

Segmentation: The Achilles' heel of object-based image analysis?

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ABSTRACT:

Much of the background material on geo-object-based image analysis (GEOBIA) begins with a description of image segmentation and suggest it as the first stage of the process. Although this approach may be reasonable in some cases, the crucial first step should be more generically defined as obtaining a set of objects which represent the features of interest in the image. In the context of land cover mapping these objects will be fields, lakes and patches of woodland etc. The application of image segmentation might be considered a 'black art', due to its dependence on the image data and the limited amount of control available to the user. The resulting segments reflect the spectral structure of the image rather than the presence of true boundary features in the landscape. For instance, two adjacent fields with the same crop could be combined into a single object even though they may be owned by different farmers. Conversely, single fields containing natural and acceptable variability may give multiple objects per field. Segments also retain the inherent area sampling of the original image. This lack of a direct one-to-one relationship between real world objects and segments has prevented GEOBIA reaching its full potential. Rarely today is any environmental analysis begun on a blank canvas, but in the context of existing mapping of some form, often in digital format. In regions of the world with high quality large scale cartographic mapping an obvious question is why this information is not used to control the GEOBIA process? Much of the earlier GEOBIA work was within the raster processing domain and only recently have fully structured digital vector cartography datasets and the necessary software tools become available. It is proposed that the GEOBIA process be made more generic to use the best existing real world feature datasets as the starting point for the process before segmentation is considered. Such an approach would increase opportunities for integration with other datasets and improve the results of map update initiatives. This approach will be demonstrated in the context of an operational national land cover mapping exercise.

1. INTRODUCTION

Geo-Object-Based Image Analysis (GEOBIA) is described as "a sub-discipline of geoinformation science devoted to partitioning remote sensing imagery into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scale" (GEOBIA wiki, 2008). This definition makes no suggestion as to the source of the image-object boundaries and the term 'meaningful' would suppose that they should be related as closely as possible to real world objects.

However, much of the published material on GEOBIA and its applications begin with the assertion that image segmentation is the vital first stage of the process. As the field of GEOBIA has developed over the last few years, the review papers that have come out to develop the theory (for instance Lang and Blaschke, 2006) have failed to identify any other source for the image-objects than segmentation. It can then be assumed that feature extraction from images appears to be a major driver behind GEOBIA.

In their paper on the strengths, weaknesses, opportunities and threat associated with GEOBIA, Hay and Castilla (2006) followed the conventional definitions and understanding, but identified an interesting set of key issues which GEOBIA should be addressing. The first is a driver from the user community regarding the sophistication of their needs and their expectations regarding products. Another key driver was seen as the need for greater integration with vector GIS data and applications. Finally, a key weakness of GEOBIA was seen as the segmentation approach itself, its uncertainties and the lack of repeatability.

In this paper we hope to address some of these issues and propose a broader definition of GEOBIA to exploit its strengths and minimise its weaknesses. The keys to this are the selection of meaningful image-objects and the appropriate and effective use of image segmentation. The end result will be to maximise the exploitation of GEOBIA products and technologies by the end user community.

2. SPATIAL FRAMEWORKS

The majority of geo-information activity and market is centred on the use of map-like and vector-based products. Raster-based image products play a more minor role and in a significant proportion of these cases are used only to guide the user or place a vector-based analysis in context. For example, aerial photographs are extensively used in GIS applications as a contextual backdrop over which to display the information of interest, for instance utility networks. Vector-based products are what most end users feel familiar with and provide a straight forward link to existing data, conventional mapping and their spatial perceptions.

Even though GEOBIA generates a vector-based product, to really tap into this area then the object structures adopted must align themselves as closely as possible to what is already known, what is already in use and what fits with the users' perception. From a remote sensing point of view image segmentation may seem a sensible first step in developing object-based approaches to a particular analysis, but when users have existing land parcel objects or clear perceptions of landscape structure the power and benefits of GEOBIA may get undersold or ignored.

Image segmentation has obviously an important role to play in monitoring and assessment of landscape characteristics, but it may be better deployed as part of a multi-source solution. The crucial first step in GEOBIA should be more generically defined as obtaining a set of meaningful land parcel objects which represent the features of interest to the user in the landscape, whether or not they have a spectral distinction in the image.

