OBJECT BASED IMAGE ANALYSIS FOR AUTOMATED INFORMATION EXTRACTION – A SYNTHESIS

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ABSTRACT

Over the last years, advances in computer technology, earth observation sensors and GIScience have led to the emerging field of "Object-based Image Analysis" (OBIA). The need for timely and accurate geo-spatial information is steadily increasing. It is necessary to synchronize technologies and harmonize approaches related to the acquisition, processing, and retrieval of multi-sensor, multi-spectral, multi-resolution data from various sensors. Moreover, the advancement of feature recognition and advanced image analysis techniques facilitate the extraction of thematic information, for policy making support and informed decisions. The availability of such data and the increasing worldwide use of geo-information have catalyzed the development of new methods to exploit image information more 'intelligently'. In this paper we investigate the technical and methodological status quo in OBIA. We provide an overview on applications bridging remote sensing, mapping, and GIS with a focus on automated operations and repeatable and transferable solutions. We analyse the outcomes of the first conference on object-based image analysis (OBIA'06) and draw conclusions in regard a) to the scientific progress in algorithms and methodologies, b) to the software situation and the commercial exploitation, and c) in particular to the conference topic 'Automated Feature Extraction'.

INTRODUCTION - BACKGROUND

Over the last years we testimony a significant increase in commercially available high resolution remote sensing imagery (< 5.0 m). Sometimes we refer to this as the '1m-generation'. While remote sensing made enormous progress over the last years in terms of improved resolution, data availability and public awareness, a vast majority of applications rely on basic image processing concepts developed in the 70s: per-pixel classification of in a multi-dimensional feature space. Blaschke and Strobl (2001) have argued that this methodology does not make use of any spatial concepts. Especially in high-resolution images it is very likely that neighbouring pixels belong to the same land cover class as the pixel under consideration. These authors have argued for classification of homogeneous groups of pixels reflecting our objects of interest in reality and use algorithms to delineate objects based on contextual information in an image on the basis of texture or fractal dimension. The recognition of limitations with pixel-based image approaches (i.e., that pixels are not true geographical objects, that pixel topology is limited, that current remote sensing) is more widely recognized today. A second set of driving forces which led to the developments described in this paper is the need to develop new markets from these multi-billion dollar investments and the one hand side and the demand of industry for repeatable and transferable image analysis and feature extraction applications on the other side. Thirdly, an ever-growing sophistication of user needs and expectations regarding GI products is at least implicitly triggering new developments (see Hay and Castilla, 2006).

Interestingly, originally developed for landscapes in a more ecological sense (and not so much cityscapes, for instance), landscape ecology provides a conceptual foundation for such an image analysis strategy 'beyond pixels'. Landscapes, patches and image objects are conceptual containers used by scientists to systematically assess dynamic continuums of ecologic process and flux. The continuums of flux that comprise ecological systems are a challenge to monitor and analyze because the underlying processes operate over a wide range of spatial, temporal and organizational scales, of which our observation techniques capture only a "jittery kaleidoscope of pattern" (Burnett & Blaschke, 2003: 233). In heavily anthropogenic shaped landscapes such as urban environments the discontinuities in an image are stronger and the gradients are steeper. Human dominated objects tend be more clearly definable at least conceptually.

Blaschke and Strobl (2001) have argued that many central concepts in geography have until recently [they referred to the situation in 2001] escaped operational use in image processing. While spatial relations like distances, topological connectivity and directional characteristics, spatial patterns as well as multiple scales or regional constructs were familiar approaches in many analysis tasks, they were not readily available to image analysis. While images often are legitimately seen as the most information-rich base data available, extraction of information frequently had to rely on human interpretation. Only now we are getting close to applying spatial thinking to image processing, paving the way to algorithmically formulate some more advanced aspects of cognition and inference (Blaschke and Strobl, 2001).

Figure 1. Pattern and structure are important elements in image analysis beyond single pixel interpretation. The identification, extraction and classification of discrete objects are easier in anthropogenic landscapes (left, oblique airphoto, Georgia, USA) since we 'know what we are looking for'. The identification of single objects in a remote area less dominated by human beings is much more depending on definitions (right, Hindukush, Afghanistan).

