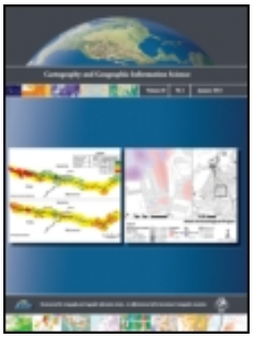

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Ontology Patterns for Complex Topographic Feature Types

Dalia E. Varanka

ABSTRACT Abstract Complex feature types are defined as integrated relations between basic features for a shared meaning or concept. The shared semantic concept is difficult to define in commonly used geographic information systems (GIS) and remote sensing technologies. The role of spatial relations between complex feature parts was recognized in early GIS literature, but had limited representation in the feature or coverage data models of GIS. Spatial relations are more explicitly specified in semantic technology. In this paper, semantics for topographic feature ontology design patterns (ODP) are developed as data models for the representation of complex features. In the context of topographic processes, component assemblages are supported by resource systems and are found on local landscapes. The topographic ontology is organized across six thematic modules that can account for basic feature types, resource systems, and landscape types. Types of complex feature attributes include location, generative processes and physical description. Node/edge networks model standard spatial relations and relations specific to topographic science to represent complex features. To demonstrate these concepts, data from The National Map of the U.S. Geological Survey was converted and assembled into ODP.

KEYWORDS: Ontology design patterns, complex features, topographic features, geo-semantic web

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Introduction

Feature types, in the sense of 'an abstraction of real world phenomena' are complex when they are assemblages of multiple components that depend on each other for functional or some other meaningful purposes (International Organization for Standardization 2002). "Complex map features can be built up from simple ones" (Clarke 2001, 60). The components of a complex feature have high relevance values and strong associations and are similar in context (Ramakrishnan et al. 2005). Assemblages may be multiple occurrences of a single feature type; for example, expanses of tree area in the form of woodlands. Other complex feature types are combinations of different feature types and associated geometries, such as the control tower points, runway lines and building areas of airports.

Complex feature formation is described as spatial objects in the topology of connected coverage frameworks or the object data model (Chrisman 1997; Longley et al. 2001). In the data model approach, feature classes are grouped by shared geometric type, points, lines, or areas, and not as semantic categorizations. As geographic objects, feature type classes are stored in relational tables with properties and relations to other objects. The representation of complex features in GIS was called graphical entities (Lo and Yeung 2002). The level of generalization in the representation of complex features may be directed by function (Chaudhry et al. 2009). The representation of geospatial features can be expected to become more complex with the spread of interactive social media on the Internet to include cultural and temporal aspects, such as person identities, social interactions, or aspects of everyday life (National Geospatial-Intelligence Agency 2007).

The published literature about complex feature data includes little about the semantic concepts that relate the components together. As data, complex features are sometimes captured from satellite or aerial imagery. Complex features are difficult to define in many remote sensing data model modalities because of the blur of multi-band signatures or the overlap of features when viewed from above in aerial photographs. As a result, the visual identification of complex features in remotely sensed images requires expert interpretation and could produce false-positives. Ambiguity in complex feature representation may even be exploited for purposeful misidentification. Traditional geometric data models, such as points, lines, and areas, are well suited to represent simple, basic feature types, such as 'lake,' 'road,' or 'location point.' GIS commonly require relational tables to relate objects from dissimilar feature classes into feature complexes. Though it can be done, most geographic information systems (GIS) cannot flexibly enable combinations of geometric types such as points, lines, and areas (ESRI 2010). As a result, the representation of a complex feature is made to 'fit' a simple shape through cartographic generalization, such as representing a mine as a dot on a map, though the features are multi-dimensional.

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Semantic attributes of geographic features are measured, categorized, and stored with the spatial geometry of the feature in the basic data table, but any advanced development and analysis of semantic complexity involves the skill of the GIS analyst to design and manipulate (Clarke 2001). This study examines the potential of using ontology design pattern (ODP) technology to represent complex topographic feature types in a way that details the semantic meaning of feature assemblages. Specifying data property semantics automates a component of geographic information analysis that is largely manual in most GIS. A range of GIS functions are researched to be more quickly accomplished with semantic specification. Ontology applications help in searching, querying, and retrieval (Teevan et al. 2005; Wang et al. 2007), annotation (Dubbeldam et al. 2001; Dill et al. 2003; Reeve and Han 2005), classification (Doina et al. 2005), and other system functions (Macías et al. 2003). In GIS, large scale application developments were described in geology (Brodaric 2004), national security (Sheth et al. 2004), and land-use modeling (Pignotti et al. 2005). Ontology is a well-known technique to improve data and system interoperability (Sheth 1999). These studies suggest that semantically-explicit topographic features would facilitate GIS functions.