3. USE OF SEGMENTATION

The use of segmentation algorithms to identify relatively homogeneous areas in images has been around for decades in experimental and semi-operational forms (Haralick and Shapiro, 1985). Recent developments in computer power and software technology have now brought segmentation and GEOBIA to the mainstream. Even so, the application of image segmentation algorithms might still be considered a 'black art', due to the dependence of the results on the image data and the limited and often vaguely specified control parameters available to the user. In the case of segmenting a complete Landsat Thematic Mapper (TM) scene three or four parameters may be the only control over the generation of in excess of 300,000 land parcels covering a broad range of land cover and landscape types.

Once a suitable set of parameters have been selected, the resulting segments reflect the spectral structure of the image rather than the true structure of the landscape (Figure 1). For instance, two adjacent fields with the same crop could be combined into a single object even though they may be owned by different farmers. Even if a boundary feature existed between them it would need to be spatially and spectrally significant at the spatial resolution of the image data to cause the segmentation algorithm to initiate a new object. Conversely, single fields that contain natural and acceptable variability may give multiple objects per field. For instance, a crop may progressively come into flower across a field and the pattern of flowering could be captured by the image data and then recorded as spurious objects. Segments and their boundaries also retain the inherent area sampling, raster structure, of the original image resulting in an unnatural stepped appearance which causes problems when comparing with other data sets, especially where they represented diagonal boundaries in a more conventional manner.

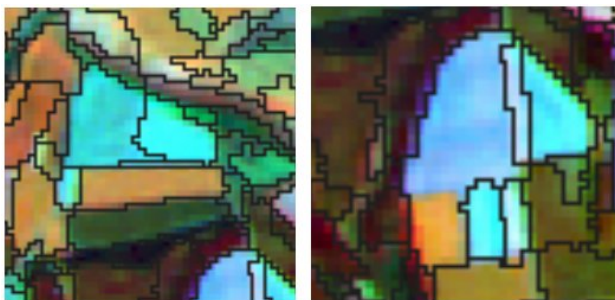


Figure 1. Examples of over and under segmentation when generating land parcel objects. The images also show the inherent image characteristics transferred to the segments.

The results of image segmentation therefore represent the sensors view of the surface rather than the users'. Unfortunately, even this view of the surface has limited repeatability over time due to changes in the surface and atmospheric characteristics caused by seasonality, illumination and climate. Also, at different times of year the combinations of

land cover types within a scene will have different relative spectral and textural separabilities and thus generate different sets of segments. The same can be said for different pre-processing methodologies and different segmentation algorithms (Carleer et al, 2005 & Neubert et al., 2006).

It could be suggested that this lack of a direct one-to-one relationship between real world objects and image segments has prevented GEOBIA reaching its full potential. The current situation is not too surprising as much of the earlier GEOBIA work was within the raster processing domain and only recently have fully structured digital vector cartography datasets and the necessary software tools become available to explore other approaches effectively.

4. EXTERNAL LINEWORK

Rarely today is any environmental analysis begun on a blank canvas, but in the context of existing mapping of some form, often available digitally. In regions of the world with high quality large scale cartographic mapping an obvious question is why is this information not used to control the GEOBIA process?

Even in the less cartographically developed parts of the world there will be some form of line work with which to at least begin the process of creating a landscape structure and thus a land parcel object data set. At the lowest level even national boundaries have been seen as controls on land cover type or condition due to, for instance, land management regimes or conflict.

Many countries with formalised systems of land ownership already have a land parcel data sets in the form of cadastral systems (Cadastral Template Project, 2008). Due to the nature of development of cadastre, the means employed for marking ownership on the surface and the consequent differences in land management, cadastral dataset can form a significant part of the required land parcel object set for a GEOBIA approach. Some cadastre also carry basic land cover information. Finally, in the most cartographically developed regions not only is ownership mapped, but also many of the key landscape features related to policy and land management.

In the context of national land cover mapping the land parcel objects required for the spatial framework will be fields, lakes and patches of woodland etc. The specific requirements will be related to the actual land cover classes present in a region and the final product required by the end user. It should also be noted that any digital cartography available is rarely acquired for the same purpose as the GEOBIA application and will require some form of pre-processing, often generalisation.

