Spatial Relation Predicates in Topographic Feature Semantics

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Abstract Topographic data are designed and widely used for base maps of diverse applications, yet the power of these information sources largely relies on the interpretive skills of map readers and relational database expert users once the data are in map or geographic information system (GIS) form. Advances in geospatial semantic technology offer data model alternatives for explicating concepts and articulating complex data queries and statements. To understand and enrich the vocabulary of topographic feature properties for semantic technology, English language spatial relation predicates were analyzed in three standard topographic feature glossaries. The analytical approach drew from disciplinary concepts in geography, linguistics, and information science. Five major classes of spatial relation predicates were identified from the analysis; representations for most of these are not widely available. The classes are: part-whole (which are commonly modeled throughout semantic and linked-data networks), geometric, processes, human intention, and spatial prepositions. These are commonly found in the 'real world' and support the environmental science basis for digital topographical mapping. The spatial relation concepts are based on sets of relation terms presented in this chapter, though these lists are not prescriptive or exhaustive. The results of this study make explicit the concepts forming a broad set of spatial relation expressions, which in turn form the basis for expanding the range of possible queries for topographical data analysis and mapping.

Keywords Semantic technology · Topographic data · Predicates

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1 Introduction

Geographical analysis is the key objective for methods of geographic information representation, extraction, modeling, and visualization. Spatial relations are a key component of geographical analysis (Foote and Huebner 1996). Many of these relations are difficult to graphically or quantitatively formalize and remain only cognitively or linguistically represented. In most cases, the wider range of spatial relations, beyond those of location, metric distances, and cardinal direction, are cognitively conceptualized by the map or geographic information systems (GIS) user (Clarke 2001; Theobald 2001). Semantics allows data analysts and users to disambiguate and articulate environmental knowledge in specific detail that is otherwise limited in large part within the scope of the cognitive knowledge of the person. Concepts of ontology engineering depict the implementation of users' cognitive environmental models integrated with logical representations of data designs and semantic (Fonseca et al. 2002). Within the scope of such models and in normal geographic information retrieval, vocabulary plays a critical role in the design and use of ontology-driven systems.

The geospatial semantic web allows users to specify and program spatial relations as predicates or properties of semantic web triples, a standard semantic web data model, to be captured and articulated in databases, interfaces, and visualization (Egenhofer 2002; W3C 2010a). Most available spatial relation terms describe taxonomic, topologic, or partonomic relations, but a range of other relations, such as those of processes, scale, or events, may be required for data applications and environmental modeling, but may not be clearly specified for a broad base of system users (Kuhn 2001). By programming these relations, and minimizing the need for manual intervention, the data analysis functions intended for database designs and applied in data queries would be easier to use. One way disambiguation and semantic detail are achieved is by expanding the range of spatial relations to enhance data applications.

Feature type vocabularies, including Wordnet (Princeton University 2010) and Alexandria Digital Library (ADL) Feature Type Thesaurus, based on the National Geospatial Intelligence Agency (NGA) GeoNet and Geographic Names Information System, are easily available (ADL 2002; NGA 2009; U.S. Board on Geographic Names). But these feature term vocabularies, with words such as beach, lagoon, or geyser, do not include the representation of spatial relations that are essential to their meaning, such as, the shore along the water (beach), water between the reef and shore (lagoon), or water ejected with force (geyser). A major source of relations is articulated in natural language statements of geospatial data users, as in spoken words, written text, metadata specifications, or glossaries. This study examines the predicates articulated in topographic knowledge statements to identify semantics of topographic spatial relations. The identification of spatial predicate concepts helps build foundations for their representation as the relation resource of semantic web triples. Because a list of predicates cannot be prescriptive, a set of specific terms is not a practical solution; the list could be

incomplete or change over time. Relation types form general classes that can be used as a foundation for predicate identification, analysis, and functioning in further studies. Subsets of terms of these classes are already represented as mereologic and topologic relations, but relations such as force dynamics, for example the control of an object's movement when it is 'in' something, remain a challenge to model.

The objective of this research is to advance a framework of natural language spatial relations terms for topographic data and information retrieval. The motivation for these formalizations is to serve the future development of reasoning algorithms to enhance functions for *The National Map* of the U.S. Geological Survey, but the study was designed for results applicable to any topographical map (National Research Council 2007). The application of natural language labels to specify spatial relations, if effectively chosen and executed, will facilitate communication with broadly diverse users.