Computational ontologies have been defined as "artifacts that encode a description of some world" (Gangemi and Presutti 2009). Human perspectives on geographic ontology are cognitive and cultural bases of knowledge about the world. Semantics are meanings that groups of people assign to features and relations. Semantic mediators in ontology-driven GIS formalize phenomenological perspectives of real-world things into logical and representational objects in databases using assemblages of feature concepts and interrelations, while recognizing that knowledge is affected by epistemological implications (Fonseca et al. 2002; Schuurman 2005). Broadly developed ontology formation, including aspects of geographical realms was addressed by the DOLCE project (Masolo et al. 2003) the SNAP/SPAN design (Grenon and Smith 2004), and others (Uschold and Gruninger 1996). Aspects of geospatial ontology were defined by Tomai and Kavouras (2004), Agarwal (2005), and others. Specific challenges in geospatial ontology semantics include the representation of location, of spatial relations, and geospatial analysis.

Computational ontology is normally expressed in the linked triple data format of two nodes related to each other by an edge. Triple resources are sometimes called the subject-predicate-object, analogous to simple natural-language sentences. Identical nodes of triples link together or are linked to diverse nodes by relations to form federated graphs in a data model called Resource Description Framework, or RDF (W3C 2010). The specific semantic information to disambiguate the components of the triples is the universal resource identifier (URI), a string of characters used to uniquely identify the resource on the Internet (Mealling and Denenberg 2002). Triple predicates enable the automatic creation of information through logical reasoning rules that are the basis of the ontology. Ontologies of complex features control the function of triples and connection of elements between classification systems by applying logical reasoning through the use of Web Ontology Language (OWL). ODP are small ontologies for reuse in multiple applications, where their implementation helps build solutions for more extensive ontology development and application (Daga et al. 2005; OntologyDesignPatterns.org 2010). Because they are small and manageable, ODP can serve as the basis for specific local conceptualizations for spatial data infrastructure diversity (Duce and Janowicz 2010). The resulting ODP can interlink topographic data with the broader semantic network by following established conventions, such as the Linked Data guidelines (Bizer et al. 2007).

An example of an ontology pattern appears in Figure 1. In this example, the ontology pattern is called Species Habitat. Every aquatic species, which is a subclass of aquatic resource, has the property "has a habitat." What that habitat is varies and whether the habitat has an aquatic species varies. The habitat has the property of 'isHabitatFor' an Aquatic Species. The pattern of concepts and mandatory or optional relations can be reused for a wide range of local implementation.

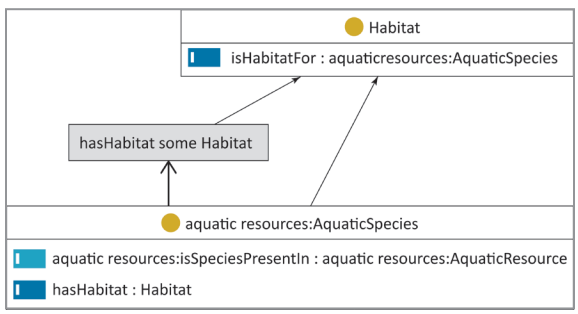

Figure 1. An ontology design pattern for the concept Species Habitat (Gangemi 2010). The tan circles represent primitive classes and blue symbols represent object properties

The concept of design patterns is generally attributed to have arisen in architecture and applied to automated computation in the late-1980s (Alexander 1979; Gamma et al. 1995). ODP have been applied in a variety of applications, such as bioinformatics, software engineering, and business (Aranguren et al. 2008; Bobillo et al. 2007; van Teeseling and Heller 2009). Typologies and frameworks for ODP and their repositories for public access have been proposed and a wide range of ontology repositories exist (Gangemi 2005; Ontolog 2010; Pan et al. 2003). ODP are appropriate models for topographic geosemantic data

because topographic data primarily serve as a base for diverse applications by the public and scientists with no predetermined specific use. The design of ontology patterns for topographic data enables their reuse. Advantages of using design patterns are to accelerate the production of digital products for novice users and that computational ontologies from similar patterns map to each other and align for interoperability. One key to successfully enabling the reuse and integration of ontologies through design is transparency of criteria and rationale. The scope of this paper is to present common concepts for topographic ODP.

