilatov, Z. (2005). Measuring Sense of Place : *Tijdschrift Voor Economische En Sociale Geografi*, *96*(5), 467–476.

Shariff, A. R., Egenhofer, M., & Mark, D. (1998). Natural-Language Spatial Relations Between Linear and Areal Objects: The Topology and Metric of English-Language Terms. *International Journal of Geographical Information Science*, *12*, 215–246.

Shusterman, A., & Li, P. (2016). Frames of reference in spatial language acquisition. *Cognitive Psychology*, *88*, 115–161. https://doi.org/10.1016/j.cogpsych.2016.06.001

Siegel, A. W., & White, S. H. (1975). The Development of Spatial Representations of Large-Scale Environments. In H. W. Reese (Ed.), *Advances in Child Development and Behavior* (Vol. 10, pp. 9–55). JAI. https://doi.org/10.1016/S0065-2407(08)60007-5

Smith, B., & Mark, D. M. (2001). Geographical categories: An ontological investigation. *International Journal of Geographical Information Science*, *15*(7), 591–612.

Smith, B., & Varzi, A. C. (2000). Fiat and bona fide boundaries. *Philosophical and Phenomenological Research*, 401–420.

Sowa, J. F. (2000). Ontology, Metadata, and Semiotics. In B. Ganter & G. W. Mineau (Eds.), *Conceptual Structures: Logical, Linguistic, and Computational Issues* (pp. 55–81). Springer. https://doi.org/10.1007/10722280_5

Speriosu, M., & Baldridge, J. (2013). Text-Driven Toponym Resolution using Indirect Supervision. *Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, 1466–1476. https://aclanthology.org/P13-1144

Spranger, M., & Steels, L. (2015). Co-acquisition of syntax and semantics: An investigation in spatial language. *Proceedings of the 24th International Conference on Artificial Intelligence*, 1909–1915.

Spranger, M., Suchan, J., & Bhatt, M. (2016). Robust Natural Language Processing: Combining Reasoning, Cognitive Semantics, and Construction Grammar for Spatial Language. *Proceedings of the Twenty-Fifth International Joint Conference on Artificial Intelligence*, 2908–2914. http://dl.acm.org/citation.cfm?id=3060832.3061028

Steinbring, H. (1998). Elements of Epistemological Knowledge for Mathematics Teachers. *Journal of Mathematics Teacher Education*, *1*(2), 157–189. https://doi.org/10.1023/A:1009984621792

Stevens, A., & Coupe, P. (1978). Distortions in judged spatial relations. *Cognitive Psychology*, *10*(4), 422–437. https://doi.org/10.1016/0010-0285(78)90006-3

Stock, K. (2008). Determining Semantic Similarity of Behaviour Using Natural Semantic Metalanguage to Match User Objectives to Available Web Services. *Transactions in GIS*, *12*(6), 733–755. https://doi.org/10.1111/j.1467-9671.2008.01128.x

Stock, K. (2014, June). *A geometric configuration ontology to support spatial querying*. 17th AGILE Conference on Geographic Information Science, Castellon, Spain. http://repositori.uji.es/xmlui/handle/10234/98734

Stock, K., & Cialone, C. (2011a). An Approach to the Management of Multiple Aligned Multilingual Ontologies for a Geospatial Earth Observation System. In C. Claramunt, S. Levashkin, & M. Bertolotto (Eds.), *GeoSpatial Semantics* (pp. 52–69). Springer. https://doi.org/10.1007/978-3-642-20630-6_4

Stock, K., & Cialone, C. (2011b). Universality, Language-Variability and Individuality: Defining Linguistic Building Blocks for Spatial Relations. In M. Egenhofer, N. Giudice, R. Moratz, & M. Worboys (Eds.), *Spatial Information Theory* (pp. 391–412). Springer. https://doi.org/10.1007/978-3-642-23196-4_21

Stock, K., Jones, C. B., Russell, S., Radke, M., Das, P., & Aflaki, N. (2021). Detecting geospatial location descriptions in natural language text. *International Journal of Geographical Information Science*.