The sections of the chapter discuss background concepts of topography, spatial prepositions, and topological relation in GIS; these form a foundation for the spatial relation classes resulting from the analysis. Key terms were extracted definition predicates and categorized on the basis of word types, such as the verb/preposition pair "flowing towards;" a number of prepositions are related to operations in GIS. Each class is presented in the sections that follow and summarized in the conclusions.

2 Background

The analysis of spatial predicates depends on a range of research crossing geographic, linguistic, and geographic information science (GISc). This section focuses on topography, spatial language, and spatial relation formalizations in GISc, and the Semantic Web to support the approach that was implemented in this study to advance new controlled vocabulary development.

2.1 Topography

The topography of a landscape refers to the physical surface and features of an area or local region, limited to a more immediate scale of experience than general geography. A common meaning of the term 'topography' focuses mainly on landform features, but historical and contemporary uses of the term include human experiences and descriptions of places, including local history and biography (Harvey 1980). Topographical experience is the perception and learning of selected features of the environment and their interaction, however the environment may be defined in a cultural context (Curry 2002). Writers often place these concepts of topography in the context of "reading the landscape" (Watts 1975). The elements of landscape and natural history are studied as dialogue, akin to telling a story or narrative.

The communication of topographic knowledge can be called a type of narrative that arises from the environmental bases of experiences and context, and appears in literary sources, way-finding, and other forms of geographical description (Pearce 2008). Spatial language attempts to relate the world as it exists with human perceptions of the world, subject to variations of environmental interaction, the appearance and configurations of an object, and concerns and purposes of a speaker. Topographic narrative draws on the articulation of features and the relations among them expressed primarily through language, but also other forms, such as mapping, tabular data, first-order logic, or as an algorithm. These feature and relation structures result from basic semantic sign selection and the composition of the selections with other basic representational units (Jakobson and Halle 1971). For queries addressing the topographic data to be effective, narratives must be in relative agreement with cognitive experiential thought that map users generate about the topographic landscape.

The relations among feature structures and landscape are essential to the morphology of topography (Leatherbarrow 2004, p. 11). Complex relationships exist in many ways, such as between a feature to its location, a feature to the resource systems supporting it, or relations among elements within the topographic feature itself. The analysis of these relations considers topography to be normally governed by physical laws, such as gravity or changes due to temperature and moisture. Functions of these features are perceived by people based on their knowledge of these physical forces and can be expressed through science and engineering principles, as well as by relatively simple human actions (Buryk 2006). However, many complex topographic relations are formed and governed by social or scientific objectives, such as the component parts of a college campus dedicated to education, or a mine site for mineral extraction.

2.2 Spatial Prepositions

In their most simple and intuitive form, spatial prepositions imply a relation between two entities in space in which the located object is the subject of the sentence and the reference object is the receiver of the action in the predicates. Studies of spatial language in linguistics indicate, through the analysis of pragmatic language and the role of embodied experiences and physical force dynamics in language, that spatial prepositions are closely related to topographic experiences.

Herskovits (1986) designed a framework to relate verb/preposition pairs to spatial concepts. The first part of the three-part framework of semantic analysis consists of the ideal meaning of a term as a geometrical ideal, based on the concept of discrete objects in space. Ideal meanings are inferred from real examples of normal use and can be formalized with such systems as first-order logic or cognitive spatial frameworks, such as an imagined geometry of points, lines, or areas. Deviances from these ideals occur when they fail to explain some uses, such as

when reference must be made to the cognitively-viewed description of some aspect of the object, not the object itself. These deviances lead to the second and third parts of the framework; sense shifts, a conceptually close relation to the ideal meaning based on the speakers' pragmatic intentions and context, and tolerance shifts, a gradual range in deviations from ideal meanings. For example, the preposition 'in' means the containment of something within something else, whether it is enclosed by an object, or is part of the structure or composition of an object. But 'in' is also used based on a geometric imagination or projection, such as "the bird in the tree" (sense shift), or within the proximity of an object, as in "the chair in the corner" (tolerance shift) (Herskovits 1986, p. 43). Tolerance limits of deviations are pragmatic principles that prevent the acceptance of variable forms that are obviously untrue or are unacceptable use forms. The discussion of pragmatics was an acknowledgment that the use of spatial prepositions strays beyond the logical limits of perceptions and descriptions of objects in space and often refers to the functions of objects and intention of users. Concepts of idealization and intention are bountiful in topography, as are fuzzy boundary concepts indicating tolerances.

