Landscape Features, Standards, and Semantics in U.S. National Topographic Mapping Databases

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Abstract—**The objective of this paper is to examine the contrast between local, field-surveyed topographical representation and feature representation in digital, centralized databases and to clarify their ontological implications. The semantics of these two approaches are contrasted by examining the categorization of features by subject domains inherent to national topographic mapping. When comparing five U.S. Geological Survey topographic mapping domain and feature lists, results indicate that multiple semantic meanings and ontology rules were applied to the initial digital database, but were lost as databases became more centralized at national scales, and common semantics were replaced by technological terms.** ***(Abstract)***

I. INTRODUCTION

Topographic mapping always has been characterized by a focus on landscape features. The local experience of a place involves movement among the landscape features with time and recording experiences cognitively and cartographically. Such experience takes the form of narratives, as symbols of the experience are recorded in some sort of order on a map. In national topographic mapping, the symbols and narratives of places initially were local, but tended to change towards the centralization of standards and data models after the implementation of digital technology and the end of field-based surveys. The difference between pre- and post-digital transition representation of features has significant ontological implications on language-based topographical narratives. The objective of this paper is to examine the contrast between local, field-surveyed topographical representation and feature representation in digital, centralized databases and to clarify their ontological implications. The semantics of these two approaches are contrasted by examining the categorization of features by subject domains inherent to national topographic mapping. Ontologies of landscape experience are reflected in legacy standards. When domains and feature lists of five U.S. Geological Survey (USGS) topographical mapping projects are compared, results indicate that multiple semantic meanings and ontology rules were applied to the initial digital database, but were lost as databases became more centralized at national scales, and common semantics were replaced by technological terms. In digital databases, data models serve as proxies for features, building ontologies of technological development, not landscapes. This finding indicates that the feature lists and data models tend to serve specific interests and not the diverse public. The findings indicate ways to expand topographic mapping feature semantics for diverse public use by expanding the geospatial ontology of the national topographic database.

The USGS began researching the ontology of feature-based topographical mapping with the assumption of digital technology the 1980s. In 2008, ontology research for *The National Map* aims to support data integration, natural-language based queries, and to prepare *The National Map* for the Semantic Web. Toward this end, important differences in geospatial ontology that resulted from technological transitions are being clarified. Before the transition to digital databases, 20th-century analog mapping features were collected by analogue photogrammetry and verified by field survey. The mapping unit was the quadrangle, completed one at a time, across government unit boundaries. This system balanced concepts of geography (a systemic mathematical spatial organization) and topography (the local knowledge gained by navigating and symbolizing the landscape). A regional focus, similar to chorography, was represented by agreements with states. The rules for data collection were specified in a series of publications called Technical Instructions (TI), printed in multiple editions from the early part of the 20th century to the time of the data standards published for national databases. Though the TIs were used as standards, regional field offices modified these texts to suit their specific regional interests. Revised versions exist, particularly from western field offices of the United States, often on the subject of water management. TIs were published at the centralized,

national-level office, but modified at local field offices as outcomes of production experience and compilation. These instructions were sufficiently general to allow detailed interpretation in mapping practice at the field office. The final maps varied in their representations of feature types, especially with time. Data collection practice details were added via a narrative vehicle called 'memos' between field and national offices. Variations and testing of mapping techniques were negotiated and modified via memos issued from regional field mapping centers. For example,

> To clarify any misunderstanding, the 1.5 meter contour to be added on all metric Great Lakes shoreline quads is the first regular contour [above the shoreline], not a contour 1.5 meters above the lake elevation (William Mengel, USGS, written commun., 1981).

Combined, the paper maps, memos, and TIs remain a record of the variable cartographic interpretation of the United States from place to place.

