

A generic procedure for semantics-oriented landform classification using object-based image analysis

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Abstract—In most landform classification studies – either per cell or object-based – the authors have ignored modeling the semantics of landforms explicitly. Thus, landform classification schemes rely on individual knowledge, and are too much tailored to specific areas and/or scales. Integration of structured knowledge models in the classification process has been proposed to overcome the limitations in transferability. We are working towards a general procedure for flexible hierarchical landform classification in object-based image analysis (OBIA). This paper presents the conceptual framework, exemplified by landforms of the glacial domain. The methodology includes (1) definition of interoperable concepts of glacial landforms, (2) segmentation-based derivation of characteristic geomorphometric object patterns from land-surface models (LSM), (3) formalization of concepts by applying semantic modeling, and (4) semantics-based extraction of quantitative and relational rules for interoperable hierarchical classification. In order to test transferability the extracted rule base will be applied to classify glacial landforms in several high alpine regions. Results will be evaluated by experts and, in addition, compared to reference maps. The proposed semantics-based framework will enable the derivation of interoperable classification rules as well as the exchange of glacial landform knowledge. Moreover, links between qualitative landform hierarchies and geomorphometric object hierarchies are provided. The semantic model may define a standard for semi-automatic reproduction of glacial landform classifications in OBIA. Results thus become comparable and independent of both the user's perspective and the spatial quality of LSM. The model can easily be extended to include landforms of other domains.

I. INTRODUCTION

Classification and extraction of landforms at multiple scales is a major research topic in geomorphometry. Object-based image analysis (OBIA) has gained increasing attention in landform research in the last decade [1], [2], [3]. Applying OBIA in geomorphometry offers four main advantages: Firstly, the processing units are geomorphometric objects that – in compa-

– rison to geomorphometric points (e.g. the grid cells of a DEM) – better relate to real landforms [4]. Secondly, objects may be created in a spatially concurrent multi-scale structure, thus enabling hierarchical modeling of landforms. Thirdly, knowledge about landforms in terms of morphometry, morphology, and topology can be incorporated in the classification process. Fourthly, OBIA allows integration of different data types and formats as separate layers (e.g. DEMs and remote sensing images in raster format, geological structure as vector layer) [3].

Especially the third aspect, the knowledge integration, is problematic and needs further attention. In many object-oriented landform studies the authors have neglected to model the semantics of landforms explicitly prior to classification [2], [3]. Only partial knowledge according to the academic background and/or preferences of the authors has been employed to classify geomorphometric objects. Thus, classification systems have been tailored to specific areas and data scales. Transferring the system to a different area or scale would involve time-consuming adaptation of rule sets.

In order to achieve higher transferability of semi-automated landform classification approaches it is essential to develop and apply structured knowledge models that capture the existing knowledge of a domain in a formalized way [5]. Semantic modeling has been proposed as a strategy to link conceptual frameworks with computer-based terrain representations [6].

The presented work is part of an ongoing PhD research aiming at providing a general procedure for semantics-based hierarchical landform classification in OBIA. The main objective of this paper is to introduce the conceptual framework, exemplified by glacial landforms. The proposed framework is structured into the following four steps (Fig. 1):

- (1) Identification and characterization of glacial landforms,

- (2) Derivation of meaningful geomorphometric object hierarchies from land-surface models (LSM),
- (3) Semantic modeling, and
- (4) Hierarchical landform classification, validation and testing.

The ultimate goal of such an endeavor is to define and classify landforms from DEMs in a similar way as humans do it from their surroundings [7].

II. METHODOLOGY

A. Identification and characterization of landforms

Landforms of the glacial domain are identified and conceptualized. Due to the absence of universal landform definitions one finds many different definitions for the same form in the literature resulting in semantic heterogeneity [8] (Tab. 1). Therefore, we acquire several definitions for each form referring to knowledge sources such as textbooks and scientific articles, encyclopedias as well as online databases (e.g. WordNet). Usually, landforms are specified by morphometry and morphology, by function, and by contextual setting. The semantic contents of the various descriptions are systematically analysed to extract the set of facts that is shared within glaciology and geomorphology. Based on the common facts the final concept for a landform is specified, incorporating at least the “semantic core” that is defined by size, shape, and context [6], [7]. Such a strategy increases the interoperability of concepts for their application.