Lakoff's concept of human embodiment in spatial relations explores the key roles that perception, body movement, and experience play (Lakoff 1987). Embodiment is the humanly-centered solution to grounding symbols, such as language, data, or graphics, in reality (the 'real'world). In embodiment, actions in the world have meaning, and symbols emerge from the perception, thought, and concepts based on that meaning. This important concept correlates closely with the traditional meaning of topography based on the experience of the world.

Coventry and Garrod (2004) advanced a concept called the Functional Geometric Framework, in which they argue that geometric spatial relations alone, such as those based on the cognitively-projected visual geometry of Herskovits, have limited influence on prepositional use. Research on force dynamics in language show that physical laws such as gravity are predominant for understanding the meaning of terms such as 'on' (Talmy 1988). The geometric relation of objects located relative to each other varies with different uses of 'on' in language, such as the 'house on the street,' the 'nose on your face,' or the 'box on the floor.' In most cases, the function of objects, afforded by the physical forces involved, predominate as the basis for the selection and use of a spatial preposition. As a result, force dynamics are semantically less ambiguous than geometric spatial relations.

Geometric imagination, pragmatic functions, human embodiment, and force dynamics are important to the analysis of spatial prepositions in topographic data. Defining the subject of topographic data as based on environmental experience and knowledge, feature definitions, and consequently their semantic specifications, reflect a vocabulary based on physical forces on the landscape and human leveraging of those forces. Topographic objects have functions that can be observed by anyone present in the proximity of a place on the land that the topographic data represent. The expression of this shared experience on the landscape through topographic mapping may help to build a common semantic framework for the public, despite the cultural and perceptual differences of a diverse society.

2.3 Mereotopological Relations

Mereotopological relations, representing whether entities are connected as parts of each other or as relations between them, form the basis for many topographical and prepositional spatial relations. These models are important to the deductive reasoning of applied ontologies, but are not widely available (Casati and Varzi 1999). Mereotopologic models could be used for topographic data for features such as engineered systems, in which the parts are critical to the function of the whole, but have topologic relations in the system assembly. Some commonly used models support the representation of topological or mereological relations separately (Rector and Welty 2005).

Mereological relations are part-whole relations that commonly involve physical contact between objects or their integrated processes involving physical matter, but motivated by a unifying function. Part relations are semantically similar to set theory, which is based on aggregation of members of an abstract class that share an identity or activity. For example, settlements may be defined by the presence of a large number of houses. Together, the houses are members of an abstract category called settlement. Topological relations represent properties of objects that do not change with modifications in form.

In GIS, topological spatial relations between objects were formally developed around the 9-intersection model (Egenhofer and Herring 1991). The classification mechanism for the intersection of the interiors, boundaries, and exteriors of two geometric shapes served implementations for operations that support Boolean relations. The concepts were incorporated into standards of the Open Geospatial Consortium (OGC) and International Organization for Standardization (ISO). Specific OGC topological relation (operator) standards are also accepted as ISO 19125—Simple Features Access (ISO 2004). This work adopted eight terms based on the 9-Intersection method using point-set topology. A "Relate" operator returns "true" if the interior, boundary, or exterior of two objects intersect (ISO 2001a, p. 129). The operations that can be implemented are Equals, Disjoint, Intersects, Touches, Crosses, Within, Contains, and Overlaps. The language terms assigned to these relations were selections from sets of synonyms. Relations terms were proposed to be coded as bitmaps, 3×3 matrices, for these relations to lend themselves toward a culturally-neutral notation in a world of linguistic diversity (Mark et al. 1995, p. 691). Other topological relations defined in geographic information science are available, though not as data standards.

Though GIS models topological relations well, mereology is particularly challenging to represent in GIS if different geometries are involved in the complex feature components. Examples of standards for spatial representation, however, reflect many partonymic qualities. Spatial properties of the ISO General Feature Model (ISO 2001b; OGC 2010) include terms that accommodate a range of spatial properties, including location, usually as coordinates; geometric elements such as "surface"; partonomic feature types, such as "memberOf"; and some that could potentially be used to represent geosemantics of scale relations, such as

"aggregationType" or "Complex." These relation types capture a diverse range of user experience representations for topographic data.

