BRIDGING REMOTE SENSING AND GIS – WHAT ARE THE MAIN SUPPORTIVE PILLARS?

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ABSTRACT:

This paper highlights recent developments that have led to object-based image analysis (OBIA). We summarize major trends in bridging remote sensing, image processing and GIS and we hypothesize that OBIA is an emerging paradigm in image analysis. We identify two initial foundations for this paradigm shift, namely the advent of high resolution satellite data and the market entry of a commercial OBIA software package. Timewise, these developments fell on fertile ground and were accompanied by other, more sectoral approaches to cope with new requirements in automated image processing, analysis and interpretation. An increasing demand for geospatial information in the light of environmental pressure and monitoring needs has catalyzed the development of new methods to exploit image information more intelligently. Beyond an overview on the development of OBIA we briefly pinpoint some challenges that – from the authors' view – arise in the retinue of the upcoming paradigm.

1. BRIDGING POTENTIAL AND A PARADIGM SHIFT

In 2001, a workshop on "Remote Sensing and GIS – new sensors, innovative methods" held in Salzburg, focused on the new high resolutions satellite sensors of the '1m-generation' and the increasing number of applications mainly based on the commercial software eCognition (www.definiens.com) which got commercial in 2000. In one of the workshop outcomes, Blaschke & Strobl (2001) have provokingly raised the question "What's wrong with pixels"? These authors identified an increasing dissatisfaction in pixel-by-pixel image analysis. Although this critique was not entirely new (Cracknell 1998) they observed something like a hype in applications 'beyond pixels'. A common denominator of these applications was that they were built on image segmentation.

Interestingly, much of these developments were driven by German speaking countries and some western European countries, mainly. Consequently, much of this literature was available in German language (for an overview see Blaschke, 2002b). This is remarkable for at least two reasons. First, image segmentation which builds the basis of this approach has been introduced much earlier (see Haralick & Shapiro 1985, Pal & Pal 1993). Secondly, software driven scientific developments are generally more likely to make their way from North America to the rest of the world.

In this short paper we concentrate on Earth applications. The majority of algorithm development in the late 1970ies and the 1980ies evolved in industrial image processing applications. Many of these algorithms use Markov Random fields or unsupervised texture segmentation (Jain & Farrokhnia 1991, Mao & Jain 1992, Pal & Pal 1993, Panjwani & Healey 1995, Chaudhuri & Sarkar 1995). Only more recently these algorithms are used for Earth applications (Dubuisson-Jolly & Gupta 2000).

Over these last about five years from this first (mainly German speaking) workshop in 2001 to now, advances in computer technology, earth observation (EO) sensors and GIScience have led to the emerging field of „object-based image analysis" (OBIA). Although segmentation is a mature technique we observe the advent of a new approach that integrates segmentation with other methodological components for an optimised analysis of very high spatial resolution (VHSR) data in earth observation. The main asset is the general potential of OBIA to tackle the complexity and multi-scale characteristics of VHSR imagery. More specifically this potential builds upon two dimensions: (1) to use segmentation for representing a complex scene content in a set of scaled and nested (i.e. hierarchical) representations, and (2) to provide means to address this complexity by means of either a rule-based production systems that makes expert knowledge explicit and formalised, or a built-in adaptive (i.e. learning) mechanism, or both of it. Typically for a new technology-driven approach, we can observe a wide range of application papers in conference proceedings and 'grey literature'. Literally dozens, if not hundreds of such papers from mainly younger scientists appeared in the years 2000 to 2004 and this development is still going on. A variety of successful applications exists (de Kok et al. 1999a, 1999b, Blaschke et al. 2000, Blaschke et al. 2001, Bauer & Steinnocher 2001, Blaschke 2002a, Schiewe & Tufte 2002, Pilz & Strobl 2002, Lang & Langanke, 2004; Neubert & Meinel 2002, Koch et al. 2003, Grubinger 2004, Mitri & Gitas 2004, Tiede et al. 2004; Langanke et al. 2004; van der Sande et al. 2004). Scientifically, some of these papers are disputable indicating some positivistic tendencies. This is not much different from the situation of GIS papers in the 1980ies. Starting from around 1989 we could observe a significant increase in methodological and theoretical research in GIS (Goodchild 1992).

