A TOPOGRAPHIC FEATURE TAXONOMY FOR A U.S. NATIONAL TOPOGRAPHIC MAPPING ONTOLOGY

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Abstract
Using legacy feature lists from the U.S. National Topographic Mapping Program of the twentieth century, a taxonomy of features is presented for purposes of developing a national topographic feature ontology for geographic mapping and analysis. After reviewing published taxonomic classifications, six basic classes are suggested; terrain, surface water, ecological regimes, built-up areas, divisions, and events. Aspects of ontology development are suggested as the taxonomy is described.

Introduction
A common stage in the development of an ontology for semantic technology is the design of a taxonomy. Taxonomies, or classification systems, infer relations behind their formation based on context. A topographic feature taxonomy was devised to precede the development of a geospatial ontology for *The National Map* of the U.S. Geological Survey (USGS). The objective of the taxonomy was to form a hierarchical classification system that enables ontologies to express multiple semantic and spatial relations of topographic features. Concepts for building an applied taxonomy for the type of national topographic data that *The National Map* delivers are based on meanings of topography and highlights characteristics of topographic features. Though *The National Map* has simpler geospatial data themes or categories than those discussed in this taxonomy, the complexity captured in this taxonomy can form the basis of complex queries based on a wide topographic vocabulary, as well as anticipate new data feature types. Additional ontological properties and resources would be required to apply this taxonomy for environmental analysis on the Semantic Web.

Topography concepts have been discussed as early as the writings of Ptolemy, through Elizabethan English and Enlightenment geography, and revived again in post-modern geographical analyses (Dilke, 1987; Harvey, 1980; Curry, 2006). The direct experience of the landscape akin to a cognitive narrative is regarded as an innate characteristic of topographic mapping. The direct cognitive experience of the land contrasts to geography, which involves broad and abstract spatial concepts. Geographical extents are too broad to be directly experienced. For example, the extensive coasts at risk for hurricane damage are largely perceived, without technological assistance, only within one's own immediate area. As a result, an innate tension arises when the localized character of topographic surveying and mapping is

extended over a much larger nation. The personal perceptions and experiences of individuals living within the country are important for participation in its communities, though the broader extent of the nation is critical for the country to be regarded as a whole. The relevance of topographic mapping services to the public lie within largely local spheres of activity, which may vary regionally or culturally, though data collection, standardization, maintenance, and mapping projects may be centralized within the Federal government.

Due to the increase in codified scientific knowledge, taxonomies are getting increasingly complex as they form from different dimensional combinations of interrelated systems. Published taxonomies of geographic features show that many are based on regional or scientific processes and may be categorized by the interplay of multiple agents. The landscape features of such scientific taxonomies are less often discrete objects, as they were in topographic mapping. For example, though visually evident, topographic features having indeterminate boundaries are difficult to quantitatively define (Mark and Smith, 2004). Landforms are scientifically represented as continuous elevation data, but thought of and discussed as individual objects (for example, as a volcano or the Ozark Mountains). A similar distinction between formation processes and surface description apply to other topographic features such as urbanization or political divisions.

The data supporting scientific categorizations were largely compiled using intervening technology, such as remote sensing. Other quantitative approaches such as network and graph theory are common in the categorization of spatial points and lines. The scientific basis of this technology can be as complex as the analyzed physical forces attributed to geographic feature formation. Technological categorization is geographical in that it is subject to perspectives of broader spatial scale, sometimes characterized as geometric ‘space’ in contrast to ‘place.’ Topography is about places.

The topographic classes and class members of the taxonomy presented here are defined and categorized according as humanly perceived and experienced, but serves to support environmental and scientific analysis. Though regional divisions pertain to physiographic types, and not descriptive appearance, places may be defined regionally in this taxonomy. Cognitive topographic concepts help determine environmental studies of interest for further scientific investigation and how that science should be conducted and communicated to the public. Science remains a secondary context for topographic classification, though common, descriptive names for features are used in favor of disciplinary scientific terms.

Any taxonomy is at risk of bias. Ontological categorizations of topography stem from experience including folk and local knowledge that can be suppressed by disciplinary science that rejects the experience of individuals as subjective. Some studies find that state-sponsored classification systems obfuscate detail in landscape categorization because of political interests in simplification or avoidance due to state policy

(Robbins and Maddock, 2000). For example, cultural sites, such as places regarded by some as sacred or devoted to historical remembrance, are rarely recognized in national topographic maps. A taxonomy of topographic features for a national map would benefit from public opinion, though avenues for such contributions rarely exist and have not been used here.