2.4 Geospatial Semantic Web

The geospatial semantic web refers to conceptual and applied developments that aim to link geospatial data in a manner similar to the Semantic Web (Berners-Lee et al. 2001). Linkages are supported by triples, which refers in computational systems to a type of data representation structured by two nodes related by an edge. The relation is sometimes called a predicate, linking the subject and object; together these resemble simplified linguistic statements. These parts of the triples, or triple resources, indicate the specific meaning of features and properties, such as their spatial relations, feature identities, or object attributes with a universal resource identifier (URI). By linking data by their URI in Resource Description Framework (RDF) and other data formats, predicates support the logical and automated reasoning governing feature type connections and information inference (W3C 2010b). Logical axioms specified in reasoning software form the rules, or the ontology, that controls the automatic extraction of information that was previously unknown. Triples and their inferences can disambiguate the representation of landscape feature contexts by shifting feature semantics between descriptive topographic object labels and complex models. A complex range of feature relations support dynamic topographical processes models reflecting processes on the landscape.

Some spatial relations and their representation as triple resources have been developed for the geospatial semantic web. A number of software packages offer eight spatial relation predicate terms formalized for data reasoning called GeoSPARQL (Stocker and Sirin 2009; Battle and Kolas 2011; Murray 2011). Parts are represented in semantic technology as, for example, federated graph subclasses or the triple property for part in the W3C standard.. The Ordnance Survey of Great Britain developed 'Rabbit' as a complement to Web Ontology Language (OWL) for spatial reasoning for national topographic modeling (Hart et al. 2007). In addition to spatial relation terms, Rabbit reasons using these prepositions: by, from, for, and of (Dolbear et al. 2007). Seven geospatial relations are available through GeoNames (2010). Of these, most are location-based; for example, ontology:inCountry, ontology:locatedIn, or approximate adjacency, such as, ontology:nearby or ontology:neighbour. Additional spatial relation predicates, found in CYC (OpenCyc 2010) include prepositions, dimension, locality, and other qualities. Most of these relations stress topological or patronymic terms omitting process terms commonly needed in topographic modeling (Brodaric 2008). Options for building those terms include customizing RDF, OWL, and SPARQL with custom or commercial ontology design software (W3C 2010c).

3 Glossary Analysis

An initial list of topographic feature type predicates intended for ontology development were derived by manually analyzing glossaries of topographical terms and relations (Varanka and Mattli 2011; Varanka et al. 2011). A similar manual method was used by others and implemented for this study (Mizen et al. 2005). Fewer constraints and checking steps were involved in the manual analysis compared to similar automated approaches (Navigli and Velardi 2008). Three primary feature type standards were developed based on USGS topographical mapping, beginning with field surveys and later adapted for digital databases. These are the Digital Line Graph (DLG), the Geographical Names Information Systems (GNIS) of the U.S. Board on Geographic Names (USBGN), and the Spatial Data Transfer Standard (SDTS) (USGS 2010; USBGN 2010). These standards or their variations have been previously studied for spatial relation development (Guptill et al. 1990; Mark et al. 1995; USGS 2009). The feature type standards included models for representing feature attributes and their appropriate values.

The definitions were formatted into three main parts to roughly approximate the structure of triples (Table 1) (Caro and Varanka 2011). The analysis was based on approximately 660 predicate phrases of glossary definitions; the variability of number is explained later in this chapter. Some terms appeared in more than one standard with different definitions. Some definitions had no predicates and consisted of a simple phrase. Some consisted of simple sentences, and some were complex sentences involving multiple predicates.

The topographic feature lists were analyzed in tandem with a concordance and spreadsheet. A concordance program lists each word in a text alphabetically along with its frequency of occurrence and a few lines of its immediate placement in the body of a work. The ability of concordance programs to provide a few lines of context clarified meanings of terms as well as the frequency of their usage. For each instance of a verb/preposition pair or other spatial relation term, the

Table 1 Sample glossary data formatted for predicate analysis (USBGN 2010). Verb/preposition pair predicates appear as lower/upper case letters in the central column

Beach: The sloping shore along a body of water that is washed by waves or tides	coveredBY	sand or gravel (coast, shore, strand)
Swamp: Poorly drained wetland, fresh or saltwater, wooded or grassy	coveredWITH	open water (bog, cienega, marais, marsh, pocosin)
Bend: A	curveIN	a linear body of water (bottom, loop, meander)
Gut: Relatively small coastal waterway	connecting	larger bodies of water or other waterways (creek, inlet, slough)
Bay: Indentation of a coastline or shoreline enclosing a part of a body of water; a body of water partly	surroundedBY	land (arm, bight, cove, estuary, gulf, inlet, sound)

concordance was sorted to find all other morphologic forms of the words so they are grouped correctly in the representative analysis. The manual approach was needed because the verbiage throughout the text is inconsistent. Checks for verb/relation consistency in meaning and use were required.