Stock, K., Morris, H., Forster, M., Paraku, R., & Egorova, E. (2019). *He Tatai Whenua: Automated Extraction of Landscape Terms and their Meanings in New Zealand Maori*. https://doi.org/10.17608/k6.auckland.9869459.v1

Stock, K., Stojanovic, T., Reitsma, F., Ou, Y., Bishr, M., Ortmann, J., & Robertson, A. (2012). To ontologise or not to ontologise: An information model for a geospatial knowledge infrastructure. *Computers & Geosciences*, *45*, 98–108. https://doi.org/10.1016/j.cageo.2011.10.021

Stock, K., & Yousaf, J. (2018). Context-aware automated interpretation of elaborate natural language descriptions of location through learning from empirical data. *International Journal of Geographical Information Science*, *32*(6), 1087–1116. https://doi.org/10.1080/13658816.2018.1432861

Strahler, A. H. (2013). *Introducing Physical Geography, 6th Edition | Wiley*. Wiley. https://www.wiley.com/en-ae/Introducing+Physical+Geography%2C+6th+Edition-p-9781118396209

Studer, R., Benjamins, V. R., & Fensel, D. (1998). Knowledge engineering: Principles and methods. *Data & Knowledge Engineering*, *25*(1), 161–197. https://doi.org/10.1016/S0169-023X(97)00056-6

Talmy, L. (2000). Towards a cognitive semantics, Vol. 1: Concept structuring systems. *Language, Speech, and Communication. Cambridge, MA, US: The MIT Press*.

Tanasescu, V., Jones, C. B., Colombo, G., Chorley, M. J., Allen, S. M., & Whitaker, R. M. (2013). The Personality of Venues: Places and the Five-Factors ('Big Five') Model of Personality. *2013 Fourth International Conference on Computing for Geospatial Research and Application*, 76–81. https://doi.org/10.1109/COMGEO.2013.12

Tellex, S., Kollar, T., Dickerson, S., Walter, M., Banerjee, A., Teller, S., & Roy, N. (2011). Understanding Natural Language Commands for Robotic Navigation and Mobile Manipulation. *Proceedings of the AAAI Conference on Artificial Intelligence*, *25*(1), Article 1. https://ojs.aaai.org/index.php/AAAI/article/view/7979

Tenbrink, T. (2007). *Space, time, and the use of language: An investigation of relationships* (Vol. 36). Walter de Gruyter.

Tenbrink, T. (2011). Reference frames of space and time in language. *Journal of Pragmatics*, *43*(3), 704–722. https://doi.org/10.1016/j.pragma.2010.06.020

Tenbrink, T. (2020). *Cognitive discourse analysis: An introduction*. Cambridge University Press.

Tichy, P. (1988). *The foundations of Frege's logic*. Walter de Gruyter.

Tomasello, M. (1987). Learning to use prepositions: A case study*. *Journal of Child Language*, *14*(1), 79–98. https://doi.org/10.1017/S0305000900012745

Tuan, Y.-F. (1977). *Space and Place: The Perspective of Experience*. University of Minnesota Press.

Tudhope, D., Alani, H., & Jones, C. (2001). Augmenting Thesaurus Relationships: Possibilities for Retrieval. *Journal of Digital Information*, *1*(8). http://citeseerx.ist.psu.edu/viewdoc/citations;jsessionid=0878B1362A23B313D346B254646254DE?doi=10.1.1.23.306

Tversky, B. (2005). Visuospatial Reasoning. In *The Cambridge handbook of thinking and reasoning* (pp. 209–240). Cambridge University Press.

Twaroch, F. A., Brindley, P., Clough, P. D., Jones, C. B., Pasley, R. C., & Mansbridge, S. (2019). Investigating behavioural and computational approaches for defining imprecise regions. *Spatial Cognition & Computation*, *19*(2), 146–171. https://doi.org/10.1080/13875868.2018.1531871

Twaroch, F. A., Jones, C. B., & Abdelmoty, A. I. (2008). Acquisition of a Vernacular Gazetteer from Web Sources. *Proceedings of the First International Workshop on Location and the Web*, 61–64. https://doi.org/10.1145/1367798.1367808

Tyler, A., & Evans, V. (2003). *The semantics of English prepositions: Spatial scenes, embodied meaning, and cognition*. Cambridge University Press.

Varzi, A. C. (2001). Vagueness in geography. *Philosophy & Geography*, *4*(1), 49–65. https://doi.org/10.1080/10903770124125

Vasardani, M., Winter, S., & Richter, K.-F. (2013). Locating place names from place descriptions. *International Journal of Geographical Information Science*, *27*(12), 2509–2532.

Wartmann, F. M., Acheson, E., & Purves, R. S. (2018a). Describing and comparing landscapes using tags, texts, and free lists: An interdisciplinary approach. *International Journal of Geographical Information Science*, *32*(8), 1572–1592. https://doi.org/10.1080/13658816.2018.1445257

Wartmann, F. M., Acheson, E., & Purves, R. S. (2018b). Describing and comparing landscapes using tags, texts, and free lists: An interdisciplinary approach. *International Journal of Geographical Information Science*, *32*(8), 1572–1592. https://doi.org/10.1080/13658816.2018.1445257

Wartmann, F. M., & Purves, R. S. (2017). What's (Not) on the Map: Landscape Features from Participatory Sketch Mapping Differ from Local Categories Used in Language. *Land*, *6*(4), 79. https://doi.org/10.3390/land6040079

Whorf, B. L. (2012). *Language, thought, and reality: Selected writings of Benjamin Lee Whorf*. MIT press.