In brief, we just want to point at ecological theory and specifically hierarchy theory which tells us that ecological systems are not continuous phenomena across orders of scale. Rather, there are significant discontinuities when leaving particular levels of organisations (e.g. the cell level). Although it is heavily disputed by some ecologists that there is something like the landscape level 'near decomposability' and discontinuities across scale are key to image understanding and to linking image objects to real world objects.

In this paper we summarize and analyse the increase of OBIA applications starting around the year 2000. Although the begin of this development cannot be sharply defined and is here just said to be 'around the year 2000' it coincides with the advent of the '1m satellite image generation', an increasing operational use of LiDAR and airborne digital scanners and camera. Especially the coincidence of this increasing availability of high resolution imagery and a commercial software product (eCognition, see Benz et al., 2004). 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. In this paper we will describe these recent trends. We will only very briefly discuss some underlying concepts. Rather, we will point at some recent references and will not repeat a recent publication by Lang and Blaschke (2006) which focuses on the conceptual pillars of OBIA.

OBJECT BASED IMAGE ANALYSIS (OBIA): CONCEPTS AND METHODS

Image segmentation is not new (see Haralick and Shapiro, 1985). Several comprehensive reviews exist, e.g. Pal and Pal (1993). Until some years ago, segmentation techniques were mainly used to produce image objects which were then either extracted or classified. The more recent innovation lies in the way how to exploit the segmentation results in a following classification and/or image extraction process. This is performed in a combination of GIS techniques and image processing techniques. Next to the spectral characteristics of the resulting objects also other descriptive features are used such as shape information, boundary length, boundary length to specific other classes, neighbourhood and distance relationships to other objects and classes etc. We therefore strongly believe that Object based image analysis (OBIA) falls into GIScience which is supposed to be a scientific discipline (Goodchild 1992). Hay and Castilla (2006) propose that OBIA is a sub-discipline of GIScience devoted to partitioning remote sensing (RS) imagery into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scale.

At its most fundamental level, OBIA requires image segmentation, attribution, classification and the ability to query and link individual objects (a.k.a. segments) in space and time. In order to achieve this, OBIA incorporates knowledge from a vast array of disciplines involved in the generation and use of geographic information (GI). It is this unique focus on RS and GI that distinguishes OBIA from related disciplines such as Computer Vision and Biomedical Imaging, where outstanding research exists that may significantly contribute to OBIA.

Wu (1999) translated ecological theory to remote sensing applications. He built on the Hierarchical Patch Dynamics paradigm (HPD, Wu and Loucks, 1995). 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 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 HDP (Wu and Loucks, 1995) as described above. 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.

OBIA APPLICATIONS

The „1st International Conference on Object-based Image Analysis“ has hosted a variety of different application domains, conducted in broad range of scales and using a series of medium to high resolution remote sensing data and advanced analysis techniques (see table below for an overview). It has shown that OBIA neither can be attached to only one particular application domain nor is the strategy of working on objects as instances of contiguous and homogenous image regions a scale-specific approach. In principle it turned out that OBIA has the power to successfully tackle with increasing complexity of image contents, no matter if caused by an increasing spatial detail and/or the complexity of the topic to be addressed or the size of the study area to be worked on.

Researchers, developers and users from universities (62), research institutions (7), companies (8), public agencies (6) in twenty-four different countries from all continents were sharing their experiences in altogether more than eighty oral presentations and interactive contributions. Application domains covered land use / land cover (12), forest (11), settlements and infrastructures (7), agriculture and fields (6), geology and natural resources (6), habitats, reserves and wetlands (9). More specifically – taking into account the fine-scale character of most studies – applications comprised: forest structure, forest diversity and stand delineation, coastal rainforest mapping, sub-field parcel analysis and vine plot detection, intra-urban land cover classification and detection of informal settlements, savannah vegetation monitoring, updating of UNESCO biosphere reserves, oil spill contamination mapping, earthquake damage assessment, detection of hedges and tree rows, wetland and FFH habitat mapping, etc. – to name just a few.