The frequency of occurrence was tabulated to identify the most commonly used terms or type of terms, but most of the desired search terms occur only once, making identification of 'top' terms more complicated. In the three texts that were reviewed for analysis, 75 % or more of specific word instances, called tokens, indicating or inferring a spatial relation occur only once. Combined with the problem of identifying and grouping different forms of the same word, the low number of repeated uses of a word created a challenge in identifying the most frequent spatial relation word occurrences. The verbs or relations and their tokenized forms that occurred more than once in texts were 175 from a total of 641 words. For this reason, the analysis is mainly qualitative and draws trends from repeated instances of similar examples, taking the form of lists of terms in a table. The list of spatial relation verbs that were found may be incomplete and other occurrences of the verb/relation terms may have passed unnoticed because of the omission of verbs in some definitions and morphologic changes of the verbs/relations in the text.

Some definitions were not composed as complete grammatical sentences, and the brevity of feature descriptions often omitted verbs. Where this kind of omission occurred, a verb or preposition or a spatial term other than verbs alone was inferred for inclusion in the data analysis for the purpose of adhering to grammatical predicate rules. An effort was made to keep inferred verbs simple and unassuming in nature while still filling the function of the verb. For example, the verb 'to go' implies a movement from one point to another without adding any other assumptions, such as speed or directionality. This property can be seen in the SDTS definition for "Route": A designated path [to go] *through* a road network. Other common verbs used in these instances include "to be" and "to use".

Definitions used in this study were sometimes composed as a long sentence, but conveyed a relatively simple meaning for its predicate. In such cases, the analysts of this research sometimes chose to focus on the salient part of the phrase. In many cases, the topographical meaning of a term was identified and chosen from among several alternative meanings; for example, some involving the use of cognitive or temporal spatial imagery. For instance, the definition for Overfalls is "Short breaking waves *occurring when* a current passes over a shoal or other submarine obstruction or meets a contrary current or wind" (SDTS). "Caused by" was replaced for "occurring when" to capture the topographic principle of process, rather than time. Risks of modifying the original semantics through generalization are involved in this approach, but the use of this semantic function narrows the potential variability of statements written by multiple authors. Time, or any other principle outside the scope of this study, is equally valid in topographic science, but parameters were set to constrain the criteria of analysis.

The definitions of topographic features often refer to partonomic relations within complex features and systems as well as relations between discrete objects.

The inclusion or exclusion of part relations in topographical feature representation are a function of scale and support feature generalization and multiple representation (Mustière, and van Smaalen 2007). Although many features are differentiated from others on the basis of size, for example a spring from a seep, generalization for many features is a function of the number of parts of the complex that are included in its representation. The geographic scale of feature classes and relations of this study are comparable to the 1:24,000 inch scale of the twentieth-century USGS topographic maps. Other quantitative metrics, such as a minimum representational unit or resolution, were not defined for the analysis.

Temporal shifts were not considered in this study, although time is a factor affecting spatial relation descriptions. For example, the use of the term 'near' may indicate that an object of reference may have shifted over time from a place where the subject and object would have been 'on' one another, such as the shift of a boundary from an old boundary marker.

4 Topographical Spatial Relation Terms

The glossary entries varied in complexity and content, including modifiers, events, objects, and material composition. Words take various grammatical forms, such as tenses or participles. Many are not defined by spatial relationships, but rather by material composition, intended purpose, or qualitative constraints. Most of the spatial relation terms extracted from the standards were verb/preposition pairs, but are context dependent and are nuanced in meaning within the syntax and semantics of sentences. For these reasons, the following sets of terms form a preliminary list that is expected to be refined after future iterative application and study.

The most frequent prepositions when summed without a paired verb were the topological relations "in" (19 times) and "on" (11 times), and the geometrical relation "between" (9 times). The basic verbs "to be" and "to have," and simple verbs of space, such as "located," and time, such as "occurred," and their synonyms, were frequently assumed or implied in the specialized categories described as follows. Locative terms imply location, such as "located," "positioned," or "place" and demand reference objects, as "underground." The locative term "where" was used 28 times as a conjunction. Many terms have inverse relations. Verbs sometimes appeared in pairs, such as "…disappears underground at…and… reappears at the surface at…" A feature can be assigned a relation to represent the things it generates and an inverse relation representing the forces to which it is subject.