With the technological transition to digital mapping, a more centralized standard concept of national topographic cartography emerged. The rise of digital databases in USGS mapping introduced the need for consistent feature coding at the national scale; a single national database strengthened centralized standardization of feature lists. Feature lists that populated the database were changeable inventories for specific practices, such as cartographic data collection, digital database centralization, interoperable programming, or defining national infrastructure standards, not landscape or user diversity. Different feature classification schemas were designed, however, to serve various systems and agencies. The U.S. Federal Government took no position with respect to feature classification, and there are no single officially sanctioned lists or definitions. Lists were designed for, and have proven useful to, separately intended applications. In a move toward technical integration, digital database design concerns came to focus on data sharing, interoperability, and similar concepts.

II. DOMAIN AND FEATURE LIST STANDARDS

Five USGS-related projects addressed feature lists and their categorization; the Committee Investigating Cartographic Entities, Definitions, and Standards (CICAEDAS) of the enhanced Digital Line Graph data (DLG-E), completed in 1988 [4]; the feature-based Digital Line Graph data (DLG-F) in two versions, [7] and [8]; Spatial Data Transfer Standard (SDTS) [3]; Federal Geographic Data Committee (FGDC) Framework Standards [2]; and Best Practices Data Model of *The National Map* [9].

The initial digital conversion of topographic map data from the original 'once-over' mapping period was called DLG-3. DLG-3 was accomplished through structured digitizing of cartographic features with topology [4]. DLG-E proposed multiple 'views' of feature classification, analogous to ontological domains and contained hierarchical classification that resemble ontology concepts. These classifications implied roles between shared features. Multiple features derived from these views could occupy the same location; some features were shared under multiple views. Additional sub-views were developed based on the Level I land-use and land-cover categories described by Anderson and others [1]. The reasoning behind the categorization hierarchy was attribution [6]. The level of hierarchy with the most attributes that were independent of others was recognized as the base level, with a superstructure level and sub types as further attribution. Spatial objects were assigned topological relations, such as "adjacent" or "inside," with corresponding coordinates, but temporal objects and relations were not defined.

DLG-E shared many of the same feature types with the Spatial Data Transfer Standard (SDTS). The Federal Information Coordinating Committee for Digital Cartography (FICCDC) was organized in the 1970s by 17 Federal government agencies to facilitate digital data sharing by establishing the Federal Geographic Exchange Format (FGEF). The FGEF was expanded into the SDTS for users beyond Federal government agencies. Two hundred entity types were defined for topographic and hydrographic mapping, and two levels of categorization or geographic feature themes were organized between them.

DLG-E was never formalized into data models, but a version of DLG-E intended for implementation was developed called DLG-F. DLG-F (F for features) decoupled the database from graphic map production that opened possibilities for modifiable feature manipulation. The standards were widely reviewed and comments were incorporated in drafts [7]. The map revision guidelines for DLG-F provided special instructions for conversion of data collection to data models, but technical questions often were complex. The difficulty of translating technical analysis into data models led to requests that the instructions be provided verbally, rather than in system notation. These revised drafts of DLG-F

database standards appeared in 1998 [8]. The hierarchical classification of features present in DLG-E was eliminated, and features were categorized into roughly equivalent data 'themes,' an organization of data compatible with geographic information system data layer themes.

The FGDC Framework standards were developed in partnership with multiple agencies for data publication on the National Spatial Data Infrastructure. FGDC partners address traditional topographic mapping domains, such as transportation, hydrography, government boundaries, geodetic control, and elevation. When compared to the DLG-E, the FGDC Framework standards have thematic layers comparable to each of the DLG-E Views except Ecosystem.

The Best Practices Data Model for vector data is the current (2008) template for *The National Map*, the USGS web-based, 21st-century topographic map. The user domains of *The National Map* focus on earth processes and land cover, political and land management divisions, and hazard and security events. The Best Practices Data model was developed in partnership with Environmental Systems Research Institute (ESRI) in response to the content definition specifications from the Department of Homeland Security. The requirements were implemented into vector data themes of *The National Map* as Foundation and Operation data groups. Foundation data are base, reference data; operational data are organized by disaster management and are event-based. Although the data model was intended to encompass hazardous events, the Best Practices data model is not time-based, thus limiting the ontology roles and events that feature instances can assume. Features and events are recorded as feature type layers within themes, where selected feature instances are stored collectively as a single group. Developing the ontology of *The National Map* is critical for web-based implementation and to reach novice users.