This paper describes an approach to topographical ontology design pattern using simple feature types categorized taxonomically within thematic domain modules of a central ontology called 'Topography.' Though the term topography can be variously defined, it was used in this study to mean landscapes which are the character of the surface of the earth as it is humanly experienced or perceived. Topographic science refers to the scientific study of those landscapes. Basic or simple features are related across domains with different spatial relation types, allowing the formation of environmental contexts of different operational scales (Lam et al. 2005).

The remainder of this paper is organized in three main sections. The first will introduce a concept of complex topographic features. The second proposes an ODP for topographic features. The third section discuss the implementation of ODP that are intended to be made available in repositories on the Internet for reuse, similar to the way that topographic data are reused in GIS. The implementation approach is to support The National Map of the U.S. Geological Survey (USGS) capabilities benefiting users of a 21st-century national topographic mapping program, including the ability to expand the range of semantic properties of data and improve the usability of the data for semantic technology (Varanka and Usery 2010). An ODP, 'Mine,' representing an excavation of the earth for extracting minerals, is used throughout the paper as an example of a complex feature type (Wordnet 2010).

Ontologies for Topographic Complex Features

The analysis of complex features is based upon a set of basic assumptions. For purposes of the project objectives, the ontology of topography is a primary-theory ontological perspective in which geospatial features are considered real and rooted in human common-sense experience of the world that is perceived in order to function in everyday life (Smith and Mark 2003). Feature properties may vary with cultural conventions or individual perceptions, but an assumption of real objects accompanies topographical ontological concepts. Spatial representation can function in different ways, such as geometric coordinate systems with each entity assigned a location, by employing relative spatial relations such as the term 'near,' or as topologic or process-based location, such as to/from directions on networks. Data for topographic ODP may be organized as seamless fields to be downloaded from servers, yet when downloaded, the data are partitioned into regional or neighborhood extents. These data of extent are expressed in terms of coordinates, but users usually add object-framework features, or their localized attributes, resembling geographic objects. The combination of representational systems creates a mixed ontology of field/object relations (Galton 2001; Mark and Smith 2004).

Most feature boundaries are crisp largely due to technological constraints, but fuzzy as conceptual entities. Space and time can be differentiated, as in static representations such as maps, or they can be combined, as in hydrological modeling. Distinctions between physical and socio-economic entity types are not considered here because of multiple perspectives on topography and its affordances; for example, a garden can be considered a physical, ecological entity type, or a socio-economic asset to a residence. A clearer distinction is practiced regarding bona fide and fiat entity types, though these are not strict (Casati and Varzi 1999; Binghamton Symposium 2005). Complex features involve both types; bona fide entities are generated by natural processes such as river deltas that are depositions of sediment, and fiat types, determined by humans, such as urban land use and city limits.

Part/whole relations are inherent in complex feature, depending on generalization and semantic meaning. The types of these part-of relations have implications for semantic similarity and interoperability. As with information specifics and process details, the feature spatial relations change scale within their topographical and semantic context. As topographical data changed media from paper maps to digital databases, features became identified as segments of a data model, and not as entities within the representational context of places on the map. One purpose of designing ODP is to relate feature semantics to their context.

A critical stage of developing ODPs is the identification of semantic primes, defined as the concepts that are innate to human understanding and require no elaborate encoding (Wierzbicka 1972). The entity 'primitive' is defined as the necessary and sufficient conditions of a feature class to satisfy the meaning of a term; these conditions can usually be found in the term definition. Without these conditions the feature would not exist, and does not depend on other associated components to still be the feature type. For example, a mine is defined in the topographical sense as, "an excavation in the earth for the purpose of extracting earth materials" (USGS 2001, 6-142). A mine is always located at the site of an expected or actual mineral or metal deposit discovery and

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earth materials will always be excavated at the site for excavating the mineral resources. Excavation is the necessary condition and the expected, discovered, or extracted minerals are the sufficient condition.

A schema of a 'Mine' feature type primitive is made up of cross-linked factors involving four subclasses; a mine operates at the surface of the earth or underground to extract metals or industrial minerals (Figure 2). In addition to the necessary and sufficient conditions for the feature type primitive, a complex feature can display an extensive number of optional components of feature types and functional roles. Secondary conditions, factors such as infrastructure, labor, and energy, may be added to the feature. Optional components and their details are typically driven by the specific context of the feature. The spatial relations between complex feature components reflect the conditions of the object primitive. In our example, 'Mine,' the power and equipment needed for excavation and the movement of minerals. In this ODP example, the properties that were used include 'connects,' 'powers,' 'carriesTo' and 'carriesFrom,' which indicates the interrelated nature of the feature (Figure 3).