5. USE OF DIGITAL CARTOGRAPHY IN OBJECT BASED APPROACHES

Compared to the amount of reported work driven solely by image segmentation, the number of projects which have used external line work is very limited. However, even work dating back to the 1980s (e.g., Mason et al. 1988) saw the value of external line work to support image segmentation, even though they were hindered by technological limitations, leading to the approaches being rather simplistic.

More recent work has still been focused small scale studies, such as that of Dean and Smith (2003) who demonstrated the value of exploiting land parcel data sets when extracting

spectral information from images for classification. A slightly different implementation was employed by Aplin et al. (1999) who first classifying pixels individually using conventional means and then grouped the classified pixels per land parcel to derive a representative class (e.g. by calculating the modal class per object). This implementation was also used by Raclot et al. (2005) when updating a land cover classification product using a rule-based decision system. A further extension of this work was to locate fuzzy (sub-pixel) land cover class proportions spatially by segmenting the actual pixels according to polygon boundaries (Aplin and Atkinson, 2001), while Shackelford and Davis (2003) used sub-pixel class proportions to derive new land cover classes at the land parcel object level.

A number of projects have exploited agricultural land parcels data sets to improve crop mapping (e.g. Arikian 2004, Ozdarici and Turker, 2006) and the agricultural land parcels have been enhanced by identifying within parcel boundaries (Turker and Kok, 2006). Wu et al. (2007) used a combination of GIS and EO data to populate and analyse a set of tax parcel boundaries for land use classification.

A relatively large scale object-based land cover mapping exercise was undertaken while producing a land cover map for the island of Jersey in 1997 (Smith and Fuller, 2001). The island government had digital cartography available for an area of approximately 215 km², but this was too detailed to integrate directly with standard EO data sets. It was therefore necessary to generalise the digital cartography before the object-based classification could be applied. Unfortunately, at the time, the only means of doing this generalisation was by manually editing the line work and building objects from the disconnected lines. This process took around 2 person months and was therefore impractical for larger areas. The use of agricultural land parcels has been integrated as part of the land cover mapping initiatives of some countries (e.g. The Netherlands (Hazeu, 2006 & De Wit and Clevers, 2004))

6. A DEVELOPMENT EXAMPLE

The United Kingdom (UK) undertakes an assessment of its landscape at intervals of 8 to 10 years known as the Countryside Survey (CS). The main component of the CS is a ground based field survey of sample sites, but the last two CSs have included national land cover maps derived from Earth Observation (EO) data. The first of these, the Land Cover Map of Great Britain (LCMGB) in 1990, was a relatively simple pixel-based classification using Landsat Thematic Mapper (TM) data (Fuller et al., 1994). An update of LCMGB was produced between 1998 and 2001, referred to as Land Cover Map 2000 (LCM2000), which adopted an object-based approach (Fuller et al., 2002 & 2005). The production of the UK land cover maps has closely tracked methodological and technical developments in GEOBIA, but within a national operation context attempting to address a broad spectrum of end users.

LCM2000 used image segmentation to deliver an object-based product with a final dataset containing around 6.6 million segmented land parcels with a minimum mappable unit of 0.5 ha (Figure 2). Although, considered extremely successful from an EO point of view and also when undertaking regional assessments, the relationship between the segmented land parcels and the real world features in LCM2000 as seen by end-users did receive some criticism. The key issues were the uniqueness of the segments relative to existing products and mapping, the need to repeat the production at regular intervals and the difficulties of integration.

Production is now underway on a further update of the UK national land cover product with a target summer of 2007. This product will again be object-based, but this time digital cartography will be adapted to give an object structure which more accurately reflects the true structure of the UK landscape. Topologically structured Ordnance Survey (OS) MasterMap (MM) digital cartography has been generalised to provide land parcels for effective integration with EO data that has a spatial resolution of approximately 25 m (Smith et al., 2007). In comparison with a Landsat TM image (Figure 3) it can be seen that the generalised OS MM is fully aligned with the needs of an object-based analysis procedure at this scale. Assessment of the land parcel objects by aerial photography interpreters (Figure 4) has confirmed the quality and utility of the results with the correspondence to the underlying aerial photography being exceptionally good. In the example in Figure 4 there is arguably one missed field boundary and in practice the plantation woodland should be divided up into blocks that could be allocated to deciduous, coniferous or clear felling.