III. ANALYSIS

To achieve process-oriented functionality in topographic mapping, such as data translation and generalization, features must be conceptually integrated for their logical cohesion. To align basic feature types and superordinate feature layer headings for comparison, they were entered into a spreadsheet and compared using separate worksheets for thematic domains. Subordinate feature types and attributes of type that closely resemble basic feature types were omitted. Findings were derived from visual inspection of these comparative lists.

The first three mapping projects, the SDTS and the DLG-E and DLG-F feature lists, stemmed from the field-based topographic mapping program. The FGDC Framework standards were developed in partnership with other Federal data producers to serve perceived digital data efficiencies by unifying efforts and avoiding duplication. Similarly, the Best Practices Data Model, the vector data for *The National Map*, was developed to integrate local and national hazard and security information.

TABLE I. A COMPARISON OF LAND COVER DOMAINS IN USGS MAPPING PROJECTS.

DLG-E (1988)	**DLG-F (1993)**	**FGDC Framework (1998)**	***The National Map* (2004)**
Cover			Cover
Cover - Barren Land	Non-vegetative surface cover		
Cover - Built up - Structure	Built up		Structures
Cover - Built up - Complex			
Cover - Built up - Utility			
Cover - Built up - Network	Transportation	Transportation	Transportation
		Transportation-Base	
		Transportation-Rail	
		Transportation-Air	
		Transportation-Transit	
		Transportation-Roads	
		Transportation-Waterways	
Cover - Cultivated Cropland			
Cover - Vegetation	Vegetative Surface Cover		
Cover - Water	Hydrography	Hydrography	Hydrography

TABLE II. A COMPARISON OF SURVEYS DOMAINS IN USGS MAPPING PROJECTS.

DLG-E	DLG-F	FGDC Framework Data	*The National Map*
Division	Boundaries	Government Unit Boundaries	Governmental Units
Division-Administrative			
Division-Boundary			
Division-Census			
Division-Hydrologic Unit			
Division-Land Parcel		Cadastral	
Division-Locale			
Division-Maritime			
Division-Political			
Division-Survey System	Public Land Survey System		

A comparison of domains was compiled from four data sets – two derived from topographical mapping, and two from Federal partnerships. (SDTS presented no domain names, though features could be grouped that way.) Initially, there is a broader classification of topographical structures and vegetative cover in the DLG-E feature list (Table I).

In the partnership projects, FGDC and *The National Map*, there is a greater simplification and emphasis on transportation. Like transportation, hydrography is represented through all domain sets. Land-cover classification as an organizing principle for the "Cover" features in DLG-E was abandoned in DLG-F. Instead of water land cover, DLG-F added a separate hydrography theme. Other land-cover categories were transferred from land cover, based on measurement and description, to morphology, based on earth processes or on themes of type of cover; vegetative, non-vegetative, or others.

The focus on land cover limited the feature list toward measurement and description, and away from processes of the physical landscape and natural resources. The latter perspective is central to land management and conservation. Initially, the "Cover" view in DLG-E was more complex than the "Ecosystem" view. Many land covers are now recognized as ecosystems. The departure of categorization from land cover may be in the indefinite feature outlines and character of land cover. The indeterminate boundaries of these systems may have posed an obstacle to implementation. Features with indefinite boundaries and based on continuous data, such as landforms, will require other classification methods.

In surveying-related domains (Table II), features derived from topographic mapping had a wider array of land divisions. Partnership projects specified government unit boundaries.

