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# Geographic Object-Based Image Analysis – Towards a new paradigm

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ABSTRACT

The amount of scientific literature on (Geographic) Object-based Image Analysis – GEOBIA has been and still is sharply increasing. These approaches to analysing imagery have antecedents in earlier research on image segmentation and use GIS-like spatial analysis within classification and feature extraction approaches. This article investigates these development and its implications and asks whether or not this is a new paradigm in remote sensing and Geographic Information Science (GIScience). We first discuss several limitations of prevailing per-pixel methods when applied to high resolution images. Then we explore the paradigm concept developed by Kuhn (1962) and discuss whether GEOBIA can be regarded as a paradigm according to this definition. We crystallize core concepts of GEOBIA, including the role of objects, of ontologies and the multiplicity of scales and we discuss how these conceptual developments support important methods in remote sensing such as change detection and accuracy assessment. The ramifications of the different theoretical foundations between the 'per-pixel paradigm' and GEOBIA are analysed, as are some of the challenges along this path from pixels, to objects, to geo-intelligence. Based on several paradigm indications as defined by Kuhn and based on an analysis of peer-reviewed scientific literature we conclude that GEOBIA is a new and evolving paradigm.

## 1. Introduction

Aerial photography has a long tradition dating back to Nadar's balloon-based images of Paris, France in 1858, while civilian spaceborne remote sensing (RS) began in 1972 with Landsat-1. This sensor set the standards and foundation for future multi-spectral scanner technologies and its corresponding pixel-based image analysis. Several digital classification methods (e.g., the maximum likelihood classifier) were soon developed and became the accepted processing paradigm of such imagery (Strahler et al., 1986, see also Castilla and Hay, 2008). Since the late 1990s, this "pixel-centric" view or "per-pixel approach" has increasingly been criticised (Fisher, 1997; Blaschke and Strobl, 2001; Burnett and Blaschke, 2003). The pixel based approach has been a dominant *paradigm* in remote sensing although very few scientific articles explicitly use the word "paradigm". In fact, compared to other disciplines, remote sensing has a surprisingly small theoretical base beyond the underlying physical concepts of electromagnetic radiation and its interaction with the atmosphere and other targets. It is repeatedly argued that this focus on the pixel was and still is understandable as long as the pixel resolutions are relatively coarse, i.e., that the objects of interest are smaller than, or similar in size as the spatial resolution (Hay et al., 2001; Blaschke et al., 2004). Once the spatial resolution is finer than the typical object of interest (e.g., single trees, forest stands agricultural fields, etc.) objects are composed of many pixels and a critical question emerges: "why are we so focused on the statistical analysis of single pixels, rather than on the spatial patterns they create?" (Blaschke and Strobl, 2001).

In this article, we discuss the limitations of this 'per-pixel' approach and the rise of a new paradigm which increasingly competes with, but also complements the prevailing concept. Castilla and Hay (2008) argue that the fact that pixels do not come isolated but are knitted into an image full of spatial patterns was left out of the early 'per-pixel' paradigm. Consequently, the full *structural* parameters of the image (i.e., colour, tone, texture, pattern, shape, shadow, context, etc.) could only be exploited manually by human interpreters.

However, around the year 2000, the first commercial software appeared specifically for the delineation and analysis of *image-objects* (rather than individual pixels) from remotely sensed imagery. The subsequent area of research was referred to as *object-based image analysis* (OBIA) although terms like "object-oriented" and "object-specific" were often used (Hay et al., 1996, 2003; Blaschke et al., 2004). Image-objects represent 'meaningful' entities or scene components that are distinguishable in an image (e.g., a house, tree

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or vehicle in a 1:3000 scale colour airphoto). Thus, image-objects are inherently scale-dependent.

OBIA incorporates older segmentation concepts in an initial but essential step while further bridging spatial concepts applied to evolving image-objects and radiometric analyses that are earth surface-centric rather than biological, medical or astronomical (segmentation is also practiced in these domains). Hay and Castilla (2008) argue that Geographic space is intrinsic to this analysis, and as such, should be included in the name of the concept and, consequently, in the abbreviation: "Geographic Object-Based Image Analysis" (GEOBIA). Only then it is clear that we refer to a sub-discipline of Geographic Information Science (GIScience). While this seems both logical and obvious to Remote Sensing scientists, GIS specialist and many environmental disciplines, the fact that remote sensing images 'model' or 'capture' instances of the Earth's surface may not be obvious to scientists from other disciplines such as Computer Vision, Material Sciences or Biomedical Imaging. In the remainder of this article, we will use the term "GEOBIA" henceforth.

In the following section, we will discuss the limitations under some situations of the traditional pixel-based approach. In Section 3, we analyse and discuss indications of a paradigm and discuss whether GEOBIA fulfils such criteria. In Section 4 we identify the key concepts of GEOBIA and we conclude that GEOBIA bridges remote sensing, image analysis and GIS analysis concepts.