Methodology

The basic topographical feature terms used in this study were taken from feature lists of five previous USGS-related standards projects: Digital Line Graph Enhanced (DLG-E) and Feature (DLG-F) versions, Spatial Data Transfer Standard (SDTS), Federal Geographic Data Committee (FGDC), and the data models of *The National Map*. USGS field-based surveying over the twentieth century became the basis for the two DLG feature lists, whereas the SDTS and FGDC lists were developed with other Federal and non-Federal agencies and partners. Features more often take the form of feature codes in the FGDC and *The National Map* standards. The legacy terms from these five projects were expanded, when required, for taxonomic completion.

Feature terms may be regarded either as subclasses or as class members (feature type). They are regarded as class members in this taxonomy, as descriptive items, as though the pronoun ‘a’ preceded the term. The feature terms are representative objects, but not the specific manifestation of a physical entity. This treatment is so that they more closely resemble subjects of triples and will lend themselves more easily for building topographic feature ontologies. The compilation of discrete topographic features with spatial coordinates in the RDF-formatted data store will later form the instances of the ontology. This approach will also avoid short-term problems associated with the difficulty of placing specific features with partially-varying characteristics in categories with sharp delimitation.

The terms in these tables do not include synonyms that do not appear in the legacy USGS feature lists, though synonyms will be included in the forth-coming ontology. Terms referring to parts of complex features, are included. The definitions of these feature terms are available by linking to data content standards at the project web site (USGS, 2009).

Six domains are defined to form the topography taxonomy: terrain, surface water, ecological regime, built-up areas, divisions, and events (table 1). These classes are roughly ordered by their physical structuring influence and by temporal extent. Terrain shapes surface water. Terrain and surface water, together with other environmental factors that are less strongly topographical, such as temperature, are the factors of ecological regimes. Though built up areas are not strictly driven by ecology, development is often a response to environmental factors, as well as giving rise to a derivative of local environmental factors. Over time, built up areas develop divisions and events are mapped by reference to those divisions.

Previously published scientific taxonomies involving topographic features were incorporated in this topographic taxonomy, though abstracted for cognitively salient features. The wetlands taxonomy, for example, is intended to describe ecological complexes (Cowardin and others 1979), but the system classification levels correspond closely to traditional topographic features, such as seas, estuaries, rivers, or lakes.

Terrain

In-depth taxonomies of landform features sometimes take geological processes into account, but recognize that contemporary landform description may be a separately developed perspective (Fenneman 1916). In this paper, landforms mean cognitively-discrete features, and the term terrain describes the connected region composed of sets of landforms. The Terrain category lists 58 USGS landform features (table 1).

Aeolian	Delta	Island cluster	Quicksand
Arch	Dish	Isthmus	Reef
Bar	Divide	Karst	Ridge
Basin	Drainage basin	Lava	Ridge line
Beach	Dunes	Lava	Salt pan
Bench	Fault	Mineral pile	Shaft
Cape	Floodplain	Moraine	Sink
Catchment	Fracture	Mount	Solution chimneys
Cave	Fumarole	Mountain Range	Summit
Chimney	Gap	Peak	Talus
Cirque	Glacial	Peneplain	Terrace
Cliff	Ground surface	Peninsula	Valley
Coast	Hill	Pinnacle	Volcano
Crater	Incline	Plain	
Crater	Island	Plateau	

Table 1. USGS Topographic Landform Features

The attributes of the landforms domain are shape (not shown in table 1), for their identification as objects. Hypsography is the logical attribution for the extension of this taxonomy to computation. For example, Landscape features can be computed from the inverse of watershed delineation (Sinha and Mark, written commun., 2009).

Some geologic features are included in this taxonomy because topographic features may correlate with or correspond to them. Either as corresponding units or as generative forces for particular topography, geologic features are characterized on the earth's surface in a way that is consistent with the criteria of this taxonomy to describe features that are cognitively easy to identify.

Links will be likely in the ontology between landforms and the environment. Surface-water features are formed by the natural or artificial materials that enclose them or

cause the flow of water; also, landforms interplay with construction processes. Also, landforms are sometimes the indicator of divisions, as with rivers, and are also related to events, such as earthquakes and volcanoes. For this reason, landforms are seen as a basic level of topographic taxonomy. Attribution in the forthcoming ontology will include process, for the description of their relation to each other and to other classes.

Surface Water

The topographic terms within the Surface Water class derive largely from DLG terms that are now incorporated in the National Hydrography Dataset (NHD). The taxonomy (table 2) differs from the NHD data model in the function of its concepts. The NHD data model has rules such that a surface water reach has common characteristics over the span that it covers. There are natural reaches composed completely of stream, or completely of lake/pond. There are artificial reaches composed completely of canal/ditch, or completely of pipeline, or completely of reservoir. This data model is appropriate for hydrological modeling, but ontologically, we separate natural and artificial features from specific functions. Recognizing that some ontological properties are shared despite this distinction, we maintain 'water surface,' 'reach,' and 'channel' as features that include natural and artificial features, based on hydrological properties. Some surface water features are regionalized, due to non-topographic factors such as climate (temperature/humidity), or geology. Wetlands are considered to be related to two taxonomic domains, water surface and ecological regimes.