Wieczorek, J., Guo, Q., & Hijmans, R. (2004). The point-radius method for georeferencing locality descriptions and calculating associated uncertainty. *International Journal of Geographical Information Science*, *18*(8), 745–767. https://doi.org/10.1080/13658810412331280211

Worboys, M. F., & Duckham, M. (2004). *GIS: A Computing Perspective, Second Edition*. Routledge & CRC Press. https://www.routledge.com/GIS-A-Computing-Perspective-Second-Edition/Worboys-Duckham/p/book/9780415283755

Yin, Z., Zhang, C., Goldberg, D. W., & Prasad, S. (2019). An NLP-based Question Answering Framework for Spatio-Temporal Analysis and Visualization. *Proceedings of the 2019 2nd International Conference on Geoinformatics and Data Analysis*, 61–65. https://doi.org/10.1145/3318236.3318240

Yu, B., Shu, S., Liu, H., Song, W., Wu, J., Wang, L., & Chen, Z. (2014). Object-based spatial cluster analysis of urban landscape pattern using nighttime light satellite images: A case study of China. *International Journal of Geographical Information Science*, *28*(11), 2328–2355. https://doi.org/10.1080/13658816.2014.922186

Zwarts, J. (2003). Shape, and Parts. *Representing Direction in Language and Space*, *1*, 39.

Zwarts, J. (2005). Prepositional aspect and the algebra of paths. *Linguistics and Philosophy*, *28*(6), 739–779.

