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Scale parameter selection by spatial statistics for GeOBIA: Using mean-shift based multi-scale segmentation as an example

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ABSTRACT

Geo-Object-Based Image Analysis (GEOBIA) is becoming an increasingly important technology for information extraction from remote sensing images. Multi-scale image segmentation is a key procedure that partitions an image into homogeneous parcels (image objects) in GEOBIA. Hierarchical image objects also provide a better representation result than a single-scale representation. However, scale selection in multi-scale image segmentation is always difficult for high-performance GEOBIA. This paper first generalizes the commonly used segmentation scale parameters into three aspects: spatial bandwidth (spatial distance between classes), attribute bandwidth (difference between classes) and merging threshold. Next, taking mean-shift multi-scale segmentation as an example, this paper proposes a spatial and spectral statistics-based scale parameter selection method for object-based information extraction from high spatial resolution remote sensing images. The main idea of this proposed method is to use the ALV graph to replace the semivariogram to pre-estimate the optimal spatial bandwidth. Next, the selection of the optimal attribute bandwidth and the merging threshold are based on the ALV histogram and simple geometric computation, respectively. This study uses Ikonos, Quickbird and aerial panchromatic images as the experimental data to verify the validity of the proposed scale parameter selection method. Experiments based on quantitative multi-scale segmentation evaluation testify to the validity of this method. This pre-estimation-based scale parameter selection method is practically helpful and efficient in GEOBIA. The idea of this method can be further extended to other segmentation algorithms and other sensor data.

1. Introduction

With the improvements in satellite sensor technology, the spatial resolution of remote sensing images has significantly increased. In very high spatial resolution images, it often occurs that different classes have the same spectral reflectance or the same class has different spectral reflectances (strong spectral variability within class). Thus, pixel-based multi-spectral image classification not only leads to misclassification but also results in broken patches. GEOBIA (Hay and Castilla, 2008), the geo-related sub-discipline of OBIA (Object-Based Image Analysis), has become increasingly commonplace over the last decade (Blaschke, 2010), and its popularity continues to sharply increase (Blaschke et al., 2014) because it can effectively incorporate spatial information and expert knowledge into the classification, and the classified image objects are a useful link on which remote sensing and GIS can be integrated (Blaschke et al., 2008; Blaschke, 2010). Multi-scale image segmentation is the foundational procedure of OBIA in which the digital image is transformed from discrete pixels into homogeneous image object primitives (Vieira et al., 2012). Blaschke et al. (2004) provide an overview of numerous segmentation techniques used in remote sensing. However, the real challenge is to define appropriate segmentation parameters (Hay et al., 2005). Object-based scale selection (scale parameter selection in the image segmentation, see Ming et al. (2011)) is the key to GEOBIA because an inappropriate scale will lead to over-segmentation or insufficient segmentation (Ming et al., 2012), which will directly reduce the accuracy and efficiency of multi-scale information extraction from high spatial resolution remote sensing images (Myint et al., 2011; Ming et al., 2011; Dronova et al., 2012). Although GEOBIA is becoming increasingly prominent in remote sensing science (Blaschke et al., 2008), the selection of segmentation scale parameters is often dependent on

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subjective trial-and-error methods. A ready-to-use application allowing the user to evaluate the scale parameter as a function of the intrinsic spatial structure of images before segmentation is not common.

Kim et al. (2008) noted that defining the most suitable scale for image segmentation is still problematic as no objective method currently exists for setting the scale parameter in segmentation algorithms. Currently, several multi-scale segmentation algorithms have been proposed and applied in remote sensing image analysis, including watershed segmentation (Vincent and Soille, 1991; Scheunders and Sijbers, 2002), multi-resolution segmentation (Definiens Developer ®) (Baatz and Schäpe, 2000; Peña-Barragán et al., 2011; Duro et al., 2012) and mean-shift segmentation (Comaniciu and Meer, 2002; Comaniciu, 2003; Rao et al., 2009; Zhou et al., 2013). Among these algorithms, watershed segmentation has specific scale parameter, namely, the sampling window size, valley threshold and catchment area threshold; however, the relationship between segmentation results on different scales cannot be easily determined. Multi-resolution segmentation (Baatz and Schäpe, 2000; Baatz et al., 2000; Benz et al., 2004) is based on the idea of Fractal Net Evolution approach (Baatz and Shäpe, 1999), and it not only provides a scale parameter but also incorporates the hierarchical relationship between different levels. The scale parameter in multi-resolution segmentation is very important and it determines the average image object size by determining the upper limit for a permitted change of heterogeneity throughout the segmentation process. However, the scale parameter is an abstract value used to determine the maximum possible change of heterogeneity caused by fusing several objects, and it is difficult for a user to quantitatively select the optimal scale parameter without repetitious trials because the practical meaning of scale parameter is different in different segmentation mode (Normal, Spectral difference and Sub obj.line analysis) provided by eCognition. The relation between the scale parameter and the image data is complicatedly tacit and cannot be directively and easily built.