## 2. Remote sensing and image processing concepts and limitations

The digital analysis of remotely sensed data evolved from concepts of manual image interpretation. Although developed initially based on aerial photographs, these protocols are also applicable to digital satellite imagery. Many digital image analysis methods are primarily based only on tone or colour, which is represented as a digital number (i.e., brightness value) in each pixel of the digital image (for a recent literature overview see Weng, 2009, 2011; Fonseca et al., 2009; Myint et al., 2011). Along with the advent of multi-sensor and higher spatial resolution data more research focused on *image-texture* as well as *contextual* information, which describes the association of neighbouring pixel values and has been shown to improve image classification results (Marceau et al., 1990; Hay and Niemann, 1994; 1996).

### 2.1. H- and L-resolution

In their classic paper Strahler et al. (1986) introduce a conceptual remote-sensing model comprising three sub-models: (i) the scene, (ii) the sensor and (iii) the atmosphere model. The scene is the landscape from which radiance measurements are acquired. These three sub-models together form the framework in their study, but for GEOBIA the scene and sensor/image models are particularly important. The scene model provides a simplification of the real world. It describes the real-world objects as the analyst would like to extract them from images in terms relevant to image processing. Thus, the legend is an important part of the scene model as it describes thematic characteristics of objects, and roughly implies the size of objects. Generally, more detailed thematic descriptions are related to smaller objects. For example, a forested area contains trees. The sensor model describes the specifics of the measurements from which the image is built including the number of spectral bands and their bandwidths. It also defines spatial aspects like the resolution cell, which specifies the surface area over which radiance is registered. Strahler et al. also introduced the concepts of *H-* and *L-resolution*, which, as they specifically note, should not be indicated by descriptors of 'High' and 'Low' resolution, as these are commonly applied to specific sensors and their associated pixel size [e.g. Ikonos (1.0 m PAN) vs. AVHRR (1.0 km)]. Here, (spatial) *resolution* refers to the combined spatial aspects of the scene and the sensor/image models. H-resolution indicates situations where scene objects are much larger than the resolution cells, thus several resolution cells may contain radiance data of a single object. L-resolution represents the opposite situations where scene objects are much smaller than the resolution cells. While a pixel contains both H- and L- resolution information, each of which can be used for image analysis (Hay et al., 2001) GEOBIA is primarily applied to very high resolution (VHR) images, where image-objects are visually composed of many pixels; and where it is possible to visually validate such image-objects (i.e. H-resolution case). The use of GEOBIA, however, is not limited to images with small resolution cells. If the legend of the scene model is generalized, i.e. a higher hierarchical level of the legend is applied, then the size of scene objects will increase and an L-resolution situation may turn into an H-resolution situation.

A common issue with coarse resolution cells is that they combine spectral properties of heterogeneous land cover. For example, in the case of a resolution cell of 1 km$^2$ in a forested area, the scene will contain mostly forest (typically of more than one species), but probably also open patches, paths and roads, or small fens etc. Although the spectral properties will be dominated by forest vegetation, they will not represent 'pure' forest. Hence, spectral mixing increases in images with coarser resolution cells which in turn leads to confusion during classification. While creating object attributes, the spectral properties of individual cells are averaged for the entire object. This reduces classification confusion as averaging diminishes the (within-object) variance and seems to be appropriate for classification of coarse resolution images. At present, per pixel image analysis of coarse spatial resolution images (e.g., MODIS, AVHRR) remains the base producer of spatially continuous land cover information. The production of classified thematic maps by broadband multi-spectral imagery, however, has evolved due to the advent of high spatial resolution imagers.

### 2.2. Advances in image classification

Throughout the last 15–20 years, advanced classification approaches, such as artificial neural networks, fuzzy logic/fuzzy-sets, and expert systems, have become widely applied for image classification. Weng (2009) provides a valuable list of the major advanced classification approaches that have appeared in recent literature, dividing the approaches into the following major categories with subsequent sub-categories: *per-pixel* (17 categories), *sub-pixel* (7 categories), *per-field* (6 categories), *contextual based approaches* (13 categories), *knowledge based* (6 categories), and *combinational approaches* of multiple classifiers (14 categories). Weng (2009) includes GEOBIA within the category '*Per-field* classification' (see next paragraph), which may be used to explain the role of segmentation in GEOBIA: segmentation is only one possible means to delineate objects of interest. If they are derived otherwise, e.g. imported from a GIS database, we may more explicitly call the subsequent classification process a per-field classification. Interestingly, GEOBIA methods are only one of the 63 specified by Weng, although its number of literature references per category (from international journals between 2003 and 2004) is the highest overall.

In an effort to improve pixel based classifications by exploiting scene characteristics other than 'colour' – such as tone, shape pattern, context etc., the most widespread approaches incorporate information on image-texture and pattern, based on moving window or kernel methods, the most common being the Grey Level Co-occurrence Method (GLCM) (Haralick et al., 1973; Marceau et al., 1990). Since the late 1980s, geostatistical approaches have