Despite linguistic challenges, terms were categorized into types of roles to help organize their analysis. Active verbs consisting of process terms were most numerous, then descriptive geometric terms. Partonomic and verbs of human intention, such as "designed for," were fewest, though terms can overlap categories. For example, "roof" is a part, but implies a geometric description (situated on the "top"), a force dynamic (held by gravity), and a function (to shelter).

Examples of triple predicates for modeling topographic data triples for each of the class types appear at the end of the sections. The examples are not in complete RDF format; they pair prepositions together with verbs to illustrate the triple predicate concept.

4.1 Partonomy Terms

Spatial relations were found to closely resemble the logical prime definitions of topographic features themselves. The types of relations between objects often depend on the identity, origins, or meaning of the features themselves. The necessary and sufficient conditions of the feature definition indicate that spatial relations are part of the feature identity (Wierzbicka 1996). Relations are often part of systems that support their formation and existence, and that relate the feature to the surrounding landscape. For example, a "mine" is an excavation of the earth for extracting minerals. Potential predicates that would be logical selections for triple predicates between parts of the mine could include that infrastructure 'is powered by' to reflect the definition predicate "excavation" and conveyor belts 'carry,' for example, for the "extraction" predicate.

The basic relation "part of" was used only 6 times. Other terms that are classified as "part" relations could include independent features of complexes that imply a part relation, for example a summit is an individual feature although it may be part of a mountain range, or are indicated by terms from a frame of reference, such as "bottom." Subject phrases can imply part relations, such as "group of islands." Part relations such as "composed of" (13 times) or "consisting of" (7 times) were considered to be more closely aligned with generative topographic processes that act on feature morphology. Taxomony was used for part relations; for example, the definition for "area" is "any one of several areally extensive natural features not included in other categories." Anything can be made a part with the use of certain topological prepositions (e.g. within) such as Grave—a place within a cemetery where…

Terms implying part relations appear in Table 2.Examples of the use of such terms include: Island Cluster—A group of islands; Cul-de-sac—The round or circular section of the end of a dead-end street; and Fishladder—A facility consisting of a series of small pools.

The type of "part" terms used most often refer to the material substance of features; these terms are "compose" and "consist," and "made of, " a synonym used only once. Groups of things sharing a common concept included "collection,"

Table 2 Part relation terms for topographic data predicates

Collection	Equipped	Made of	Series
Compose	Fitted	Portion	Set
Consist	Group	Section	Subdivide

"group," "set," and "series," the last term slightly more semantically specific than the first three. "Portion," "section," and "subdivide" imply that the entire feature would be significantly altered by additions or removals, unlike sets of object. A more specialized use of "part" relations is indicated by "equipped" and "fitted," referring to parts that are involved in functions. Triple examples are: Water—portionOf—EarthSurface, or Cul-de-sac—section of—Street.

4.2 Descriptive/Geometric Terms

The group of active verbs used as predicates in the definitions was organized as two classes of terms, depending on whether they function as descriptors or form cognitive geometric visualizations of forms, to be called here descriptive/geometric terms, or terms referring to a generative process or functional role driven by physical forces, called process/function terms in this study. These are not strictly different categories, but are loose generalizations depending on whether the definition refers to primarily one or the other. Several terms fall in both categories. The action may be expressed in the active or the passive voice relative to the subject. For example, the subject can "bury" something or be "buried." Verbs are listed in the tables as infinitives, except the passive voice is used when the active voice is inappropriate, for example, as where a place is "charted," but does not "chart."

Description/geometry terms use spatial relations to develop an image or appearance, such as "flanked by." Terms are often geometric, including "curve," "depression," "slopes," and "steep," and can be topological, such as "contact," "cross," or "fits." Not all terms are verbs; adjectives, such as "nearly," "characterized by," or "vertical" were included in the list, as the meaning of the word is relative to a reference framework, description, or geometry (Table 3).

Table 3 Descriptive/geometric terms for predicates

Align	Cover	End	Low-point	Roof
Along	Cross	Erect	Lower	Rotate
Angle	Curve	Exit	Measured	Slope
Approach	Descend	Extend	Narrowing	Steep
Attach	Deformation	Fill	Nearly	Strung
Border	Delineated	Flank	Network	Submerge
Broken	Depart	Forming	Open	Surface
Characterized	Depression	Fronted	Overhanging	Surrounds
Confluent	Depth	High, higher	Parallel	Trends
Connect	Devoid	Hold	Pass	Upright
Contain	Distinct	Level	Project	Vertical
Contact	Enclose	Lie	Rise	Visible

The types of terms found in the Descriptors category include closely related concepts in geometry and topology, and relative spatial frames of references. Geometric terms referred to specific shapes involving curves and angles, and terms inferring continuity, such as "confluent" or "strung" indicate topological relationships. In several of the definitions, the descriptive term served visualization. A "crossing" (a feature) serves the role of "forming" an intersection. Two terms, "characterized" and "visible," refer to visualization rather than description itself.

