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OBJECT-BASED ANALYSIS OF REMOTE SENSING DATA FOR LANDSCAPE MONITORING: RECENT DEVELOPMENTS

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Abstract. Environmental remote sensing is dominated by land use and land cover classifications. Different land cover features reflect electromagnetic radiation in different ways and remotely sensed images provide a basic and synoptic representation of land cover variation on the Earth's surface. The pixel based analysis has been 'the holy grail' for many years. Land-based features may be categorized according to land cover classes (e.g., grass, concrete, water, etc.) but not likely according to land use classes (urban park, golf course, etc.). Only contextual information allows to encountering spatial relationships, object shapes or neighbourhood information. Even where land cover information is not the ultimate goal of remote sensing studies, it is often a useful aid for further analysis. This Progress Report will focus on one recent development in land cover research, namely the advent of object-based image processing. We report on the rapid diffusion of this approach and critically discuss the possibilities and methodological shortcomings. We discuss that tangible objects are desirable in many applications and conclude that many environmental management applications necessitate the control and use of object-based land cover distributions – in the opposite to pixel-based pattern - to exploit land resources while safeguarding environmental concerns.

Keywords: remote sensing, landscape monitoring, object-based image analysis, image segmentation, image classification.

1. Introduction

It is widely recognized that it is essential to assess and monitor ecological resources objectively in order to formulate appropriate rural policies. Satellite imagery and aerial photography are the principal ways in which land use data can be collected. Satellite imagery has the advantage of synoptic coverage but usually, at a relatively low level of detail. The new "1m-generation" does however contain much greater detail. Aerial photography is able to provide more detail at a local level, whereas field survey, whilst expensive and time-consuming, provides detailed information which will allow analysis of species composition. Thus, the first two approaches are primarily powerful for estimating the extent, and the latter for estimating the quality of the features concerned (Brandt et al., 2002).

Two perspectives seem to be important for an understanding of complex environments and spatio-temporal processes. Firstly, although there is no single correct scale to describe a system, not all scales serve equally well. A majority of ecological research focus on small study areas. The second, highly interrelated aspect is the spatially explicit approach founded largely on computer-based tools, namely GIS and remote sensing. At the landscape scale not all relevant processes can be measured and monitored directly. Therefore indicators are used and land use and land cover very often serve as a 'super indicators', although this hypothesis is usually implicit rather then formulated explicitly. Throughout the world, land cover today is altered principally by direct human use such agriculture, rising of livestock, forest harvesting, settlement, road construction, or mining activities.

These activities also change landscape structure by altering the mosaic of natural habitats and human introduced land cover types and by changing the shapes of single entities and by intensifying gradients between spatial entities. This may lead to more complex situations or to monotone structures if the latter, the human-introduced features dominate and exhibit a low internal heterogeneity. But what exactly is spatial complexity and what role does spatial heterogeneity play? These questions are not only of scientific interest. The European Landscape Convention seeks to conserve 'traditional landscapes', their specific characteristics and Europe's diversity. It aims to provide guidelines for a diversified management of European landscapes. Clearly, the concept and meaning of the word 'landscape' has changed through time, landscapes are increasingly being recognised as a fundamental part of our natural, historical, cultural and scientific heritage and it is acknowledged that they serve as the basis of our territorial identification. We start from the hypothesis that for remotely data based monitoring approaches we need more sophisticated ways to exploit contextual information and to allow for multi-scale investigations.

2. Landscape monitoring and scale implications

Since the start of the first civilian Earth observation satellite Landsat 1 a widely used analysis strategy is to assign the analysis and interpretation scale to the pixel dimension. This is regarded as being straightforward when the typical size of the objects of interests are in the range of the pixel dimension or smaller. A vast majority of applications rely on this basic image processing concepts developed in the 1970s: one spatial scale, per-pixel classification of a multi-scale spectral feature space. Burnett and Blaschke (2003) have argued that this methodology does not make sufficient use of spatial concepts of neighbourhood, proximity or homogeneity.

In high resolution imagery the user is challenged with the fact that what may have seen to be a relatively homogeneous forest canopy cover in a Landsat imagery may exhibit enormous internal variation in a Quickbird image. This requires a "zoom-out" perspective: in order to get an understanding the user tries to get a broader view including context information. Another aspect is object recognition and feature extraction: only recently these approaches which are common in specific applications e.g. road extraction, building reconstruction etc., are integrated into "wall-to-wall" classifications. A common denominator of both the geometric and the thematic aspects of object generation is that trends in computer vision also try to recognise objects in images by first isolating components of objects and the relationships between them (Sowmya and Trinder, 2000).