This trend of the first years of the 3rd Millennium is, at least from the perspective of application-oriented research, often

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associated with one single commercial software. The perceived ‘omnipresence’ of this product, which was formerly called eCognition and is now available under the brand name Definiens, is an obstacle for the scientific community. Just in brief we shall mention at this point that this software was never the only option for scientists. Many different image segmentation algorithms are available for years (Pal & Pal, 1993, Hofmann & Böhner 1999, Blaschke 2000, Tilton 2003). Beyond algorithms also fully functional image segmentation software is available for several years (for a comparison see Meinel & Neubert 2004). In fact, the approach developed by Kettig and Landgrebe (1976) is still used and widely available in an open-source environment. Nevertheless, it is a fact that with the advent of the software eCognition in 2000 the number of segmentation-based image processing applications has taken off.

Only in 2003 and 2004 first journal publications were published around the OBIA idea and/or applications based on eCognition. Burnett & Blaschke (2003) developed a multiscale segmentation / object relationship methodology (MSS/ORM) building on Koestler’s ideas of multi-levelled hierarchies and on an extended and on a more applied vision of a scaling ladder (Wu 1999). The multiscale segmentation based approach is designed to utilize information in the scales inherent in our spatial (image) data sets in addition to a range of auxiliary data sets, including for airborne and satellite data, but also to the scales of information inherent in single images. Flanders et al. (2003) describe transferability experiments of classifications by using eCognition but with a more technical focus. In 2004, Benz et al. publish an ‘eCognition paper’ in the ISPRS journal. Although there is also not too much of theory basis this paper is very often referenced since prior to its appearance for detailed explanations of the object-based methods beyond the underlying segmentation algorithm which was published earlier (Baatz & Schäpe, 2000) only the eCognition user guide could be referenced.

Various authors have developed their own methods independently from the approaches mentioned so far. Gorte (1998), Melgani & Serpico (2002), Walter (2004) or Castilla et al. (2004), just to mention a few. Most of these approaches have in common that they are demonstrated for specific applications and their availability to other interested potential users is limited. Especially developments in academia very often demonstrate that something works in principle. It is more the exception rather than the rule that a commercial or open source software is developed out of these undertakings as it is the case with the algorithms of Kettig and Landgrebe (1976), Hofmann and Böhner (1999) or Tilton (2003).

Clearly, OBIA has more roots than the software-centric ones and the selected developments mentioned above. A much more theory driven approach starting from the question of scale is represented by a Canadian group (Hay et al. 2001, 2002, 2003) and international co-workers (Hall et al. 2004, Castilla et al. 2004, Hay et al. 2005). They started very much from systematically exploring scale as a ‘window of perception’ (Marceau 1999). Meanwhile OBIA has also been introduced in text books and book chapters under this or similar terms (Jensen 2004, de Mer and de Jong 2005, Schöpfer et al, in press).

The rapid spread and further maturation of the OBIA approach has triggered the demand for the “1st International Conference on Object-based Image Analysis – Bridging Remote Sensing and GIS (OBIA 2006)” which has been organized and hosted by the Centre for Geoinformatics (Salzburg University, Austria), and co-organized by ISPRS working groups IV/4 & VIII/11 as well as ESA. The two-days conference has likewise stimulated advanced methodological discussions on this paradigm shift in image analysis as it has opened the stage for presenting straight-forward, tangible solutions to problems of complex classification, change detection and accuracy assessment. Three conference themes were addressed from various aspects: (1) a*utomated classification, mapping and updating techniques*, (2) *potential and problems of multiscale representation* and (3) *further development of standard methodologies*. The world wide response to the conference announcement demonstrated that the challenge of linking methods and concepts from both remote sensing and geoinformatics is coupled with a range of expectations from various fields of applications including urban planning, mapping of settlements and infrastructures, forest management, land-use/land-cover mapping and change analysis, assessment of wetlands, habitats and species composition, natural resource management and geological exploitation, agricultural land use and crop monitoring.