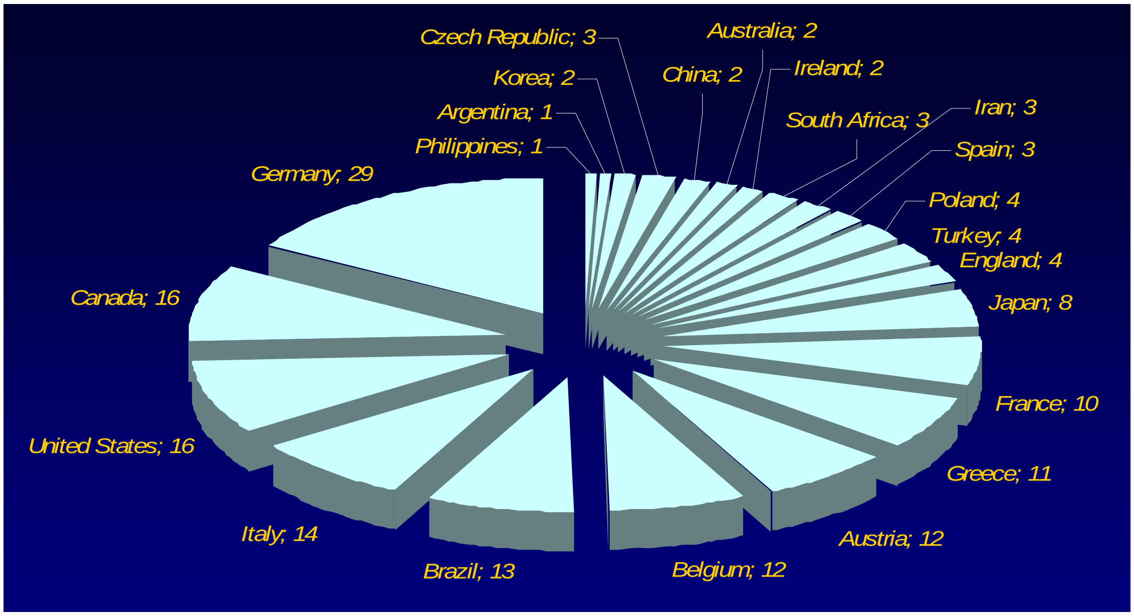

Figure 2. A total of 175 authors contributing to OBIA papers, coming from twenty-three different countries. Numbers next to the country's name indicate the number of authors.

About one third of the papers addressed generic issues regarding segmentation approaches and strategies and further adaptation and advancement of the object-based paradigm. After an overview session on the pillars and roots, the self-understanding and the strengths / weaknesses / opportunities / threats of OBIA, talks were focusing on the potential and challenges of multi-scale and scale-specific representations, the possibility of integrating texture features in the process of object description, wavelet based approaches and learning algorithms / neural net classifiers.

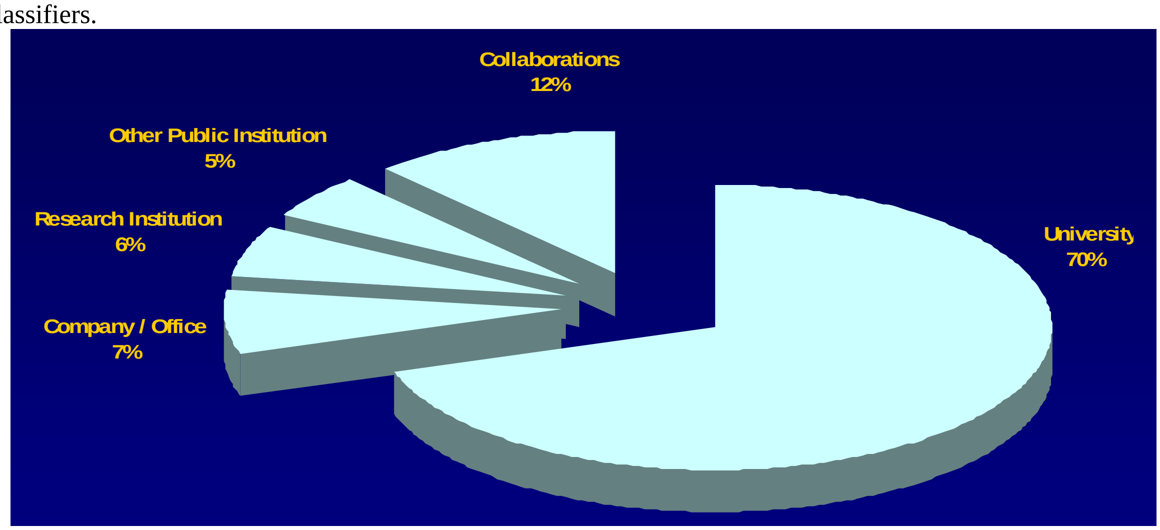

Figure 3. A total of 83 different institutions were involved in the OBIA contributions. "Collaborations" means that several institutions were collaborating on one particular contribution.