This multifaceted notion of landscape is a challenge to landscape monitoring. For land use and land cover as super indicators we do have hundreds of measures of the spatial arrangement of the constituting spatial entities of a landscape, sometimes called landscape metrics. A prerequisite is the dissecting of the whole at a chosen scale. Ecologists define scale as having two components: grain and extent. Grain corresponds to the smallest spatial sampling units used to gather a series of observations. Extent is the total area over which observations of a particular grain are made (O'Neill and King, 1998). It is more and more recognized that many processes in nature produce clusters of entities that are typically generated by a small set of self-organizing principals (Allen and Starr, 1982). These entities emerge at specific scales, and result in visually distinct spatial patterns.

Developing rules for identifying the 'correct' scale for a particular application is an important field of current research. Spatial statistics aims to identify scales through fractal analysis or multiple regression techniques (e.g. Gergel et al., 1999). Nevertheless, the identification of a suite of scales or multi-scale analysis is still a developing field. Similarly, issues of extrapolating to broader scales in space and time, or scaling up, continue to be a cutting edge of research in landscape ecology (Turner et al., 2001, p.40). The same is true for scaling down issues.

Complexity can best be explored using spatial analysis tools based on concepts of landscapes as continuums that can be partially decomposed into objects or patches. Complex systems are inherently multiscale systems. Thus to monitor, model, and manage our interaction within the landscape, we require appropriate approaches to assess the multiscale dynamics of such systems, and the ability to link these dynamics at multiple scales. But in practice even the first part, to analyse and describe multiscale pattern is crucial and not fully operational although various methodologies were suggested (e.g. Hay et al., 2001, 2002). Hierarchy theory was developed in the framework of general systems theory, mathematics and philosophy in the 1960s and 1970s (Wu and Loucks, 1995) as a conceptual framework that built upon the idea of natural scales. In general terms, a hierarchy may be defined as 'a partial ordering of entities' (Simon, 1973). The underlying idea is that ecosystem units are both objects and parts of objects at a higher level at the same time. This concept is central to Hierarchy theory, as described by Koestler (1967) and Simon (1973). These 'holons' or 'object-not-objects' (suggested by Burnett and Blaschke, 2002) are derived from theories of complexity, emergence, hierarchy, scale and non-linearity. Wu (1999) has synthesized this body of theory and added the patch-matrix ideas of Forman (1995), suggesting a 'theoretical framework' (paradigm according to Wu) called Hierarchical Patch Dynamics. The central tenets of HPD are summarized below:

- Ecological systems can be perceived as spatially nested patch hierarchies, in which larger patches are made up of smaller, functioning patches.
- The dynamics of a given ecological system can be derived from the dynamics of interacting patches at adjacent hierarchical levels. Patches at higher levels impose top-down constraints to those lower levels by having slower or less frequent processes, while lower levels provide initiating conditions and mechanistic explanations for, and give apparent identity to, higher levels through interactions among patches.

- Pattern and process have components that are reciprocally related, both pattern and process, as well as their relationship, change with scale.

Hierarchies are composed of interrelated subsystems, each of which in turn is made of smaller subsystems until a lowest level is reached. More formally, a hierarchically organized system can be seen as a nested system (Figure 1) in which levels corresponding with progressively slower behaviour are at the top (Level +1), while those reflecting successively faster behaviour are seen as lower levels (Level -1). The level of interest is referred to as the Focal Level (Level 0).

Burnett and Blaschke (2003) introduced a five-step methodology based on multi-scale segmentation and object relationship modelling. They built on the Hierarchical Patch Dynamics paradigm (HPD, Wu and Loucks 1995). Burnett and Blaschke adopted HPD as the theoretical framework to address issues of heterogeneity, scale and quasi-equilibriums in landscapes. Hay et al. (2003) compared different strategies to identify scales in spatial data and consequently evaluated different multiscale analysis methodologies. From these and other studies we conclude that the fixation to the pixel resolution as the one and only dimension seems to be a little bit limited.