Difference between the description and process/force dynamics may be time. For example, a "descending" slope is descriptive if it is static, but a "waterfall" descends if the process is happening with time. Another example is "divide."

Examples of triples are Lake—contains—Water or Levee—structures—Channel.

4.3 Force Dynamics/Process Terms

Process/function terms of feature generation include active verbs representing causes or processes that directly relate to the formation of the feature or an influence upon the feature. For example, "built," "caused," "constructed," or "formed" all indicate topographical processes of feature formation. Terms caused by gravity, such as "falls" appear in this category. This set of terms applies to a wide range of human activities on the landscape, such as "cultivated" or "developed." Other terms are more general, such as "adapted," "maintained," or "created." Triple examples are quicksand, sand—mixedWith—water, and dunes, sand—blownBy— wind (Table 4).

Table 4 Force dynamics/process terms

Adapted	Convert	Dwell	Generate	Pile	Result
Advance	Course	Eject	Go	Plant	Run
Affected	Descend	Emit	Interrupt	Position	Rush
Block	Deposit	Enter	Inundate	Project	Saturate
Bore	Direct	Exit	Issue	Pump	Send
Break	Disappear	Erode	Join	Purify	Subject
Built	Discharge	Extract	Launch	Raise	Support
Bury	Divide	Fall	Load	Receive	Suspend
Carry	Drain	Float	Made	Remove	Swing
Cause	Draw	Flow	Mix	Render	Transport
Change	Due	Force	Move	Resist	Wash
Control	Dug	Form	Obstruct	Restrict	

4.4 Human Intention Terms

Attributes, such as "known," had a strong relation to human intentionality, meaning the purpose, activity, or the feature importance (Couclelis 2010; Câmara et al. 2000). For example, an airport is "…maintained for the use of aircraft." A list of these verbs appears in Table 5. The verb "used," together with a preposition, such as "used for," occurs with high frequency when inferred (21 times), but only once with the four prepositions as, by, for, and to. Also referring to function are the verb/preposition pairs "functioning as" (5 times) and "set aside for" (8 times). Terms of affordances, such as "affords" or "capable of", relate features to a key concept of topography as experience, events, or action on the landscape (Gibson 1977; Sen 2008). Relations and attributes can combine to form simultaneous complex properties. For example, an area designated for a purpose can have signs explaining that designation. Verb/preposition pairs that indicate purpose, such as "intended for" or "intended to be," indicate the motivation for applied physical forces, true also for power relations, such as ownership, administration, or control. Several verbs are events involving features that are not considered to be topographical, such as "ship." In this example, verbs such as "anchored," "berthed," and "moored" were categorized as events relating to the topographical feature "port," as affordances and not predicates or spatial relations.

Predicates indicating human intentions and their subsequent impact on the landscape are often indicated by the preposition "for." These processes and their impacts are intentional for a purpose and include specific affordances and events (load ships) as well as general, complex purposes (administer park). Human-driven processes, however, may have unintended consequences, and because the study aims to focus on physical reality for semantic disambiguation, terms with a purpose, like "built," would be categorized as a process, unless solely the intention is expressed (managed), or used with non-topographical objects (ships).

Triple examples include BuildingComplex—functionsAs—MilitaryBase and PrincipleMeridian—followsAlong—TrueMeridian.

Table 5 Spatial relation verbs of human intention from feature type definitions

Able	Create	Entry	Intended	Passage	Serve
Access	Cultivate	Established	Kept	Place	Set aside
Administrative	Danger	Form	Known	Prescribe	Store
Afford	Defined	Fortify	Limit	Provide	Subject
Application	Designated	Function	Load	Pump	Submerge
Capable	Designed	Hold	Maintain	Reference	Test
Carry out	Determined	Identified	Obstruct	Require	Jurisdiction
Charted	Develop	Incorporated	Operate	Restrict	Use
Construct	Divide	Indicating	Own	Secure	

4.5 Prepositions

Prepositions take many forms, but prepositions that serve spatial uses are a form of spatial relations. Transitive prepositions are 'pre-positioned' before the complement (or the object) of the spatial relation, but intransitive prepositions do not require a complement. Transitivity of prepositions has implications for their modeling as triples.