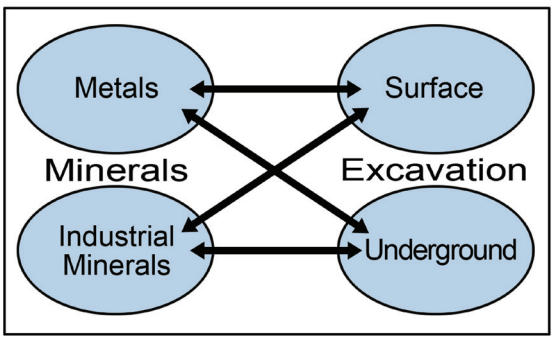
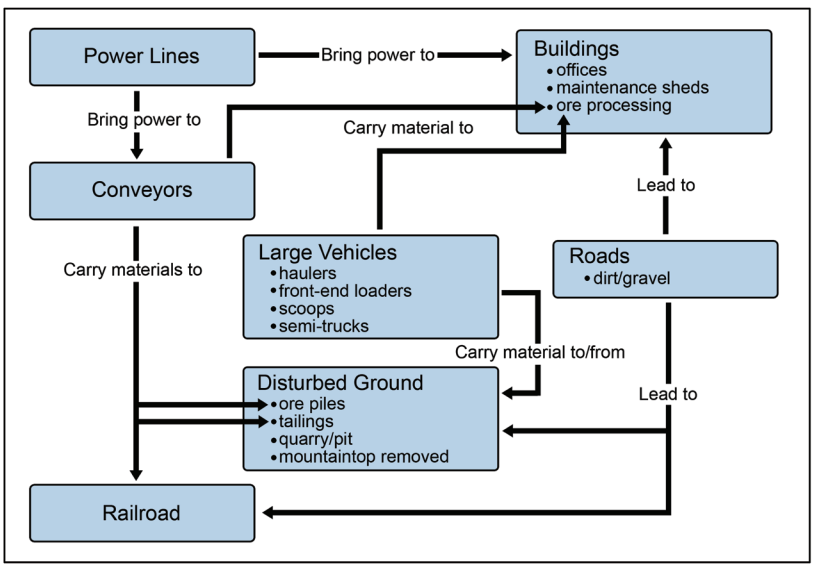


Figure 2. Primitive of a complex feature class, mine.

Figure 3. A sample semantic graph for surface mining operations (Varanka and Jerris 2010).



An important distinction between the similarity or dissimilarity of complex feature components is whether their parts are masses of the same material or assemblages of varying material and functioning properties. The semantic meaning of a complex feature of dissimilar components will depend more on a meta-notion of purpose or function of the complete feature, and less on the physical characteristics of the basic features. The semantic similarity of complexes formed of multiple features of the same type is greater, as is of stones that form a hill, than of complexes formed of diverse feature types, such as recreational parks with basketball or tennis courts, landscaped walking paths, and visitor services buildings (Rodríguez et al. 1999). Semantic specification enhances data reuse and interoperability, though the organization of the domain content must be articulated.

Topographic Science Ontology

The approach to the study of topographic data ODP begins with a framework for topographic feature complexity. This framework references the general geographic development of features on the landscape and moves to concepts to support technical ontology applications, including a topographic feature class taxonomy for leveraging common properties, spatial relations between classes and instances for data triples, and feature class properties for data instances.

Topographic Feature Complexity

An ontology concept for topographic data is composed of three inter-relating levels of elements – features, systems, and landscape (Figure 4). Complex features are typically a part of resources that extend beyond the limits or boundaries of their immediate location. In addition to their components, complex features connect to broader support systems, such as infrastructure or natural resource systems, such as hydrology. Also, all complex features and systems depend upon and affect the landscape of varying extent. The landscape level of the complex feature includes ecological regimes of influence, or landscape materials that involve the broader locality or region, such as mineral deposits, and references to location systems referred to in various ways, such as within administrative regions, coordinate systems, or with spatial relations such as 'by the lake.' The inter-relation of these three levels of complexity – features, systems, and landscape – begin