2. THE MAIN PILLARS

2.1 GIS concepts and methods

We have briefly described a sharp rise of applications starting around the year 2000 together with the availability of high resolution satellite imagery and commercial software. Another important factor is the widespread day-to-day use of GIS. The use of remote sensing (RS) and geographical information systems (GIS) were formerly evolving as two rather disjunct disciplines of methodological science. But to reasonably encounter and manage information residing in high-resolution images, GIS functionality needs to be integrated in image analysis software. Consequently, over the last years, spatial concepts are increasingly utilized for image analysis. A crucial point is data integration. Spatially referenced and co-registered data material can be integrated through map overlay techniques. By this we can combine both continuous as well as discrete spatial data, without physically merging it. Moreover, from spatial science or ‘GIScience’ (Goodchild 1992) we can adapt a variety of spatial concepts which can be used when defining classes: size, form and shape, as well as topological properties and neighbourhood relations are key concepts in this respect. Segment-based image processing provides objects with distinct boundaries. These geographic entities in space that can be analysed based on their spatial attributes by logical queries (Boolean retrieval). Structurally complex classes can be addressed by combining results of this Boolean analysis of spatial properties. Applying the concept of spatial coincidence we can investigate relationships among objects. Basic descriptive parameters of hierarchical interrelations can be obtained in simply calculating the number of sub-/super-objects or variance within an object.

These ‘new’ options arising from a tight coupling of image processing and GIS algorithms fall on fertile ground: hundreds of thousands of GIS users worldwide have strong demands for updating geodatabases. Simply speaking: they know what they are looking for in an image. An integrated software which allows to formulate spectral rules, size and shape rules of objects and also topological relationships seems to meet the user’s needs. As many applications have demonstrated, even panchromatic information can be utilized together with other descriptors of the targeted objects (e.g. deKok 1999a, Pesaresi & Bianchin 2001, Segl & Kaufmann 2001).

2.2 Image segmentation, automated object delineation and the issue of scale

Segmentation is a form of regionalisation. Regionalisation means delineating units according to given criteria of homogeneity and, at the same time, requires spatial contingency. In real space, regionalisation differs from classification. Classification based on spectral values is the result of regionalisation in artificial, i.e. feature space. Transforming feature space regions to real space produces disjunct spatial categories, but not regions. Traditionally, image segmentation requires both proximity in real and in feature space (be it created by spectral or other dimension of continuous properties) although there are options to link spatially disjunct properties to regions (Tilton 2003). As stated earlier, segmentation methods are legion (Pal & Pal 1993). But no matter, which one of the methods is applied, segmentation provides the building blocks of object-based image analysis. Segments are regions which are generated by one or more criteria of homogeneity in one or more respectiv dimensions (of a feature space). Thus, segments have a spectral dimension (or another property comparable to spectral reflectance, like signal strength). The spatial dimension is subdivided in several sub-dimensions, as for example form, arrangement and vertical hierarchy.

Object-based image analysis aims at scene representations at several levels of resolution, thus relying on segmentation results at multiple scales. Multiscale denotes the multiple spatial dimensions at which entities, patterns and processes can be observed and measured (Hay et al. 2005). We believe that multiscale segmentation reveals image objects that reflect a range of inherent scales and by this produces a nested hierarchy of image objects belonging to each of these scale domains. As a metaphor, we may use the aforementioned scaling ladder of Wu (1999). A crucial point is the appropriateness of object generation, which is a matter of choosing the 'right' scale. This scale has to be translated to appropriate segmentation parameters (typically based on spectral homogeneity, size, or both) for the varying sized, shaped, and spatially distributed image-objects composing a scene, so that segments can be generated that satisfy user requirements (Hay et al. 2005, Lang 2005).