3. Tangible objects – image segmentation

Usually, GIS representations of spatial phenomena and processes are discretized into spatial objects, raster or vector objects. The implicit modelling step behind is sometimes not documented: How are boundaries and objects created? Our discretization abilities are relatively effective so that we rarely have to think of a flux-gradient conceptualization of Nature. Instead we jump between scales of domain, treating them independently. But it takes human convention to discretize, discuss, compare and inventory objects. Thus, it is doubtful that there are any a priori objects in our ecological theory-based system, scanning electron microscopes and satellites, are relative and biased: prejudiced by their spatial, temporal and spectral characteristics (Burnett and Blaschke, 2002).

The conceptual models currently employed for digital geographic data analysis and representation do not incorporate any explicit consideration of how humans cognitively use geographic knowledge. While a number of GIS researchers have explored characteristics of cognitive representation and conceptual modelling (e.g. Mark and Frank, 1996), they have not extended their findings into a usable framework for landscape analysis. Burnett and Blaschke (2003) demonstrated the utility of the HPD framework as a theoretical basis for a multi-scale object based landscape analysis and extend it to remote sensing data in an integrated GIS/remote sensing software environment. Introducing GIS functionality in image processing is considered as one step to overcome the classic ‘pixel-centred’ image analysis and the focusing on one single scale. In Geographic Information Science, object-oriented techniques have primarily been applied to the representation of complex geometry of geographic phenomena while they are used herein to model semantic relationships between objects at different levels or scales, respectively and to express knowledge about their structure, texture, shape or neighbourhood relations.

The most widely used methodological step to derive areas of interest is image segmentation. Traditional image segmentation methods have been commonly divided into three approaches: pixel-, edge and region based segmentation methods (for a comprehensive discussion see Blaschke et al., 2004). In an object-based environment we conceptually work on polygons and therefore may use all structural properties for classification (Blaschke and Strobl, 2001). Structural properties comprise all geometrical or morphometrical characteristics as well as topological and hierarchical characteristics. When segmenting an image on several scales (MSS), we can classify the generated segments by modelling their structural properties (ORM). Hierarchical properties of image segments can be expressed by various measures characterizing the averaged properties of (sub)-objects and/or their spatial arrangement (proximity measures). However, in some cases ORM cannot provide a solution for the intended modelling of a target class. This applies when the required geometry of the target class polygons is not provided by segmentation due to restrictions of (region- or edge-based) segmentation algorithms. In many cases the human brain can easily manage to detect and delineate features that otherwise in a machine-based way are hardly to extract. This we can prominently observe for features whose boundaries are mentally constructed and not directly seen in an image.

4. Integrating knowledge other than reflection values: Examples

Knowledge is a cumulative understanding of information, i.e. an overall representative structure and a set of generalized rules of the relevant phenomenon. Here, we use the term knowledge for all levels of derived description, including information, in order to distinguish it from observational data and to use it in the classification process of landscape elements. The proposed framework and the semantic modelling approach built upon it allow for the derivation of a geographical model capable of representing both observational data, as well as higher-level semantic abstractions that can be derived from that data and external expert knowledge. The analysis methodology is designed to utilize information in the scales inherent in our spatial (image) data sets in addition to a range of auxiliary data sets. Scales in plural refers to the exercising of a multi-scale image data set, including both airborne and satellite data, but also to the scales of information inherent in single images. The latter is possible because the multi-scale segmentation / object relationship modelling methodology is a move away from pixel-based analysis, to an object-based analysis, and multiple scales of objects can be explored within a single data set. The applicability of the methodology is proofed in ongoing projects in several study areas in Europe.

4.1 Fine-scaled changes in a mire system and alpine pastures

For a remnant mire (Wenger Moor) in the Province of Salzburg, Austria, a multi-temporal analysis and change detection has been performed to encompass the complex living ecosystem. Ecosystem integrity assessment requires a systematic assay of processes occurring across a range of time scales. Using an MSS/ORM approach, changes in the mire's ecological status be detected on remotely sensed images and spatially analyzed on aggregated levels. Therefore expensive fieldwork can be targeted by pre-selecting areas of change dynamics. This study aimed at the detection of fine-scaled change dynamics that reflect human-induced changes due to activities within the bog (drainage, wood planting and logging) and in its immediate surrounding (agricultural cultivation). The focus is set on remnants of active raised bog that have changed to degraded raised bogs due to changes in vegetation and bush encroachment (mainly *Pinus mugo*).

