Ontology of Landforms: Delimitation and Classification of Topographic Eminences

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INTRODUCTION

A landform is a shape-based part of the Earth's surface, occupying a finite region, and which has some degree of perceptual or functional coherence of shape. This definition has some circularity: an arbitrary region is unlikely to contain topography that has a coherent shape, yet without specifying the region in advance, there is no object for which shape can be determined. Thus, land surface shape and landform boundary are mutually dependent. Smith and Mark (1998) observed that "geographic objects are not merely located in space, but are tied intrinsically to space in a manner that implies that they inherit from space many of its structural (mereological, topological, geometrical) properties." In the case of landforms, the shape of the landform is inherited from the form of the Earth's crust.

In information systems, an ontology provides a formal specification of a conceptualization (Gruber 1993). A taxonomic tree of basic entity types and their organization into superordinate categories and refinement into subordinate or included types often forms a central part of such an ontology. For some domains, especially in biology, the entity types are well defined by nature. But for landforms, cross-cultural ethnographic comparisons of definitions have found cultural and linguistic differences in landform type definitions (Mark and Turk 2003). If the basic categories and even their relationships differ across languages, different taxonomic hierarchies may be needed for the same areas, one for each language or culture. If our goal is to provide on-line access to geographic information about any area of the world to speakers of any language, feature delimitation and classification procedures that can take any landform definition and extract instances from digital elevation data must be developed.

TOPOGRAPHIC EMINENCES

In this paper, we present first steps toward such a system by outlining a strategy for definition-dependent extraction of *topographic eminences*, that is landform features such as mountains and hills that stand above their immediate neighborhoods. Eminences are chosen as a landform subdomain for investigation because they are visually prominent. Perceptual characteristics such as size, shape, color, texture and material character may influence the perception and classification of eminences. Whereas shape and size alone may not always be sufficient to define eminence types completely, they are the most important factors determining how people perceive eminences. In this paper we focus only on *form*-based extraction and classification of eminences for categories commonly recognized in English.

DELIMITATION AND EXTRACTION OF EMINENCES

Quantitative terrain descriptors such as local relief, slope, aspect and curvature have been used to label locations according to a prescribed morphometric classification system. Such pixel labeling efforts can only detect localized features such as peaks, saddles etc., but are generally incapable of capturing the global footprint of massive landforms such as a hill or a mountain. Consequently, our approach is based on both field based descriptors and morphometric pixel classifiers to identify locations that can serve as cores and/or boundaries for eminences. For example, morphometric peaks or ridges can be good starting points for delimiting the top of some types of eminences, while regions of gentle slopes and planar curvatures are good candidates for the lower boundaries of eminences.

There are two ways to structure the extraction of eminences. The first is to develop *a priori* an ontology of eminences, which would entail listing the known eminence types and structuring them into a taxonomy. The taxonomy would then be transformed into a knowledge base with rules to search for and extract eminences of different types from digital terrain data. However, the taxonomies for kinds of eminences are likely to be shallow, and to differ across languages.

In the absence of a universally applicable landform description system, we propose to extract eminences based only on objectively determinable geometric criteria. No a priori classification of eminences into types is required. Wood (1996) identified morphometric peaks as representatives of eminences and later defined summit regions as inclusive of all points on the eminence within a user-specified elevation difference from the peaks (Wood 2004). A less subjective method for delimiting summit regions is prominence, which is defined as the elevation difference to the highest neighboring saddle.

While summit-driven eminence definitions may be relatively easy to implement, they do not provide methods to delineate the lower boundary of eminences. Slope and curvature can be used to locate the boundaries of eminences. Another alternative is to ‘reverse’ drainage accumulation algorithms and ‘assume’ that something is flowing uphill; this simple logical switch will enable extraction of ridges and peaks of a sort.

Our approach combines such methods, detecting candidate eminences whose shapes can be parameterized to account for variations in physiographic conditions or cross-linguistic variations in categories.

CLASSIFICATION

Once eminences are extracted, they can be classified based on properties such as:

i) *Morphographic character*—shape, size, position, orientation
ii) *Spatial relationships*—proximity, prominence, topology
iii) *Visual signature*—viewshed statistics, angle of depression/elevation, visual prominence.

A combination of these characteristics can be determined for eminences extracted by the methods sketched above, and a parameter space can be used to determine whether eminences vary continuously or cluster into types. Clusters of eminences can help identify natural groupings based on form attributes and relationships. A lack of clear clusters would suggest that landforms form continua and do not form 'natural kinds', but that landform categories are based on perceptual and utilitarian factors.

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