In earth process-related domains, ecosystem was abandoned quite early (Table III). Morphology changed first to named landforms and then elevation. Geoposition domain eventually was abandoned in favor of digital orthoimagery, often used to digitize vector data. The different views showed inconsistencies in scale and detail, partially because of a lack of a well-structured hierarchy of ontology levels. For views such as "Ecosystem," only general and broad labels are applied compared to built up land cover, which maps to the detail level of a tree trunk in a body of water (Snag), or "Morphology," whose land form features mainly are at a middle level, ranging between the local and regional scale. Greater partnerships with agencies outside of the USGS show feature lists with increasing focus on development and land management, and less attention on ecosystems and natural land formations. The DLG-F feature catalogue, emerging from topographic mapping,

TABLE III. A COMPARISON OF EARTH PROCESSES DOMAINS IN USGS MAPPING PROJECTS.

DLG-E	DLG-F	FGDC Framework	Best Practices Data Model
Ecosystem			
Morphology	Named Landforms	Elevation	Elevation
	Hypsography		
Geoposition		Geodetic Control	
		Digital Orthoimagery	Digital Orthoimagery

TABLE IV. SECURITY DOMAIN IN USGS *THE NATIONAL MAP*.

Ops_IncidentLine
Ops_AccessLine
Ops_SearchRescueLine
Ops_SearchRescuePoint
Ops_IncidentPoint
Ops_AccessPoint
Ops_EmergencyFacility
Ops_IncidentArea
Ops_AccessArea
Ops_SearchRescueArea
Ops_AlertArea
Ops_ResourceAssignment
Ops_DamageAssessment

retains representation of hydrography, elevation, and ecosystems.

Security never was identified as a domain of national topographic mapping, but a new 'view' emerged in the Best Practices data model addressing security (Table IV). The historical relation between national topographic mapping and defense mapping sometimes was not articulated, except as agency partnerships. In the Best Practices data model, specific thematic layers address risks and hazards. Although security considerations historically were relevant to topographic mapping, their representations were discreet, perhaps because of the research needed to collect the information, or because hazards and emergencies occurred rapidly and mapping data maintenance could not address those events. The forms of these feature types often are event-based, short-term temporal periods.

IV. CONCLUSIONS

Several implications result from the reorganization of feature lists and categories from field-based surveys to public GIS data sources. The layers do not accommodate sub-types of features. The DLG-E feature list was the only project to use hierarchies of multiple levels. All following data model projects were flat, or organized by a theme. This limited the transformation of features across scales that ontology strives to recreate.

TABLE V. LANDSCAPE FEATURE TERMS COMPARED TO TECHNOLOGY FEATURE TERMS.

DLG	**Best Practices**
Cable/Pipeline Site	Util_Line
Dam Site	Util_Point
Substation	Util_Structure
Pipeline Regulation Station	Util_Area

Many features play more than one role in the data models and feature lists that emerged from the USGS topographic mapping (SDTS, DLG-E, and DLG-F) and in data models derived with multiple partners (FGDC Framework and Best Practices data model). Features that are ambiguously natural or artificial or areas formed by changing divisions, cover, or use, are not differentiated by change with time, as a critical component toward defining multiple ontological roles. Events offer long-term applicable information when recorded with time.

The number of geographic perspectives in the form of layers and feature types increased between DLG-E and Best Practices, but included fewer features and more layers that were defined by data model type. For example, joining DLG feature data with U.S. Environmental Protection Agency Reaches, the dataset allows features, events, and measurements to be added to the base data content, increasing user focus on the data model type, and less on features themselves. Features from analogue topographic mapping were organized primarily as real-world entities, with secondary aspects of technological data model. Feature codes in FGDC and thematic layers in Best Practices more often primarily higher-level categories or aspects of the data model.

Cognitive studies of object classification show that humans initially categorize on the basis of physical experiences, basic shapes, and common-language terms [5]. For this reason, geospatial feature classification by code lists impedes the integration of data categories that are most well-known among the public and are most widely understood by relying on semantic information that is obscure and semantically non-specific. Though semantic meanings may be defined in accompanying metadata, geospatial database classifications based on data-model types tend to serve a smaller community of technological professionals and their purposes rather then public users participating in experiences on the land.

5. References

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