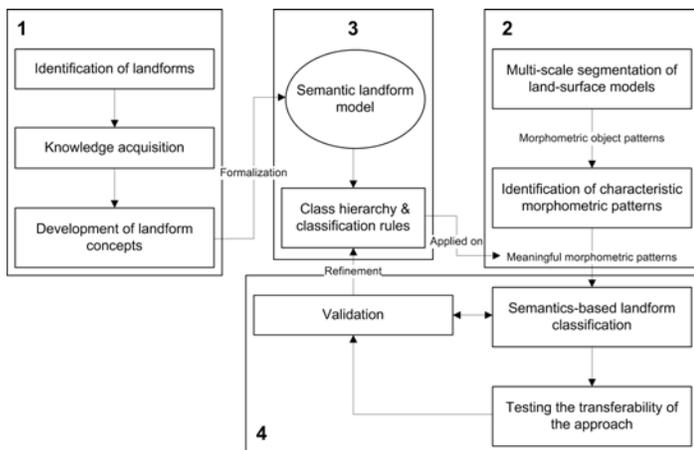


Figure 1. The methodological workflow consisting of four stages: (1) Identification and characterization of landforms, (2) Derivation of meaningful geomorphometric object hierarchies from LSM, (3) Semantic modeling, and (4) Hierarchical landform classification, validation and testing.

TABLE I. SEMANTIC HETEROGENEITY OF *GLACIAL CIRQUE* DEFINITIONS

Source	Definition
Bitters [9]	A deep, steep-walled, flat or gently floored, half-bowl-like recess or hollow, situated high on the side of a mountain and commonly at the head of a glacial valley, and produced by the erosive activity of mountain glaciers.
Evans [10]	A hollow formed at glacial sources in mountains and partly enclosed by steep, arcuate slopes (headwalls).
WordNet ^a	A steep-walled semicircular basin in a mountain; may contain a lake.
SDTS ^b	A deep natural hollow near the crest of a mountain.
ADLFTT ^c	A horseshoe-shaped, steep-walled valley head caused by glacial erosion.

a. <http://wordnet.princeton.edu/>

b. Spatial Data Transfer Standard
http://mcmeweb.er.usgs.gov/sdts/SDTS_standard_nov97/p2anxa.html#342523

c. Alexandria Digital Library Feature Type Thesaurus
<http://www.alexandria.ucsb.edu/gazetteer/FeatureTypes/ver100301/>

B. Deriving meaningful geomorphometric object hierarchies

Multi-resolution segmentation (MRS), a bottom-up region-merging technique as implemented in eCognition Developer 8¹, was applied to produce geomorphometric object patterns from LSM. MRS iteratively performs pair-wise clustering of neighboring objects (respectively cells at the initial level) based on the two optimization principles of minimizing internal heterogeneity of objects while maximizing their external heterogeneity [11]. Thus, for an object A and for the set of possible merges of object A with one of its neighbors B, C, D, etc., the merge that causes the minimum increase in heterogeneity in both directions is determined (= local mutual best fitting, e.g. A→C, C→A). If this minimum increase is below an user-specified threshold (scale parameter), the merge is performed, otherwise the object stops growing. Heterogeneity is defined in terms of both morphometric value and shape characteristics of the object. Weights have to be set that indicate the relative importance of both criteria for MRS. According to our recent experiences, segmentation of LSM delivers better results when shape influence is omitted. The value attached to a geomorphometric object is calculated as the mean of cell values that compose the object

We produced consecutive coarser geomorphometric object patterns from LSM by constantly increasing the value of scale parameter. In order to identify significant patterns that best represent a group of real-world landforms the statistical measure of local variance (LV) was calculated for each pattern. LV seems to be a valuable method for analysing the spatial arrangement of geomorphometric objects at different aggregation levels, as has been envisioned by [4]. Peaks and steps in the plotted scale signature of LV indicate the most relevant scales for the hierarchical landform modeling [12].