Optical image data most intensively used were: QuickBird (17), Ikonos (16), Landsat ETM (12). Radar data were used from Radarsat (2), JERS-1 (2), Envisat (1). ALS data were used in seven studies. Ancillary data mainly comprised DEM (16), digital orthophotos (6), reference points (GCPs). Study area sizes ranged from sites smaller than 10 sqkm (10), over sites between 11 and 100 sqkm (9) and sites between 101 and 1000 sqkm (4), up to sites larger than 1000 sqkm (2). Site types included protected areas, forests (economical, natural and protective), lakes, mountainous areas, settlements (both rural and urban), agricultural fields, floodplains, and wetlands.

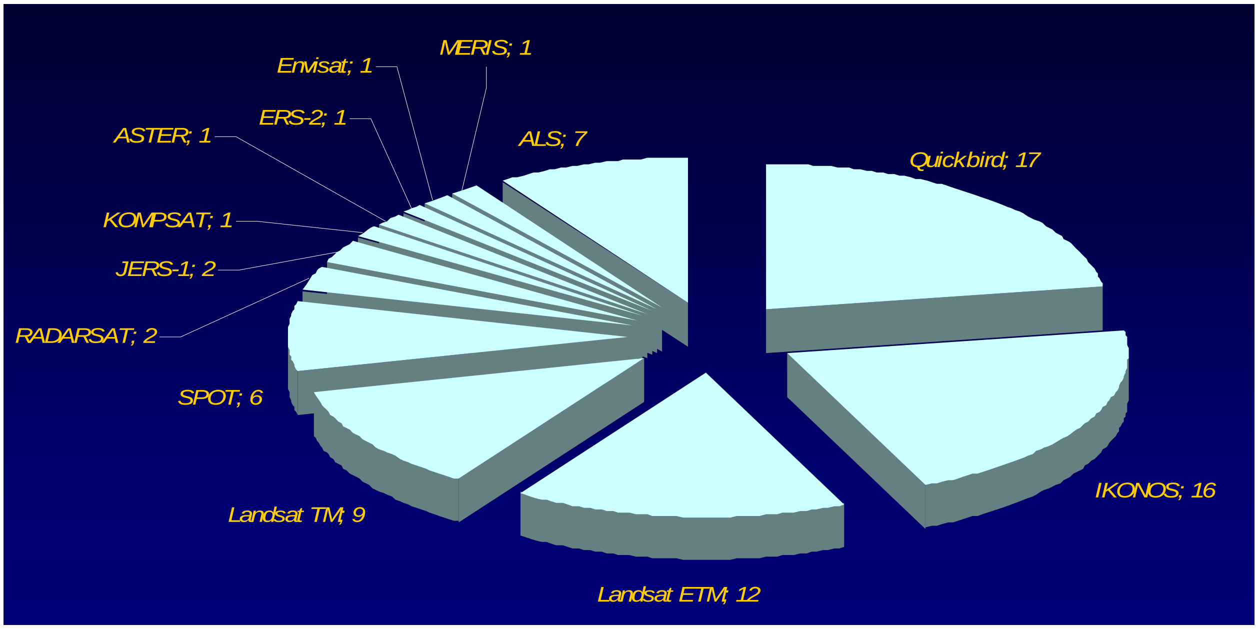

Figure 4. Thirteen different sensors have been used in a total of 76 applications, the majority of which has been used optical sensors (62), whereas 7 applications were using radar data or airborne laser scanning (ALS) data, respectively.