Two different strategies may be pursed in multiscale segmentation. Considering the concept of generalisation, we may terminologically differentiate between scale-specific vs. scale-adapted multi-scale segmentation. The first one is free of strict hierarchy and only obeys the level of aggregation. Boundary lines are smoothed, forms are simplified etc. The latter builds upon a strict hierarchy, where *n* sub-objects exactly form *one* super-object. This approach is very much associated with the commercial software eCognition. Alternatively, Hay et al. (2005) present multiscale object-specific segmentation (MOSS) as an integrative object-based approach for automatically segmenting meaningful forest-objects at multiple scales from a high-spatial resolution EO scene. Segmentation is based on spatial measures explicitly related to the varying sized, shaped, and spatially distributed image objects that compose a scene rather than on arbitrarily defined scale parameters. While the resulting objects and the corresponding shapes in the approaches of Hay et al. (2003, 2005) and Castilla et al. (2004) seem to address the chosen scales appropriately it seems to be much more difficult to formulate classification rules on non-congruent spatial entities. Vertical hierarchy is given but how to make topological rules like '*contain*' or '*are part of*' operational?

In a scene with natural features it is even more ambiguous to find the appropriate level of segmentation than in a built up environment with dominant anthropogenic features (Lang & Blaschke, 2003). Object-based image analysis techniques have opened the door to technically implement the way of human perception (ibid.). Common region-based segmentation algorithms are limited in delineating higher level objects that consist of high contrast, but regularly appearing objects. Those arrangements which are characterised by regularity in their heterogeneous structure are hardly captured by segmentation algorithms, whereas readily detectable for humans (e.g. an orchard or a mire complex with pools and hummocks, cf. Lang & Langanke, 2006). As segmentation relies on the principle of homogeneity, pattern-like heterogeneous arrangements can hardly be directly captured. In other words, the rules of homogeneity to identify similar regions throughout an image do not capture more complex topological relationships found in natural hierarchies. As stated by Navon (1977), a scene is rather decomposed than built-up: since egmentation routine is starting usually working in either direction (bottom-up or top-down), it can hardly mimic the way of visual processing, namely to start from a global analysis of the overall pattern and to proceed to finer structures.

2.3 Modelling and classification

OBIA supports image object modelling (Burnett & Blaschke, 2003) by explicitly utilizing the interrelationships among objects in the classification process, guided by a conceptual framework of target classes. The related concept of 'structural signatures' (Lang and Langanke, 2004) supports the classification of phenomena which are represented in a multi-levelled representation. A structural signature reflects the typical spatial structures of a target class and formalised the interrelationships of the constituting elements. Characterising the constituents the approach builds upon the principles of hierarchy theory. Specific within-patch-heterogeneity (Blaschke 1995) can be modelled both spatially explicit by e.g. distance measures or implicitly by percentage of sub-objects (Blaschke 2002a). To achieve this task at least two levels of segmentation have to be introduced. The basic level (level of elementary landscape units) is considered to cover the constituting elements, whereas the mapping level reflects the aggregated habitats. Habitats with a homogeneous structure can be described with the simple rule 'consists mainly of type x'. As the human eye generalizes little disturbances or noise, we can use softened (fuzzy) percentage rules defining the relationship between one (super-)object and its constituting (sub-)objects. If the internal structure is more heterogeneous and spatial configuration is critical to the specific habitat type, the description the structural arrangement of constituents is more advanced.