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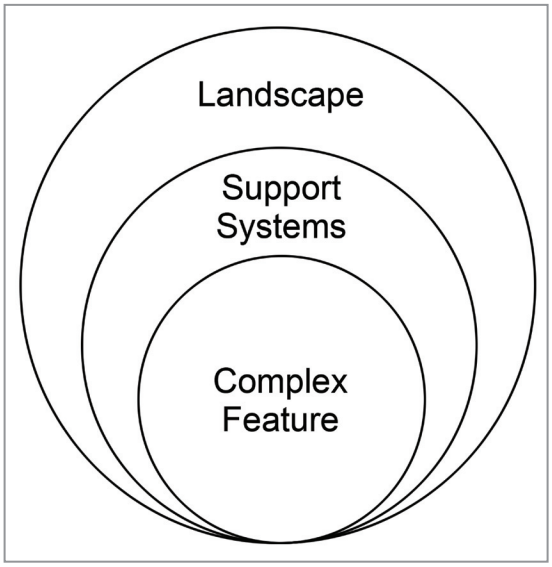


Figure 4. Complex features type, supporting systems, and affected landscape extent.

to build context for complex features representation.

A mine, for example, could have two component features: roads and railroads that extend beyond the immediate area of the excavation. A mine must be operated and controlled by humans commuting from home, and resources are consumed by a market at a distance. The transportation for labor and mineral extraction takes a form depending on the landscape. Workers may reside in housing provided at the mine site, or may commute from nearby built up areas. If developed areas are far from the mine, the transportation may be provided by a company bus. Where the mine is located near residential areas, the road system may be able to support privately-owned cars. Roads may be rough, but manageable for certain types of vehicles.

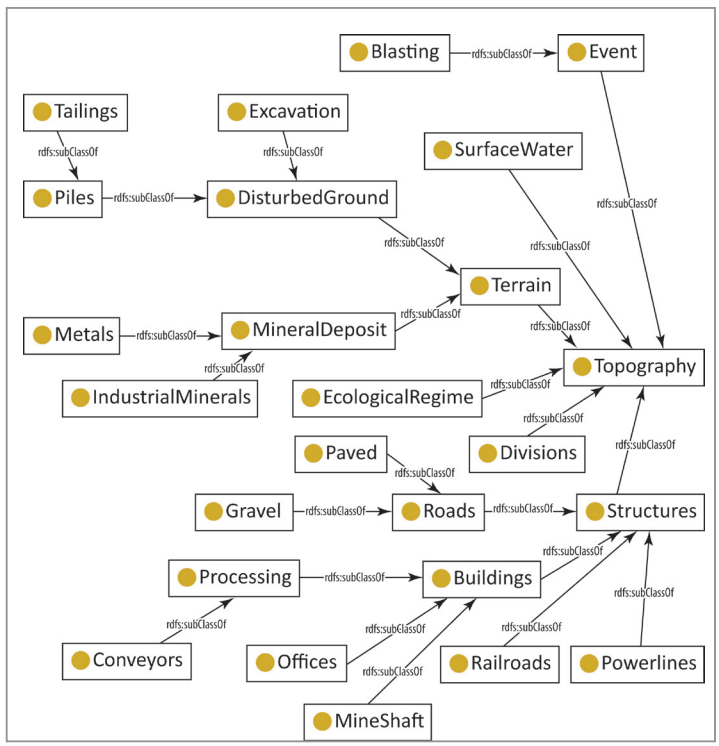
The influence of the landscape can determine alternative properties of a mine. Resource types are geologically determined. Surface and underground mines vary in the degree of their disturbed area and extraction method. Industrial minerals, such as crushed limestone for example, do not require extensive processing facilities at the mine location. Metal ores require more processing to achieve the final product. The mineral processing can leave waste deposits at the mine site, or they may be transported to other locations depending on economics, management, or regulations.

Topographic Feature Class Taxonomy

Based on a domain taxomony, ODP leverage data properties through inference, which allows the properties of a taxonomic class to be automatically assumed by the members of its subclasses (Allemang and Hendler 2008). In the 'Mine' example, 'piles' and 'excavation' are subclasses of 'disturbed ground,' and have all the properties of 'disturbed ground,' such as its natural pattern or function disrupted, in addition to their specific semantic qualities of mine waste dump 'piles' or earth 'excavation' (Figure 5). Taxonomy can be used to indicate relative geographical scale by taking a form of broader or narrower classification level detailing generalization with many or fewer properties or instances. Tree structures, such as taxonomies, are still incomplete for the representation of complex features because their definition depends on cross-relations between features. In ontology, broad thematic taxonomic modules could be interrelated to represent complex feature types.