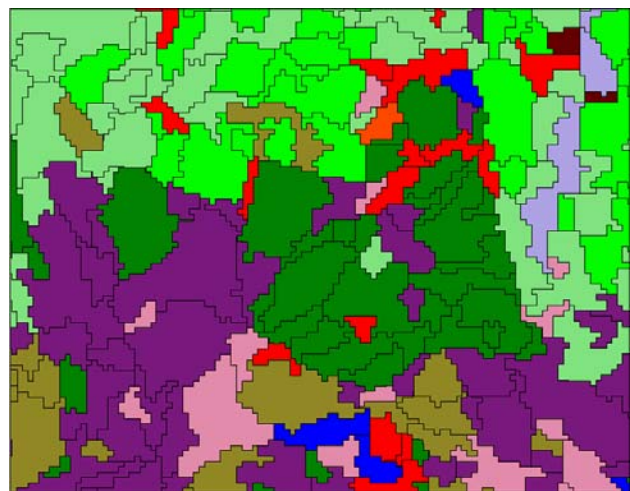


Figure 2. An example of LCM2000 data showing the land parcel object structure and the pixelated segments.

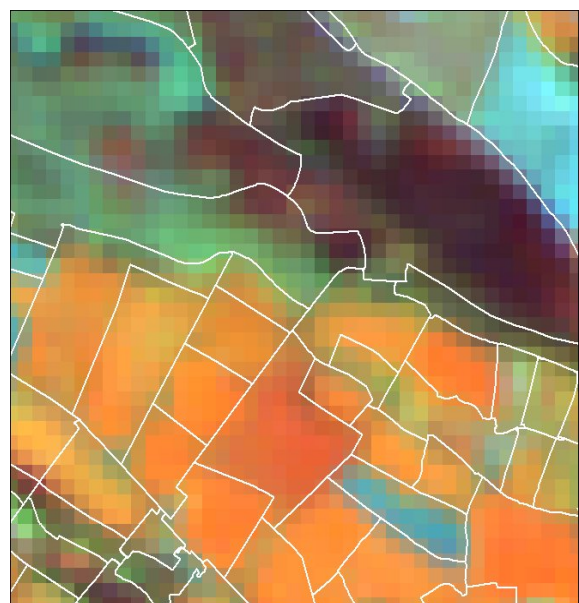


Figure 3. A comparison of generalised OS MM and Landsat Thematic Mapper data with a spatial resolution of 25 m.



Figure 4. A comparison of generalised OS MM and conventional aerial photography with a spatial resolution of less than 1 m.

When the generalised OS MM for LCM2007 was compared to contemporary EO data for a wider area two main issues related to its appropriateness for GEOBIA were identified. The generalisation of OS MM worked best in urban areas and rural areas dominated by pasture farming. The urban areas were well defined and changes in land cover were virtually always accompanied by some form of boundary which was mapped by the OS. In the agricultural landscape issues related to the presence of actual boundary features or just the operation of different land management practices comes into play. As pasture farming requires that all boundaries are stock proof, all land parcel boundaries will be mapped by the OS in this case. The generalised digital cartography appeared to be slightly less successful for deriving land parcel objects in the arable landscape where land cover boundaries appeared to be missing. Some of these missing boundaries were related to the 'open gate' problem where the original OS LandLine, a 'spaghetti' data set which formed MM, could not be built into complete area objects related to fields. Other missing boundary features were related to different farming practices being applied to different parts of the same field with no physical boundary present for the OS to map.

In the UK, for farmers to join and receive grants from government schemes there is a need to map the extent of different cropped areas and thus additional and complimentary land parcel boundaries are available. The Rural Land Register (RLR) held by the Rural Payments Agency (RLR) captures and maintains permanent field boundaries to create a spatial permanent boundary layer and produce an accurate digital map of declared agricultural land parcels (Figure 5). The second stage of the construction of the spatial framework for LCM2007 is therefore the integration of agricultural land parcel boundary information with the generalised OS MM where appropriate within the spatial specification and in a hierarchical fashion.