When dealing with high-resolution imagery and a vast set of potential target classes, both object delineation and classification imply a level of uncertainty. In other words, we are dealing with fuzziness in boundary delineation as well as in labelling. The ultimate instance for benchmarking object delineation and classification is human perception, tightly coupled with experience and knowledge. A rule-based production system has been established based on fuzzy rules. It allows for making intuitive knowledge explicit, though admitting a certain degree of uncertainty. The ambiguity of object delineation has implications for performing adequate object-specific accuracy assessment and change analysis (see respective papers in this volume). Any way of delineation (visual interpretation, segmentation or ground measurement) is intrinsically scale-dependent. This requires new, spatially explicit and scale-sensitive methods for assessing congruencies between automatically delineated objects and reference data.

2.4 Supporting image understanding

By forming the conceptual link to human perception image segmentation is considered an essential prerequisite for image understanding (Gorte, 1998). Object-oriented image analysis (OBIA) offers valuable methodological assets in breaking down scene complexity into meaningful image primitives. By providing "candidate discretizations of space" (Burnett & Blaschke, 2003) a scene can be modelled in adaptive scales according to the domain of interest. Humans do recognize discrete objects, whose size, shape, spatial arrangement and context change(s) depending upon the scale(s) at which they are assessed (Marceau, 1999). A profound prerequisite of image object modelling is the provision of a clear underlying concept regarding the domain of interest. This comprises an understanding of the target scale, the target object set, and the target class scheme. Note that the domain of interest of a skilled interpreter may differ from that of a simple user; the experience of the former makes him specifically look for certain features, whereas the latter is mainly interested in the information he or she wants to obtain.

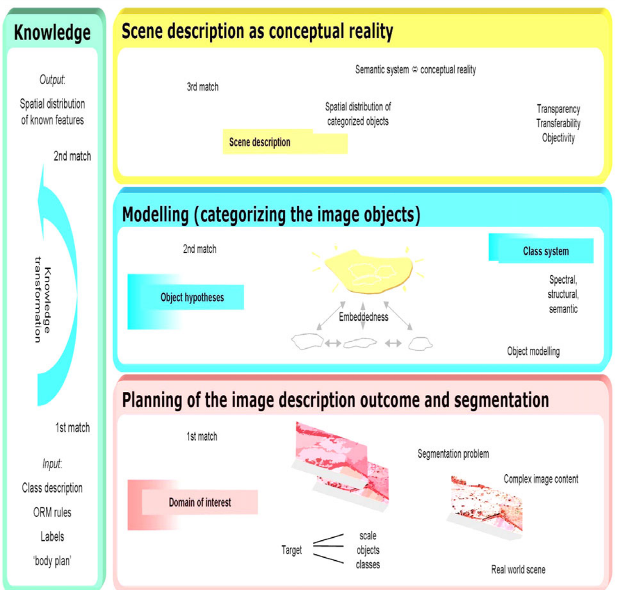

Figure 1. OBIA and image understanding: The process is characterized by the utilization and transformation of knowledge. Expert knowledge is adapted and improved through progressive interpretation and object modelling and made explicit. The knowledge is otherwise enriched by analyzing unknown scenes ; the transfer of knowledge may stimulate the creation of new rules (from Lang 2005, adapted by F. Albrecht).

Finally, a challenge lies in the translation of the rulesets from the image domain to an application domain (see figure 1). Starting from a real-world scene subset captured by an image of high complex content the first step comprises the provision of scaled representations through aggregating information and reducing complexity. The multi-scale segmentation should be governed by a clear picture in mind of how target objects are structured by sub-level primitives (or – conversely – by super-level aggregates). The critical choice of appropriate segmentation levels makes up the 1st match of a scene-centred view with conceptual reality (Lang, 2005). Having object hypotheses in mind (Bruce & Green, 1990) the modelling is realized by encoding expert knowledge into a rule system. Modelling aims at categorizing the image objects by their spectral and spatial properties and their mutual relationships. In order to categorize the grouping of this kind of knowledge one can differentiate between spectrally, structurally, and semantically defined classes. This may be considered the 2nd match and the shift to an object-centred view is accomplished (Lang, 2005).

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