					Roche, 2013; Sadeghian & Kantardzic, 2008)	landmark salience			
Vertices			Sense of place	(Canter, 1997; Fish et al., 2016; Shamai & Ilatov, 2005; Tuan, 1977; Wartmann & Purves, 2017)	(Brown & Brabyn, 2012; Derungs & Purves, 2016; Gliozzo et al., 2016; Jeawak et al., 2017; Jenkins et al., 2016; Jordan et al., 1998; Seresinhe et al., 2018; Tanasescu et al., 2013)	Digital methods for capturing sense of place			Vertices
			Spatial relation concepts	(Stevens & Coupe, 1978)	(Cohn et al., 1997; Cohn & Hazarika, 2001; Freksa, 1992; Mark & Egenhofer, 1994)	Qualitative spatial reasoning (QSR)			
	spatial language	Symbols that represent objects in the world, mediated through human thought	Syntactic structure of spatial language	(Herskovits, 1986; Jackendoff, 1983; Tenbrink, 2007)	(Bateman et al., 2010; Burenhult & Levinson, 2008; Chen et al., 2018; Khan et al., 2013; K. Lee et al., 2010; Mani et al., 2010; Pustejovsky et al., 2011; Stock & Yousaf, 2018)	Spatial language representation schemes	Digital representations of human thought (cognition, reasoning, etc).	*structured representa-tion of language*	
			Terms for real world features	(Lopez & Gwartney, 2011; Smith & Mark, 2001)					
			Spatial adjectives and adverbs	(Carlson & van der Zee, 2005; Coventry et al., 2010; Diessel & Coventry, 2020; Klein, 1983; Levinson, 1997; Pruden et al., 2011; Stock et al., 2021; Zwarts, 2003)					
			Spatial verbs	(Levinson, 2003; Papafragou et al., 2002; Talmy, 2000; Zwarts, 2005)	(Egorova et al., 2018)	Classification of fictive motion (verb) expressions			
			Frequency and distribution of types of spatial expressions	(Auer et al., 2010)	(Stock, 2014)	Computational analysis of frequency and distribution of types of spatial expressions			
Edges	*spatial language symbolises spatial cognition/ spatial cognition structures spatial language*	The use of spatial language to describe spatial cognition, and the influence of spatial cognition on the use of spatial language.	Cognitive factors that influence location language and frames of reference	(Carlson-Radvansky & Radvansky, 1996; Coventry & Garrod, 2004; Daniel et al., 1996; Lakoff & Johnson, 2008; Le Guen, 2011; Levinson et al., 2002; Levinson, 2003; P. Li & Gleitman, 2002; Mark, 1989; Schober, 1995; Shusterman & Li, 2016; Talmy, 2000; Tenbrink, 2007, 2011)	(Stock & Yousaf, 2018)	Cognitive factors in automated interpretation and georeferencing of spatial relational expressions	The representa-tion or emulation of human cognition via digital representations of human language, and the automated generation of human language from digital representations of human cognition.	*structured representa-tion of language symbolises spatial cognition modelling*	Edges
					(Freksa, 1992; Hois & Kutz, 2008; Mark & Egenhofer, 1994; Shariff et al., 1998)	Mapping of QSR relations to natural language			
			Cognitive factors that influence route descriptions	(Caduff & Timpf, 2008; Daniel et al., 2003; Denis, 2017; Klippel et al., 2005; P. U. Lee & Tversky, 2005),	(Dale et al., 2005; Huang et al., 2010; Tellex et al., 2011)	Automated spatial reasoning for navigation			
			The influence of language on spatial cognition.	(Levinson, 1997)					
			Acquisition of spatial language	(Becker & Carroll, 1997; Choi et al., 1999; Piaget & Inhelder, 1956; Shusterman & Li, 2016; Tomasello, 1987)	(Golledge et al., 1985; Schulz et al., 2006)	Computational models of acquisition of spatial language			
			Methods for uncovering the links between spatial language and underlying cognitive factors	(Bohnemeyer, 2008; Cutler et al., 2005; Ericsson & Simon, 1984; Levinson, 1997; Majid et al., 2004; Tenbrink, 2020, p. 2)	(Reinecke & Bernstein, 2013)	Adaptation of automated dialogue system to cultures and languages.			
			Spatial dialogue and communication	(Coventry et al., 2009; Rickheit & Wachsmuth, 2006)	(Cai et al., 2005; Cuayáhuitl et al., 2010; Kruijff et al., 2007; Mai et al., 2018; Rose & Lehmann, 2020; Scheider et al., 2021; Spranger et al., 2016; Spranger & Steels, 2015; Yin et al., 2019)	Automated spatial dialogue systems, geospatial question-answering and conversational GIS			
	spatial cognition conceptual-ises the spatial world	The human conceptualisa-tion of a real world object.	Human conceptualisations of landscape	(Mark & Turk, 2003; Riley, 1994; Schubert, 2006)	(Beaudoin, 2007; Derungs & Purves, 2016; Dimitrova et al., 2008; Jones et al., 2001; Kuhn, 2005, 2009; Mocnik et al., 2017; Tudhope et al., 2001)	Geographic ontologies, thesauri and folksonomies	The digital representation of the spatial world.	*spatial cognition modelling conceptualises the spatial world*	
			Cultural differences in the relationship between people and land	(Holton, 2011; L. M. Johnson, 2010; L. M. Johnson & Hunn, 2010; Mark et al., 2011b)					
			Mapping and cartography	(MacEachren, 2004)					
	spatial language stands for the spatial world	The representa-tion of a real world object in symbolic form, always mediated by thought and thus indirect.	Properties of objects referenced in location descriptions	(Talmy, 2000)			The representa-tion of a real world object in symbolic form in an information system, always mediated by thought and thus indirect.	*structured representa-tion of language stands for the spatial world*	
			Vagueness in places referenced in spatial location descriptions	(Montello et al., 2003; Varzi, 2001)	(Arampatzis et al., 2006; Bennett, 2001; Cunha & Martins, 2014; Hollenstein & Purves, 2010; Jones et al., 2008; Twaroch et al., 2019)	Modelling the geographic extent of places			
			Landscape language	(Burenhult & Levinson, 2008; Mark et al., 2011b; Mark & Turk, 2003; Wartmann et al., 2018b)	(Stock et al., 2019; Wartmann et al., 2018a)	Computational analysis and classification of landscape terms			
			Place names including vernacular place names	(Gudde & Bright, 2010; Hercus et al., 2009; Kenyon, 1991; Riley, 1994)	(Davies et al., 2009; Jones et al., 2008; Ju et al., 2016; Karimzadeh et al., 2019; J. Li et al., 2020; Speriosu & Baldridge, 2013; Twaroch et al., 2008; Vasardani et al., 2013)	Place name extraction. Gazetteers.			
			Geometric factors that influence the use of spatial language	(Coventry & Garrod, 2004; Lautenschütz et al., 2006; Talmy, 2000; Tenbrink, 2020)	(Acheson & Purves, 2021; Kordjamshidi et al., 2015; Melo & Martins, 2017; Purves et al., 2018; Scott et al., 2021)	Document georeferencing			

spatial cognition modelling represents spatial cognition.	The representation and emulation of spatial cognition in a digital system.	Use of language to create computational models of spatial cognition	(Bateman et al., 2010)