Projective prepositions refer to frames of reference where the intrinsic point of observation based on objects, as in the phrase "a series of connected mountain ridges" (they would appear connected regardless of where a viewer would be) or an absolute reference point, referring to a environmental orientation, such as "west of here" (Levinson 2003). Topographic semantics are written as though humanly relative spatial frames of reference, reference systems where a speaker is the reference point, for example, when someone says to the left or to the right of an object, rarely exist, perhaps because they imply a role for the observer as a part of the observation, which reveals the observation subjectivity. Relative frames of reference are used in distinguishing one object (feature) from a context, for example, a salient landmark that seems to stand out. It is expected that few relative frames of reference for spatial prepositions are used in topographical feature class definitions, though perhaps more so in user interfaces (Table 6).

Despite that the meaning of a preposition seems ambiguous when considered a verb or other word of relation or attribute, the meaning of the predicate can vary considerably with the selection of the preposition to use with a term. For example, the term "carry" can work as a force dynamic when used along, as in a bridge "carries" traffic, but "carry out" assumes an entirely different meaning, the execution of work, with the preposition "out."

Table 6 Prepositions (Coventry and Garrod 2004)

Spatial preposition		Intransitive prepositions	
Above	By	Through	Away
Across	Down	To	Back
Along	For	Toward	East
Alongside	From	Under	Landward
Around	In	Up	North
As	Into	Upon	South
At	Near	Where	There
Below	On	With	Together
Between	Out	Within	West
Beyond	Over	Without	

5 Spatial Relation Predicates

The spatial relation terms in the previous tables function in complexes, alone or in phrases, with other nouns, verbs, prepositions, and modifiers. The manual analysis of this study allowed for subtle distinctions of spatial relation semantics that were reflected in the complex assemblages of natural language statements. For example, in all cases in GNIS and SDTS, the use of "surrounded by" is always in reference to land surrounded by water; however, the use of "surrounding" is always in reference to a prominent land feature rising from an area of land. The use of "enclose[d] [by]" usually is reserved for the reverse situation—land situated around water in some way, for example, a bay. Interestingly, the use of "enclose[d]" also extends to the ice around a polyna and the land around a basin; in SDTS, "enclose" also is used for walls. This would imply that there is some semblance of a common semantics that "surround" usually means that the item of prominence occurs in an otherwise level or watery scape, whereas "enclose" usually means the solidity or rigidity of the boundary marker. (i.e., even though it makes sense colloquially, there would never be an instance of "Lake: A body of water surrounded by land" or "Island: An area of land enclosed by water.")

As spatial relation verb/preposition pairs follow semantic patterns, triple predicates require the identification of term usage rules. The Merriam-Webster's Dictionary definitions for "surround" and "enclose", have no connotations in applying to solidity, level, land, or water, yet RDF enables such models (Merriam-Webster 2010). Though W3C standard logical axiom properties are intended to model deductive reasoning about observable spatial patterns, such as the transitive property to organize political boundaries, rules control the linguistic semantics of spatial relations as well. Spatial topographic language patterns, such as the "enclose" and "surround" example, are largely regarded as language rule memorization by natural language speakers, though further study may reveal less ambiguous semantics of their use.

6 Conclusion

Although topological relations are well-recognized in GIS, relations represented by linked-data graphs provide increased clarification of topographic features semantics. Topographic feature vocabularies are readily available, but vocabularies for spatial relations characteristics of topographic features are limited and incomplete. The spatial aspects of topographic feature definitions were analyzed to understand relation concepts for developing a vocabulary for semantic web triples. The semantics of spatial predicates agree with major concepts of environmental experience, language pragmatics, cognitive imagination, embodiment, and force dynamics found in studies of topography, linguistics, and geographic information science. The analysis of predicates found in topographic feature definitions

identified spatial relation terms that indicate five major types of natural language spatial relation semantics, including (1) part relations within complex features, (2) active verbs providing descriptive relations, (3) active verbs providing process relations, (4) verbs of human intention, and (5) spatial prepositions for forming verb/preposition pairs. These categories create a framework for building vocabularies for characterizing and organizing topographic relations and for guiding further development and refinement of potential applied solutions to the conversion of natural language spatial relations to predicate operations in RDF triple data.

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