Ecological Regimes

Only a small number and general types of regimes appeared in twentieth-century U.S. national topographic mapping. These were:

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- Tundra
- Desert
- Grassland
- Scrub
- Forest
- Pasture
- Cultivated Cropland
- Transition area
- Nature reserve

Natural/Artificial							
Reach							
hasPart: Bottom							
Channel							
Pond							
Basin							
Natural				**Artificial**			
Marine/Estuarine		**Freshwater**		**Impounded**	**Diked**	**Channel**	**Flow Control**
Cove		Watercourse	Waterbody	Reservoir	Levee	Siphon	Weir
Foreshore		Stream	Lake	Fish ladder	Embankment	Aqueduct	Lock
Flat		*hasPart*: Mouth	Ice cap (regional)		*hasPart*: Revetment	Canal	*hasPart:* Lock chamber
Ice field (regional)		*hasPart:* Source	Snow field (regional)		Dam	Flume	*hasPart:* Stram
Marine	**Estuarine**	*hasPart:* Streambed	Sastrugi (regional)		Masonry shore	Turning basin	Spillway
Ocean	Estuary	*hasPart:* Streambanks					Jetty
Sea	Bay	*hasPart*: Crossing					Breakwater
Gulf	Inlet	*hasPart:* Ford					Water intake
Submerged Stream		River					Pump
Shore		Creek					
hasPart: Shingle		Brook					
Shoreline		Arroyo					
Beach		Rapids					
Ice floe (regional)		Bend					
Polyna (regional)		Falls					
		Cascade					
		Waterfall					
		Innundation area					
		Spring					
		Mud pot					
		Geyser					
		Slope spring					
		Ice berg (regional)					
		hasPart: Iceberg tongue					
		Glacier (regional)					
		Crevasse (regional)					
		Wetland					
		Marsh					
		Swamp					
		Bog					

Table 2. Features and subclasses of the topographic class Surface Water. *hasPart:* refers to partonymic terms.

The land cover theme of *The National Map* of the USGS uses a modified Anderson Land Use Land Cover Classification System for image interpretation (Anderson and others, 1976). Other classification schemes of U.S. land cover or ecoregions have been developed, primarily through the use of remote sensing (Omernik, 1995; Bailey, 1980). These ecological regime classifications are based primarily on their user applications, so that no one system best reflects the observers' experience of the landscape on the ground. This taxonomy of topography aims to identify core or central concepts found in multiple systems. Such basic concepts and terms persist, for example, in semantic similarity studies of land use/land cover change (Alquist, 2008) and in topographical narratives. As complexes, ecological regimes may more easily be considered topographic feature types than features. These types are complex cognitive entities in addition to empirically detected physical land cover substances. The elements that ecological regime types share with land cover can be ontologically specified as well (Sorokine and Bittner, 2005).

Built up

The 17 subclasses of Built Up topographic feature class (table 3) were initially based on the U.S. Census Bureau North America Industry Classification System (Office of Management and Budget, 2007). Additional topographic feature classes that are not economically based were added to accommodate features from USGS data.

Transportation and warehousing	60
Entertainment and Recreation	26
Utilities	16
Resource Extraction	13
Structure	12
Agriculture and Fishing	11
Military	10
Communication	7
Waste Management	7
Real Estate	6
Place of Worship	6
Manufacturing	4
Institutions	3
Burial Grounds	3
Disturbed Surface	3
Trade	3

Table 3. Subclasses of the Built Up topographic class and number of features.

Because of the large number of transportation features, a table of topographic features in the Built-Up Area class appears at the end of this paper (table 4).

Divisions
The Divisions class (table 5) has three subclasses, Boundary (8 features), Civil Unit (31 features), and Shipping (6 features).

Civil Units		**Boundaries**
Cadastral	Nation	Fenceline
Parcel	Territory	Hedge
Public Land Survey System	Tribal reservation	Place
Land grant	State	Region
Homestead entry	County	Locale
Survey line	Census	Boundary line
Principle meridian	State	Boundary point
Baseline	County	Hydrologic unit
Survey point	Census county division	
Point monument	Block group	**Shipping**
Survey corner	Block	Lane
Government unit	Tract	Traffic separation scheme area
Municipality	Special use zone	Pilot water
City	Time zone	Roundabout
Town	Nature reserve	Inshore trafic zone
Villiage		Exclusive Economic Zone

Table 5. Topographic features of the Divisions class.