A time series of three aerial photographs of the bog (1953, 1976 and 1999) has been used showing different spectral characteristics: a black and white panchromatic photo (1953), a three-band colour infrared air-photo (1976), and a three-band colour air-photo (1999). All aerial photographs were resampled to a spatial resolution of 0.37m. By applying a hierarchical image segmentation (MSS) polygons were created on two scale levels revealing homogenous units on different levels of aggregation. In the Wenger Moor case study two such levels were created, namely the level of elementary landscape units (level -1) and the reporting or mapping level (level 0). Level -1 is classified by collecting representative samples for each basic class throughout the image. Classification of this level was done using a nearest-neighbour classifier that has been by optimized by feature space de-correlation. The second step (ORM) defines class composition by modelling the relationships among the segmented image objects and utilizing expert knowledge for semantic and structure-related descriptions of the specific target classes. By explicit integrating expert knowledge the process of classifying becomes more objective and transparent.

On the mapping level classes are established according to the specific stages of degradation in the bog (**figure 1**). Representative image sections were documented as structural signatures (Lang et al., in press) according to their typical spectral, textural and contextual characteristics. The geometry that shows the spatial distribution of degraded stages has been produced by a rule set that can be fully reconstructed. Based on a production system the outcome strictly depends on the underlying object relationship model, but is also flexible for adaptations when changes in the parameterization are required.

Post-classification change detection as the final step revealed to which degree the original open raised bog has been transformed to the other degradation stages. It turned out that within the 25 years between 1976 and 1999 an area of 3.3 ha has been lost in favour of the three different degradation stages heath (0.2 ha), bushes (2.1 ha) and tress (1.0 ha).

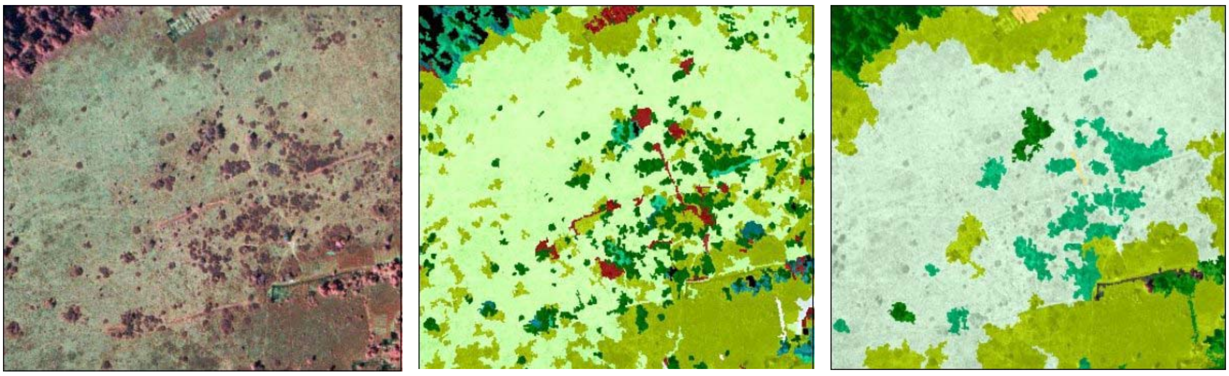

Figure 1: Classification of a CIR aerial photograph from 1976. From the original image (*left*), first the level -1 was classified (*middle*) showing high detailed (single bushes in dark green; pathes, peat extraction areas in red). Classified image-objects were then aggregated in the focal mapping level (*right*). Bush encroachment is low and the undisturbed active raised bog (bright green) is still dominant.

The second example comprises a mountainous landscape in the same province. Dominated by intensive grazing over centuries the landscape faces recent changes due to the socio-economic situation, namely the extensification of agriculture in peripheral areas. The methodology is applied to a classification of different types of meadows and pastures according to their texture. Some pastures exhibit specific characteristics while they show at the same time similar reflection values per pixel in an infrared aerial photography. The exploration and understanding of this spatial pattern opens new ways to explore and understand changes of the driving processes and will enable landscape planners to design grazing schemes to preserve the cultural landscape.

The driving factors of the prevailing landscape changes are very different from most areas in Europe where intensification of land use and urbanisation are the main pressure indicators. In large parts of the Eastern Alps, it is the decreasing use followed by land abandonment. A phase of encroachment of bushes und shrubs, mainly mountain pine (*Pinus mugo*) new morphodynamics systems are initiated. The vegetation higher than grass allows more snow accumulation and shows more friction for avalanches. Studies demonstrated that less intensive human management (removal of brushwood, clearing of avalanche deposits on the pastures, draining waterlogged areas) on this alpine pastures lead to erosion problems.