Another issue when building the spatial framework for LCM2007 concerned environments associated with semi-natural and upland land cover types. In these areas the total extents are mapped well by the OS MM data, such as the area

delineated by the 'high wall mark' in the uplands, but the internal divisions were poorly mapped. These internal divisions were often indistinct, complex and dynamic and the lack of permanent physical boundary features, walls, hedges, roads etc in upland areas generates large land parcels that do not adequately record the semi-natural vegetation structure within these landscapes. To complete the final part of the LCM2007 spatial structure, sub-segmentation based on EO data will be applied to large upland land parcel objects to generate the necessary internal boundaries (Figure 6). Landscape knowledge and the examination of within parcel variation of the EO data will limit the need for segmentation to only the areas where it is necessary.

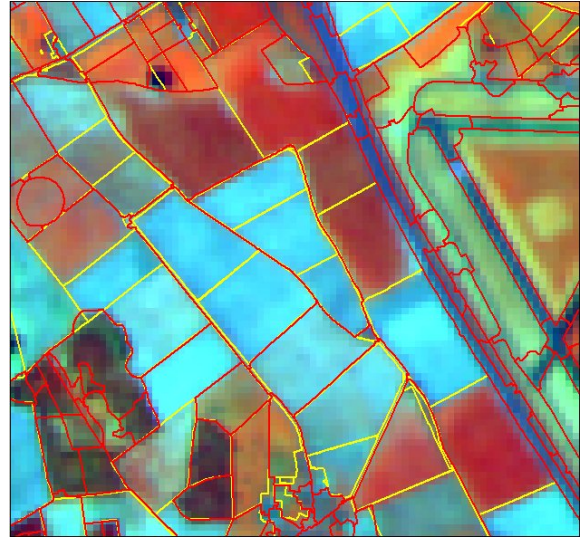


Figure 5. A comparison of generalised OSMM (red) and the additional boundary information available in arable areas from the agricultural land parcel datasets (yellow).

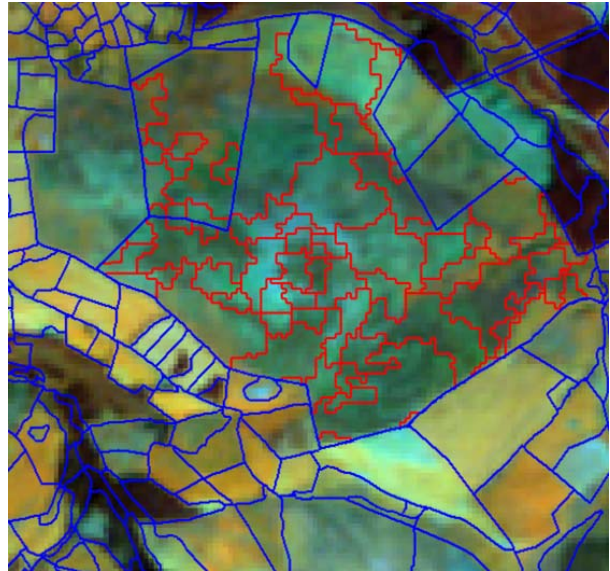


Figure 6. An example of a generalised OSMM land parcel objects subdivided by image segmentation of EO data applied within the land parcel object only.

The production of the LCM2007 will use all of the above processes to generate a consistent and objective landscape structure for the UK prior to the classification of land cover types by GEOBIA. This is therefore a multi-source solution that still contains image segmentation, but applied in the most effective manner.

7. CONCLUSIONS

One data source or one approach to the generation of land parcels for GEOBIA will rarely provide all of the necessary boundary information to a level of quality acceptable to all end users. Various sources of boundary information need to be combined in such a way as to maximise the quality of the final spatial structure and retain a level of traceability so that end users can effectively interpret the results. The details of this approach will obviously be application specific, but the use of existing linework first if appropriate and available would seem to represent an initial rule.

The use of external linework removes the constraints imposed by the image specification and characteristics from the majority of the process and allows the strength of the GEOBIA approach to be exploited. Tests have identified a further improvement of the performance of GEOBIA approaches when the land parcel objects are derived from external validated datasets. The segmentation can then be used where is most needed and most effective, deriving additional boundaries within existing land parcel objects which are either not mapped at all or are too subtle or dynamic to be mapped by conventional cartographic update.

It is proposed that the GEOBIA process be made more generic to use the best existing real world feature datasets as the starting point for the process before segmentation is considered. Such an approach would increase opportunities for integration with other datasets and improve the results of map update initiatives. The adoption of such approaches should result in great uptake of GEOBIA products and technologies by the end user community.

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