Six subject domains fall within the scope of the topography ontology of this study: Terrain, Surface Water, Ecological Regimes, Structures, Divisions and Events (Figure 6). Feature type classes falling within these modules were developed using a top-down approach of topographic science knowledge and a bottom-up approach using feature type terms based on standards developed by the USGS and its partners; the USGS Digital Line Graph (DLG) and National Hydrography Dataset (NHD), the Spatial Data Transfer System (SDTS), and the Geographic Names Information System (GNIS) gazetteer (USGS 2001; USGS 1999; SDTS Technical Review Board 1997;

Figure 5. Taxonomic subclasses for a complex feature example, mine, to leverage property inference and relative geographical scales of feature components.



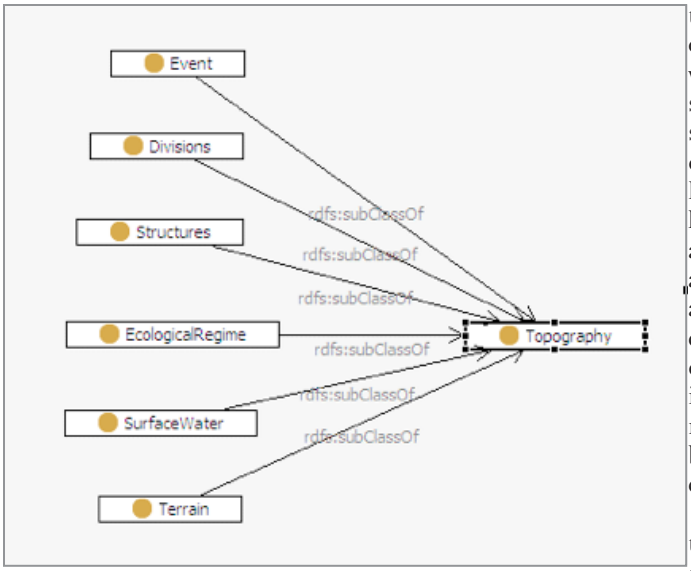


Figure 6. Taxonomic classes of Topography ontology.

USBGN 2010). A sample of complex feature classes from the standards appears in Table 1 (Varanka 2009).

Feature Properties and Relations

Three general categories of feature attributes are used in the topography ontology: locators, generators, and descriptors to reflect the spatial location, causal attribution, and general perception of subjects and objects of triples. Though space is innate to these attributes, these are not organized as spatial relations between features.

Complex feature classes based on different topography domains trend toward a range of property and spatial relation complexity. Natural features, such as 'waterfall,' 'peak,' or 'crater,' tend to be more easily described in familiar or relative terms, or as features of multiple similar parts such as 'range' or 'talus.' Though physical landforms are easily grasped perceptually, they are associated with highly complex, generative processes studied through science. Part relations of natural features tend to be sections of the physical object that are related by connections, not separate objects related together by concept or function. Surface water features are variations of shapes that are all composed of a single material flowing to the general shapes of their channels or basins. Of the other classes presented in Figure 6, Ecological Regimes, such as 'Tundra,' 'Desert,' or 'Grassland,' are highly complex physical entities, in part because these terms capture environments involving data fields such as temperature, radiation, moisture, or vegetative extents, not specific topographic features. These terms would be restricted to the landscape level of complexity. Structures tend to be more clearly organized as conceptual or functional features with component parts with topological spatial relations between them, such as the examples listed in Table 1. Network structures are often assemblages of similar component parts, such as pipelines or power lines, as are divisions. Structures and divisions have engineering generative processes. Events are characterized as temporal features. In addition to physical aspects of the environment, activity plays a critical role in ontology (Perry et al. 2009; Kuhn 2001). Features generally classified as structures were selected for ODP implementation because the topological spatial relations were most explicit for these types, and because the feature concepts or functions can be easily clarified in basic terms for public data use.

Specialized applications developed for topographic science process models and integrate discrete data for complex systems analysis by drawing on spatial relations. Different types of spatial relations between features, such as measureable distance and cardinal direction can be used in GIS, but terms that have diverse meanings are rarely applied. Topologic relations standards developed by the Open Geospatial Consortium based on the 9-Intersection model are widely used (Herring 2006). These include: equals, disjoint, intersects, touches, crosses, within, contains, and overlaps. A set of topographic relations were extracted for topography ODP from standard feature definitions used to develop the topography taxonomy in Figure 5 (Table 2) (Mizen et al. 2005;

Table 1. A sample list of complex feature terms used in this study, taken from DLG/NHD, SDTS, and GNIS.