The two case studies are controversy not just because they belong to totally different ecosystems and landscapes. The nature conservation problems studied somehow contradictory. The *Pinus mugo* bushes are a priority species in the case of the mountainous zone while they follow anthropogenic transformations in the mire system and are to be removed in the central parts of the mire system. The methodology supports both aspects. Rather then treating bush encroachment as texture in remote sensing images the bushes are created as (sub)-objects in a database and are being modelling with GIS rules. The multi-scale segmentation / object relationship modelling methodology of Burnett and Blaschke (2003) has been proved to address the changing environmental conditions in both studies. The scale of interest (focal scale in hierarchy theory) is in both cases dictated by the research question and the multiscale exploration of pattern addresses the utilization of the corresponding lower or higher levels. Fine-scale processes are viewed as the details being required for explaining the phenomena at the focal scale. Through the integration of GIS rules based on sub-objects we were able to address and quantify a 'within-patch-diversity' (Blaschke, 1995) for the focal scale.

4.2 Urban applications

Remote sensing imagery of urban areas usually provides a very high resolution in the range from 0.1m – 0.2m. Human interpreters clearly identify the different urban features contained in the imagery without any training, even without any general experience in remote sensing image analysis. They just may use their trained knowledge of the ground appearance of features. Mainly different shapes and colours can be differentiated in these aerial photos, when they are used without any additional equipment like stereo interpreters etc.

These artificial objects consist of a more or less regular shape with sharp edges and a straight border to their neighbouring objects (e.g. buildings, cars, trucks). Those manmade features do not show the huge shape variety as well as the uniqueness of natural objects. The surrounding borderline of manmade features appears in most case shorter compared to natural objects. Using spectral reflectance as one classification criteria and in addition some special tools of sophisticated software like: degree of compactness in relation to the ideal compact feature, a circle, length of the surrounding borderline and size of an object, a reliable detection is possible. Working on an extremely large scale good results for the automated detection of buildings have been carried out by Hoffmann and van der Vegt (2001). In this research airborne scanner data with an extremely high spatial resolution of 0.15m per pixel have been used, providing a really large scale. The spectral resolution consists of the blue, green, NIR and SWIR bands. Though this are not the most valuable image data for the detection of urban buildings, the investigation led to high classification accuracies in terms of building extraction. However some manual edits are still necessary for this method, the complete reconstruction of exact building ground plans needs additional future research.

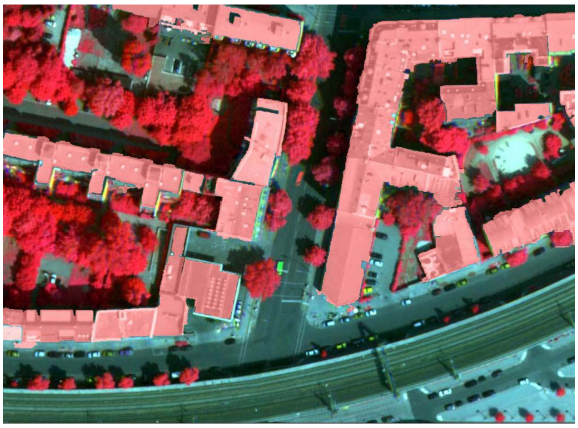

Figure 2: Color Infrared (CIR) Aerial Scanner Image (spatial resolution: 0.2m, size: 210m x 150m) (*left*). Extracted Buildings (light red) using advanced Texture and Shape Information in an object oriented software environment (*right*).

5. Conclusions and outlook

Only recently a larger portion of the remote sensing community pays attention to the fact that levels of organization are not scalar but rather definitional — in that they come solely from the observer (or point of observation) — and at each user defined level, phenomena exhibit properties that do not exist at other levels. This underscores the importance of a solid understanding of the objects of interest. Jelinski and Wu (1996) concluded from a thorough literature review that there was no suitable encompassing theory for indicating how sensitive results are to the scale of the analysis and to variations in the way in which data are represented. As Gardener (1998) states, the identification of appropriate scales for analysis and prediction is an interesting and challenging problem. Even if the factors producing scale-dependent patterns may not be clearly understood, accurate and reliable descriptions of scale-dependent patterns and processes are required to design data sampling procedures and test the accuracy and reliability of methods of the analysis and consequently modelling procedures. The object-based approach is currently very much associated with one commercial software package (eCognition, Benz et al., 2004) although neither contextual image classification nor image segmentation is new. Apparently, a methodology/paradigm will only get wide attention if the tools necessary are readily available.

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