¹ <http://www.ecognition.com>

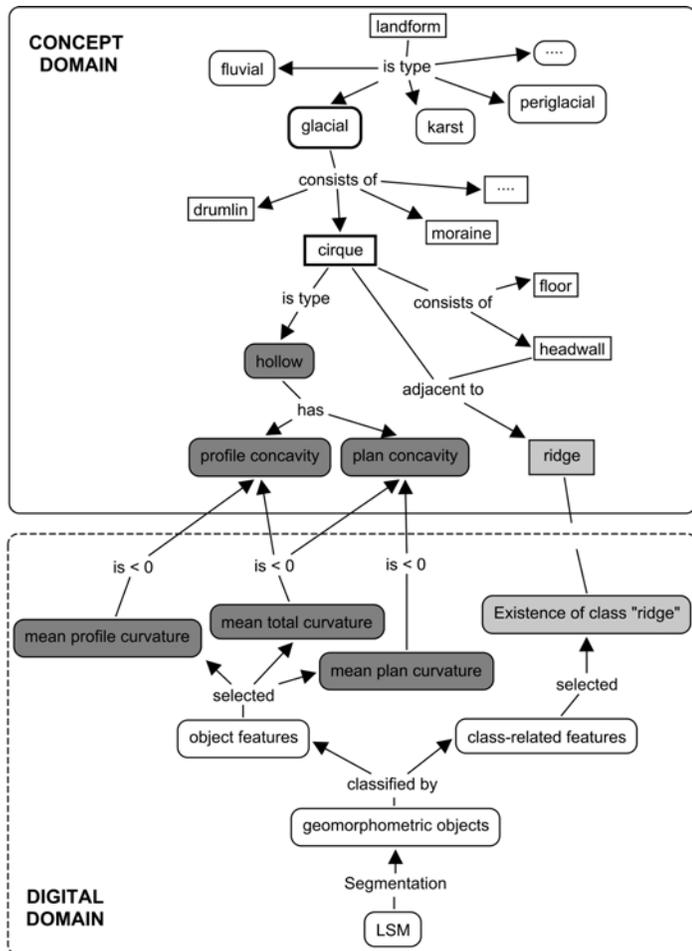


Figure 2. Semantic model of the 'glacial cirque' concept integrating morphologic knowledge (dark grey boxes) and context information (light grey boxes).

C. Semantic modeling

Semantics is defined as “the relationship among computer representations and the corresponding real-world feature within a certain context” [8]. Formalization of landform semantics relies on the previously established principles of semantic modeling of landform structures [6] and presents the core of the methodology. The semantic landform model provides the necessary links for relating the characteristic geomorphometric object hierarchies of LSM with the verbally conceptualized geomorphological knowledge of glacial landforms. Furthermore, the proposed model facilitates the matching of formalized landform facts (e.g. shape and context information) with the corresponding features (e.g. mean profile curvature) in the digital domain (Fig. 2). Features in OBIA are geometrical and relational descriptors

that can be derived for either individual objects (object features) or a group of objects (class-related features). The semantic model guides the user through the crucial step of selecting the appropriate set of features (out of the several hundreds) that should be used for the specification of objective and transferable classification rules [13].

There are several ways to create a semantic landform model that vary in the degree of formalization. We base our semantic model on the concept map approach (Cmaps) as originally introduced by [14]. Cmaps are two-dimensional graphical representations that structure the knowledge of a domain in a hierarchical manner. Thus, it is well-suited for capturing the conceptualized knowledge facts of glacial landforms.

D. Landform classification, validation and testing

The class hierarchy and rule base as extracted from the semantic landform model will be the basis for the hierarchical semantics-based classification of glacial landforms from LSM in OBIA. The system will initially be applied to a high alpine study area.

If the test classification satisfies certain quality criteria the methodology will be applied to other areas with similar terrain characteristics. Thus, the transferability and area sensitivity of the approach will be examined.

Validation of classification results has been acknowledged a general problem in OBIA. Therefore, our evaluation approach will be twofold: We will publish classification results via a map server. Invited experts will be asked to validate the quality of results by filling a form. Additionally, we will compare classifications with digitized landform maps from fieldwork.

III. RESULTS

The research towards developing a general framework for semantics-based landform classification in OBIA is still ongoing. Main results will include the semantic model that explicitly represents the glacial landform knowledge and the way how high alpine glacial landscapes are subdivided and named by geomorphologists. Such a model will define a standard set of quantitative and relational rules for OBIA-based (semi)-automated reproduction of hierarchical landform classifications for high alpine glacial reliefs. Preliminary results for the extraction of glacial cirques and cirque components from curvature object patterns showed that the semantics-based methodology is well-suited for landform classification/extraction at local scales [15]. However, glacial cirques are just a first instantiation of the methodology.

IV. DISCUSSION

Semantics-oriented analyses are promising due to a closer relation with the domain logic [16]. This is especially valid for geomorphometric approaches, where the geomorphometric objects resulting from terrain segmentation have to be associated with knowledge and semantics to be transferred into meaningful objects. Through semantic modeling we link landform concepts with computer-based representations of LSM, thus making an attempt to integrate “*the qualitative ontology of landform objects and categories with the quantitative field-based ontology of DEMs*” [7]. The resulting model captures the “*semantic signature*” of landforms [5], which consists of morphometric, morphologic, and contextual attributes, enabling the derivation of interoperable classification rules as well as the exchange of landform knowledge [6]. Thus, results of landform classifications become comparable and more independent of the spatial quality of the LSM increasing the interoperability of the system dramatically. The proposed framework will not only be practical for geomorphologists, but may also be adopted by people having vague geomorphological background.

Although we are only at the beginning of a long-term research, we anticipate that the presented procedure will pave the way for object-based terrain analysis (OBTA) incorporating knowledge and semantics.

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