Events
The character of a taxonomy of events is not offered, but was anticipated because terms appear as a code list in the newest form of *The National Map*, the Best Practices data model. These Events terms fall within two subclasses, Security (8 features) and Historical Site (6 features).

Security		**Historical site**	
Hazard	Hazard zone	Military history	Archeological site
Earthquake	Incident	Historical marker	Cliff dwelling
Flood	Fire	Tree	Ruins
Area to be submerged	Restricted area		

Table 6. Events subclass features.

Conclusions
Preliminary examinations of legacy topographic feature terms indicate that a topographic feature taxonomy for national topographic mapping will require some particular semantic

software modeling solutions. Among these are models that accommodate a large number of polysemes (words with multiple, but related meanings), such as ‘arch’ ‘mouth,’ ‘pass,’ ‘stream,’ ‘chimney,’ or ‘dish’ or multivalents (words with multiple meanings), such as ‘wash.’ Special considerations of classes may be that they be based on regions or scientific processes of formation. Value categories must be clarified; for example, classes such as ‘barren land,’ may not be barren, just not being used, or ‘disturbed’ land, may be vegetated, but just weedy.

The limitations of the taxonomy lie in its ability to support science, which will depend on modeling geographical concepts to relate structures such as networks and complexes, and complexes and structures. Earth process cycles such as the hydrological cycle require representation as both processes and objects. The structure and extents of features such as mine and mineral prospect, hydrology and hydraulic engineering, may depend on symbiotic characteristics, such as those supported in ontologies and other semantic technology.

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Transportation/warehousing	Pedestrian Path	Ice rink	**Resource Extraction**	Holding pen	House
Aircraft facility	Piling	Launching ramp	Drill platform	Hopper	Mobile home park
Airport	Pilot waters	Marina	Energy sources	Range	Populated place
Anchorage	Port	Marine activity site	Kiln	Stockyard	**Place of Worship**
Approachway	Pump out facility	Park	Mine	**Military**	Basilica
Berth	Railway	Parking lot	Mine entrance	Ammunition dump	Cathedral
Boardwalk	Railway yard	Pier	Off shore	Base	Church
Bridge	Refueling track	Projection booth	Offshore platform	Bunker	Mosque
Bridge superstructure	Rest site	Racetrack	Oil field	Demilitarized zone	Synagogue
Cargo accomodation	Road	Recreation site	Prospect	Fort	Temple
Channel	Roundabout	Recreational slide	Shaft	Installation	**Manufacturing**
Control tower	Roundabout	Screen	Tank farm	Mine field	Cableway
Crib	Route	Ski Area	Well	Missle site	Chimney
Cul de sac	Runway	Ski jump	Well field	Proving grounds	Conveyor
Cut	Shipyard	Sports site	**Structure**	Zone of occupation	Industrial site
Draw span	Sign	Stadium	Arch	**Communication**	**Historical site**
Drydock	Toll plaza	Tennis court	Building	Antenna	Archeological site
Gantry	Traffic separation scheme area	Trailer park	Earthen structure	Antenna array	Cliff dwelling
Gentry	Trail	**Utilities**	Enclosure	Beacon	Ruins
Guard rail	Tunnel	Cable site	Fence	Post office	**Institution**
Hanger	Tunnel entrance	Dam site	Post	Radar dome	Hospital
Harbor	Turntable	Irrigation system	Pyramid	Radar reflector	Institutional site
Helipad	Underpass	Pipeline	Terrace	Signal	School
Inshore traffic zone	Warf	Pipeline site	Tower	**Waste Management**	**Burial Grounds**
Interchange	Watering place	Power site	Wall	Disposal Grounds	Grave
Intersection	Wind indicator	Powerlines	Windbreak	Disposal site	Graveyard
Landing place	**Entertainment/Recreation**	Pump	Wreck	Dumping ground	Tomb
Lane	Athletic Field	Pumpline regulation station	**Agriculture/Forestry/Fishing**	Filtration beds	**Disturbed surface**
Lane	Campground	Sewer	Agriculture	Filtration plant	Ditch
Launch pad	Cemetary	Solar collectors	Aquaculture site	Sewage Disposal Plant	Fire breaks
Mooring	Concession stand	Substation	Cultivated cropland	Wrecking yard	Trench
Off-road vehicular area	Drive -In Theater	Tank	Farm	**Real Estate**	**Trade**
Overrun stopway	Exhibition ground	Transmission Line	Fish hatchery	Building complex	Conference Center
Parking site	Golf course	Utility	Fish trap	Built up area	Shopping center
Passenger accomodation	Grandstand	Windmill	Fishing ground	High-denisty building area	Store

Table 4. Topographic features of the Built-Up Areas category. Features are listed in order under subheadings in bold read down and from left to right.