A reference landform ontology for automated delineation of depression landforms from DEMs

Gaurav Sinha[1], Samantha Arundel[2], Kathleen Stewart[3], David Mark[4], Torsten Hahmann[5], Boleslo Romero[6], Alexandre Sorokine[7], Lynn Usery[2], and Grant McKenzie[3]

[1]Ohio University; [2]Center for Excellence in Geographic Information Science (CEGIS), USGS; [3]University of Maryland; [4]University at Buffalo, SUNY; [5]University of Maine; [6]University of California, Santa Barbara; [7]Oak-Ridge National Laboratory;

GeoVoCamps provide a forum for building ontologies or controlled vocabularies for tractable knowledge domains. This paper reports initial findings from a GeoVoCamp meeting held in College Park, MD in November 2016 to guide the US Geological Survey with its design of a conceptual reference ontology to support natural language topographic information retrieval and context-sensitive algorithms for user-controlled automated delineation of cognitively salient landforms (e.g., hill, mountain, valley). Thus, reusing concepts from the *surface network* (SN) and *surface water feature* (SWF) terrain ontologies that resulted from previous GeoVoCamps was the first step at this GeoVoCamp meeting. The SN ontology (Sinha et al. 2015) formalizes the minimum mereotopological semantics for describing the shape of a surface. The SWF ontology (Sinha et al., 2014) formally distinguishes between terrain features that act as containers (channel, depression, and interface) and the contained bodies of water (stream segment, water body, and fluence).

The primary category of this reference ontology is *landform*, which represents entities that are 3-dimensional features hosted by the solid surface of the Earth or similar planetary bodies. Landforms may be assigned some characteristic geometric, topological, mereotopological, temporal and material *properties*. Knowledge of the *agents* and types of *processes* that create landforms or in which landforms participate should also be specified when possible to support geoscientific conceptualizations. However, because this is a reference ontology intended for broad usage in both scientific and naïve geographic contexts, only a few landform properties that people can intuitively sense and cognize are used to define the top level categories.

Based on the most important intuitive criteria of form (shape), landforms are subdivided into three mutually exclusive categories: *convex landform*, *concave landform*, and *plane landform*. Convex landforms protrude outward or upward from the surface. *Eminence* covers an important sub-group of convex landforms (e.g., mountain, hill, butte) that stand above their surroundings. Eminence ontology is still being developed as part of another project. The reference landform ontology described here is focused on helping delineate *depression landforms* (defined below).

In contrast to convex landforms that protrude out, concave landforms are indented or host holes, giving rise to a sense of material missing from the surrounding host surface. The most significant subcategory of concave landforms is *depression landform* which span low-lying areas surrounded by higher land (e.g., basin, river-bed, valley). Examples of concave landforms that are not depressions would be caves or tunnels. Depression landforms can be further classified as *closed* or *open.* Note that the *closed depression landform* category specializes the *SN:Basin* category and is conceptually identical to the *SWF:Depression* category. For terminological simplicity and specificity, in this reference ontology, the term *depression landform* refers to the superordinate category of *all* depressions. Whereas, a *closed depression landform* is surrounded by higher ground, and has, as part, one level rim (represented by a *SN:contour*) marking the depression's upper edge, one pour point at the level of the rim, and a wall or basal surface that is impermeable enough to allow water storage. In sufficiently wet conditions, closed depressions store water and maybe perceived to host still water bodies (e.g., puddles, lakes, ponds).

All other depressions are examples of *open depression landform* because they lack either an enclosing rim or their basal surface is impermeable, and, therefore, these depressions cannot store water (e.g., sink-hole). Both open and closed depressions can be further categorized by shape. The named sub-category, *open-longitudinal depression landform*, reflects the importance of elongated open depression landforms (e.g., valley, canyon, ravine, canal, trench, fissure, fault) that are frequently referenced in natural language. These depression landforms have a primary, sloping longitudinal axis bounded by upward sloping sides, and are generally open at both longitudinal ends. In wet conditions, they contain or host flowing bodies of water (e.g., rivers, streams). Most instances of the *SWF:Channel* category are examples of and also parts of instances of *open-longitudinal depression landform*.

How can such a conceptual reference ontology help in landform delineation? Its usefulness lies in specifying a controlled vocabulary and categorical relationships and properties that can help in reasoning about which automated delineation tools must be chosen or which type of landforms can be delineated. For example, delineation of closed and open depression landforms requires different methods. Valley, canyon, gorge, ravine, gully, hollow, gulch, chasm, rill, canal, and trench in the English language are possible sub-categories of *open-longitudinal depressions*. Differentiating between instances of these types maybe quite challenging, requiring detailed 3D morphometric measurements, and even knowledge of agents and processes. If such specific information is not available, at least, based on semantic similarities (e.g., canyon/gorge, gully/gulch), delineation requests for one related category could return instances of all related categories, or recommend searching for only the superordinate category and manually processing results. Geoscientific classifications, on the other hand, may be more precisely specified and supported for delineation. Linking this reference ontology to the SN and SWF reference terrain ontologies extends inferencing capabilities about when or how to delineate. For example, a search for lake boundaries can be automatically inferred as also requiring delineation of a closed depression landform. Finally, ethnophysiographic research (Mark and Turk, 2003) has shown that many ontological commitments about landforms exist. Thus, diverse validations methods including multilinguistic, multicultural and multimodal (e.g., using text, maps, photos, videos) human subject experiments are needed to support more specialized categories and to test the validity of results from delineation methods guided by this reference ontology.

References

Mark DM, Turk AG, (2003). Landscape Categories in Yindjibarndi: Ontology, Environment, and Language. In: LNCS 2825, 28-45. Springer, Berlin, Heidelberg.

Sinha G, Mark DM, Kolas D, Varanka D, Romero BE, Feng C-C, Usery LE, Liebermann J, Sorokine A (2014). An Ontology Design Pattern for Surface Water Features. In: *LNCS 8728*, Springer, 187–203.

Sinha G, Kolas D, Mark DM, Romero BE, Usery LE, Berg-Cross G, Padmanabhan A, (2015). Surface Network Ontology Design Patterns for Linked Topographic Data. *Revised manuscript to be submitted to Semantic Web journal*.