Dry-dock	Inshore traffic Zone	Cableway	Installation
Fish hatchery	Railway yard	Aquaculture site	Base
Fishing ground	School	Farm	Fort
Irrigation system	Post ofice	Stockyard	Institutional Site
Airport	Hospital	Mine	Aircraft facility
Cable site	Antenna array	Prospect	Shopping Center
Proving grounds	Radar dome	Disposal grounds	Gantry
Rest site	Redar reflector	Oil field	Refueling track
Toll plaza	Sports site	Drill platform	Building complex
Gentry	Recreation site	Tank farm	Exhibition ground
Bridge	Drive-in theater	Well field	Dam site
Draw span	Racetrack	Power site	Marina
Built-up area	Campground	Harbor	Sewage disposal plant
populated place	Trailer park	Port	Disposal site
Mobile home park	Park	Shipyard	Filtration plant
High-density building area	Ski area	Warf	Industrial site
Golf course	Athletic field	Pump-out facility	Cliff dwelling
Marine activity site			

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FLOW		
Water	flowTHROUGH	Arroyo (Watercourse or channel)
Water	flowTHROUGH	Channel (Linear deep part of a body of water)
Underground water	flowTO	the surface of the Earth
CAUSED		
Crater (Circular-shaped depression at the summit of a volcanic cone or on on the surface of the land)	causedBY	in impact of a meteorite
Crater (a manmade depression)	causedBY	an explosion
FORM		
Crossing (A place where two or more routes of transportation meet)	form	a juntion or intersection (overpass, underpass)
REMOVED		
Mine (Place where commercial minerals are found)	removedFROM	Earth
Oilfield (area where petroleum is/was)	removedFROM	Earth

Table 2. An example of the geospatial relations extracted from feature definitions. Four terms are shown from the results – flow, caused, form, and removed.

Kokla and Kavouras 2005).

Legacy material from decades of topographic data development both from analogue maps and from GIS databases provides a substantial basis for ontology development needs in the 21st-century. Complicated domain knowledge can be displayed in graphic form by converting GIS data to Extensible Markup Language (XML) diagrams. Though more research is needed on contemporary landscapes and related users' semantics, and their adaption to data platforms and technical tools, these knowledge bases form valid content for a controlled vocabulary for the semantic implementation of topography ODP. Programming logical reasoning for spatial relation predicates remains a major challenge for applying spatial relation in triples.

Ontology Design Pattern Implementation

The implementation of ODP involved the selection of appropriate sample data, data conversion, and ontology development using a semantic technology platform. To achieve a complete sense of semantics, including cognitive and linguistic aspects of spatial objects, a change in approach is necessary from the design of GIS databases, which are often based on specialist codes. The semantics in a geospatial database can be recognized and reused with an automated knowledge extraction approach based on relational database reverse engineering (Lubyte 2007; Baglioni et al. 2007). The test of ODP is in the application in use cases.

The developing geospatial and geosemantic web requires the ability to enable diverse combinations of features for users' solutions (Egenhofer 2002). As base data, it was expected that automated and manual approaches for developing topographic ODP would be required. To create a large number of feature ODP, automated approaches using converted data were researched. Concurrently, the ability to manually customize the patterns is needed for local applications. Both approaches are allowed in ontology-driven geographic information system (ODGIS). Critical components of an ODGIS can be built to enhance an original GIS. These components would include a semantic model representation, ontology graphs, knowledge inference and reasoning software, the triple store or bridge to the legacy data, query translation to pass from an endpoint to data, and visualization tools.

An ODP involves a generic use case, involving both a domain and a use case to answer competency questions (Gangemi and Presutti 2009). The level that the use case matches the local need for the ODP helps determine how much or which parts of the ODP that will be applied. The use case for applying an example complex topographic feature was selected that could commonly be applied in multiple topographic data needs (National Research Council 2007). The following presents steps in the use case application:

1. *An event and its named location is reported to the geographic information science specialist;*
2. *The feature name is searched using a gazetteer-driven interface;*
3. *The feature footprint is retrieved from the database with its name label;*
4. *A map of the area is made using the feature footprint over an image;*
5. *Compute topologic relations with neighboring features;*
6. *Query the feature relations using GeoSPARQL;*
7. *Link with ancillary data; the feature name and footprint are used to create ontology from the relational database;*
8. *View a 3D image or visualization of the footprint with ancillary data;*
9. *Select point or area on the feature and annotate;*
10. *Deliver assembled data scenario to user.*

The design of topography ODP must be sensitive to the wide range of landscape characterizations represented by topographic data (Brewer et al. 2009). The sample data selected for creating prototype topographic ODP consists of six hydrological basins and three urban areas (Figure 7). The data

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represent catchment areas that fall within different physiographic types identified through analyzing digital elevation models (Stanislawski et al. 2007). The data were converted from proprietary formats based on relational tables, to Geography Markup Language (GML) for the representation of geometric coordinates, to RDF (Portele 2007). Four vector themes were converted including hydrography, structures, transportation, and divisions. Though they require some modification of their semantic representation inherent in the data, these data form the basis for developing prototype ODP for complex topographic features. The converted data, the conversion program, and a report on the conversion process are publicly available (USGS 2011).