Because the mean-shift segmentation algorithm has the advantages of a specific scale parameter and a hierarchical relationship between segmentation levels, this paper adopts the mean-shift multi-scale segmentation algorithm to extract the homogenous parcels from high spatial resolution images. Based on the essence of spatial dependence for scale, this paper combines the theories of geospatial statistics and pattern recognition and proposes an optimal scale parameter selection method based on average local variance (ALV) for mean-shift image segmentation. Compared with existing studies on scale parameter selection that are based on post-evaluation, the characteristic feature of this method is that it is based on pre-estimation. The method is further validated based on multi-scale segmentations of Ikonos and Quickbird panchromatic image data.

2. Object-based scale and optimal object-based scale selection

Scale is a broadly used term in geoscience and has a variety of meanings in different contexts. Although GEOBIA has drawn considerable attention in remote sensing image processing and analysis, a specific concept of an object-based scale of remote sensing images has not been given. Ming et al. (2011) generalized the three levels of connotation of the spatial scale of remote sensing images (pixel-based, object-based and pattern-based scales). The object-based scale is considered the size of the meaningful unit (image primitive). An image object is defined (Definiens, 2007) as a group of connected pixels that have homogenous features. Thus, the object-based scale refers to the spatial extent or the size of image object, and the optimal object-scale refers to the optimal size of the smallest class or the optimal size for different classes. From the viewpoint of using an algorithm to extract the image objects, the object-based scale corresponds to the scale parameters in the multi-scale image segmentation, and the optimal object-based scale corresponds to the optimal segmentation level that contains the most pure objects and the least mixed objects, and as a result, the subsequent object-based classification can achieve high accuracy.

In image processing, some attempts have been made to select the optimal scale parameters for multi-scale segmentation. For example, Claudio (2007), Tian and Chen (2007), Tan et al. (2007), Kim et al. (2008), He et al. (2009) and Johnson and Xie (2011) used the indices of the homogeneity within the segmentation parcels and the heterogeneity between the segmentation parcels to select the optimal scale parameter. Drăgut et al. (2009) presented a focal mean statistics-based procedure to optimize the parameterization and to scale for terrain segmentation. Drăgut et al. (2010) proposed the idea that the local variance (LV) of object heterogeneity within a scene can indicate the appropriate scale level, and they introduced an ESP (Estimation of Scale Parameter) tool to find optimal parameters for the multi-resolution segmentation. Karl and Maurer (2010) use variogram-based spatial dependency prediction to determine appropriate segmentation scales for producing land-management information. The rule Eid et al. (2010) use to detect the optimal scale is that if the area of an object is kept static or nearly static in a set of successive scales, then any of these scales can be chosen as the appropriate scale. Anders et al. (2011) evaluate the quality of the segmentation results for each specific geomorphological feature type to optimize segmentation parameters. Zhao et al. (2012) employed the changed ROC-LV method, similar to the ESP tool by Drăgut et al. (2010), to judge the optimal scales in the slope segmentation by using multi-resolution segmentation and eCognition software. However, these methods and applications are actually intended to select the scale by post-evaluation of the multi-scale segmentation, not pre-estimation of the optimal scale parameters. Additionally, most of them are basically based on the multi-resolution segmentation provided by Definiens Developer®, in which the meaning of the scale parameter is complicated, making it practically difficult to understand the relationship between the scale selection indictors and the scale parameter.

Scale parameters selection for multi-scale image segmentation in image processing is also called bandwidths selection for mode clustering in pattern recognition. In pattern recognition, some bandwidth selection methods in this context also have been explored for multi-scale clustering. Comaniciu (2003) discussed the optimal bandwidths (based on asymptotic bias-variance trade-off) originally derived for the purpose of multivariate normalized density estimation, however this idea was discarded quickly for practical considerations (Einbeck, 2011). An alternative family of methods, which is tailored toward the extraction of reliable scale information for multi-dimensional data, attempts to maximize the stability of the partitioning under variation of the bandwidth (Comaniciu et al., 2001; Comaniciu, 2003; Einbeck, 2011). However, it is not clear whether a bandwidth which is optimal for the clustering is necessarily optimal for the problem of finding local modes. What's more, these works are mostly based on discrete simulated data sets which seldom present in reality, therefore the resulting bandwidth is often of little practical use (Li et al., 2005; Li et al., 2007; Zhang et al., 2012). In addition, (Park et al., 2009; Sun and Xu, 2010; Vojir et al., 2014) employ estimation of local structure to select the bandwidth or scale parameter for image segmentation or filtering. However, these methods are mainly based on natural color images that are greatly differing from remote sensing images, their performance on complex remote sensing image segmentation need to be further verified.