In terms of the chronology of the analysis we may ask: is the provision of objects a prerequisite or the target of the analysis or both? In other words is the approach primarily based on objects or rather oriented towards them? An answer is not straightly given, since OBIA in a process-centered view may be considered a cyclic procedure of mutual interaction by the operator and processing by the machine, extraction, validation, classification and final approval. Establishing rule bases and performing object-relationship modeling is not a uni-directional process from operator to machine. We may envisage this process as “natural computing” (Binnig et al., 2002), leading to an evolutionary net (ibid.) by which we gain our own understanding and enrich our knowledge, that again is fed into the analysis process. By this, dealing with all kinds of uncertainties and inaccuracies (both spatial and thematic) researchers start reconsidering findings from cognitive psychology as well and incorporate these considerations into their rule-base design.

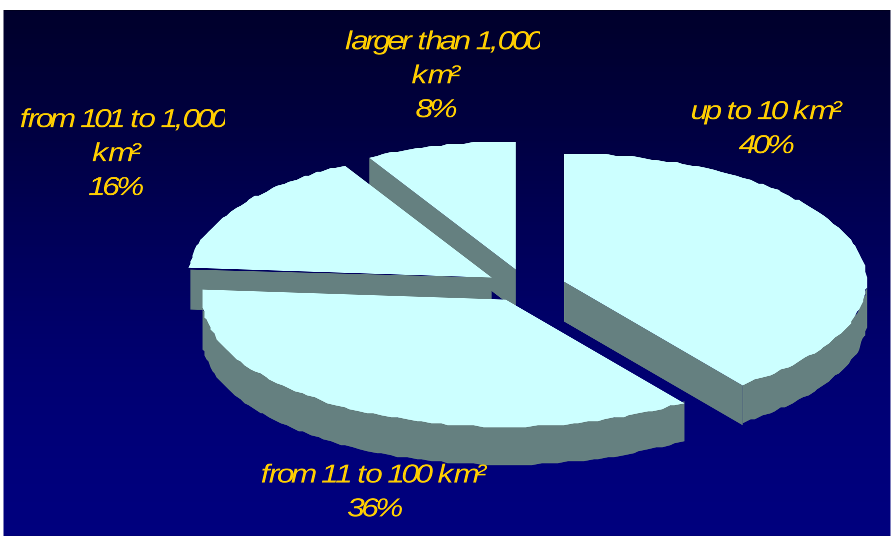

Figure 5. Out of 25 contributions in which the study area was explicitly mentioned more than three quarters worked in study areas smaller than 100 sqkm.

CONCLUSIONS

Object based image analysis is becoming a widespread methodology. Some would argue that it is also a new paradigm in image processing. The authors conclude that the sharp increase in application numbers was correlated with both, the advent of high resolution data sets and the availability of an operational software product which followed a very different strategy compared to most software products available on the market which have been developed over the last twenty years or so. This development was clearly demand driven and software driven. Similarly to the development of GIS it can be argued that a theory deficit is very likely in such a situation. The 2006 OBIA conference brought together many researchers in this field. It turns out that there is still not a comprehensive theoretical framework but there is more and more work related to a scientific foundation of OBIA. Industry demands repeatable and transferable solutions. Such solutions will only be put in place when they are based on a sound methodology. The challenge is developing a flexible approach for transferring domain knowledge of a feature extraction model from image to image that is capable of adapting to changing conditions (image resolution, pixel radiometric values, landscape seasonal changes, and the complexity of feature representation).

Blundell & Opitz (2006) distinguish two types of approaches for identifying and extracting objects of interest in remotely sensed images: manual and task-specific automated approaches. The first approach involves the use of trained image analysts, who manually identify features of interest using various image-analysis and digitizing tools. Features are hand-digitized, attributed and validated during geospatial data production workflows. Although this is still the predominant approach to geospatial data production, Blundell and Opitz regard it as not efficient mainly because of the laborious, timeconsuming nature of manual feature identification. Researchers since the 1970s have been attempting to automate the object recognition and feature extraction process from imagery. This has traditionally been done by writing a task-specific computer program.

The object-based approach is currently somehow associated with one commercial software package (eCognition, Benz et al., 2004) although neither contextual image classification nor image segmentation are new. Apparently, a methodology/paradigm will only get wide attention if the tools necessary are readily available. The visual appeal of image-objects, their easy GIS integration and the enhanced classification possibilities have recently attracted the attention of major RS image processing vendors, who are increasingly incorporating new segmentation tools into their packages. Conversely, a solid methodological framework is crucial for the success of a new paradigm – if OBIA is such a paradigm.

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