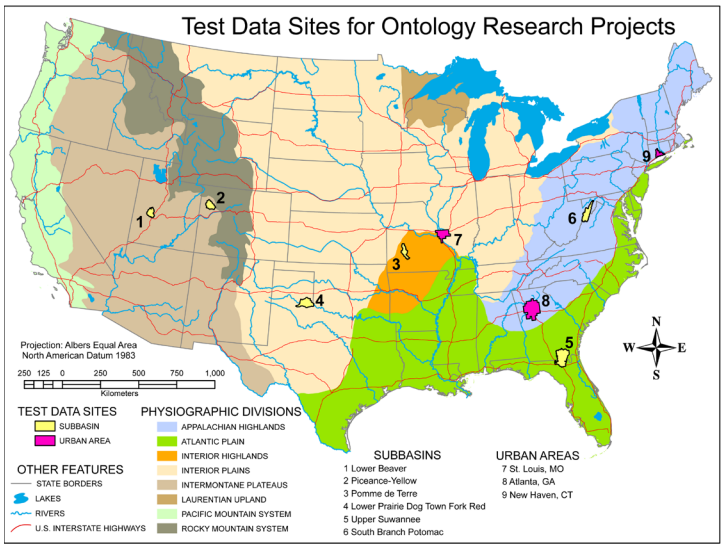

Figure 7. Data sites and physiographic divisions of sample data sites.

Reverse engineering methods evaluate the database schema and metadata, classify core tables into entity, relationship, and description tables, and construct ontology by creating concepts or classes, datatype properties, object properties, and cardinality constraints by following rules. The National Map sample data converted to RDF were extracted from the database using Quantum GIS (QGIS 2011). QGIS was chosen because it is an open source GIS software package that implements the Geospatial Data Abstraction Library and supports the OGR Simple Features Library formats necessary for the conversion process (GDAL 2011). The separate layers of data are then output to GML. GML version 2.1.2 was chosen because of its interoperability with GIS software packages. Once in GML format, the data were then processed into RDF using a program developed at the USGS.

The data conversion produced semantic property values from the data model of The National Map, though without some ontologic implications, such as the feature type primitive or natural language term in place of a feature type code. Also, logical axioms were required to model landscape processes. To define these additional semantic elements, cognitive cartographic abstraction was employed to expand feature ontology in the federated graph of the converted data and for manually created ODP using ecological interpretation to simulate normally linguistic articulation. Prose texts serve as a source for replicating commonly-agreed semantics.

Samples of topographic feature ODP were produced from converted NHD data, for the feature type 'Bridge,' and a new ODP was created for the feature type 'Mine.' In both cases, the complex feature was formed from two component features connected with a topologic spatial relation taken from the OGC standards. 'Bridge' demonstrated the integration of features from two thematic domains, 'Road' (structure) and 'Stream' (surface water) to complete the semantic primitive of 'a structure for transportation over an obstacle.' The 'Mine' ODP completed the primitive described earlier in this paper. Together with the 'Mine' ODP, the coordinates for a polygon representing a mine were added to demonstrate the relation of a feature instance contained within the feature type class.

Conclusions

ODP are small assemblages of reusable program components and properties that provide a basis for application development. The use of ODP provides some degree of representational consistency that facilitates data interoperability. This paper described an approach for adapting the concept of ODP to topographical databases as re-useable baseline data. Complex features are formed from component features with functional relations to each other, to outside systems, and to the surrounding topography. These relations enable complex features in the form of ODP to cross-integrate and enable science modeling of a wide range of landscape types and processes by using the triple data model for features, spatial relations, and GML coordinates.

The study developed an approach to designing geo-semantic topographic data in the form of ODP by converting samples of the topographic data already collected and tested for The National Map to RDF. The aim was to allow geo-semantic web users to reproduce data for local applications. By developing a vocabulary for spatial relation predicates from data standards to support environmental modeling, a taxonomic structure that supports inference and generalization, and identifying three categories of triple resource properties, this research furthered a conceptual and logical method for complex topographic feature ODP.

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