UNSUPERVISED LANDSCAPE UNIT MAPPING BASED ON MULTI-SCALE ANALYSIS*

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ABSTRACT

We present the preliminary development of a segmentation algorithm for landscape unit mapping. A multi-scale approach is used (i) to establish local proportion of land cover types within different window sizes centered around each pixel and (ii) to determine the suitability of each window size to support pattern unit candidacy. A fusion process of the multi-scale proportion map is then carried out at each pixel position based on minimum acceptable size of pattern unit. An unsupervised segmentation algorithm is finally utilized to cluster the resulting fused map into homogeneous regions. Preliminary results are presented for a 10-class land cover map derived from a supervised classification of a 30 km x 30 km subarea of a Landsat TM scene.

1.0 INTRODUCTION

Landscape measures, also referred to as landscape metrics or landscape indices, have been widely used to quantify environmental heterogeneity (see, Gustafson 1998 for a review on landscape measures). These indices are particularly useful to monitor the dynamical change of landscape patterns (Pan *et al.*, 1999). The sampling design for landscape monitoring, *i.e.* the partitioning of the landscape into units within which landscape metrics are computed, is an important issue. For example, it is well established that landscape metrics are scale-dependent (Turner *et al.*, 1989) and thus sensitive to the sampling design. The sampling design issue is furthermore somehow complicated by the fact that there is no unique definition of landscape (EPA, 1994). In most applications, landscape units are usually delineated based on (i) administrative (e.g. county) or physiographic regions (e.g. watershed), (ii) on a regularly spaced partitioning grid (e.g. rectangles), or (iii) on landscape pattern types (limited number of cover types that form a consistent pattern). It is also recognised that landscape units are scalable (EPA, 1994). The impact of using inadequate landscape unit boundaries is that heterogeneous land cover patterns may exist within the same landscape unit reducing the ability to discriminate between homogeneous units (Cain *et al.*, 1997). Moreover, a loss of sensitivity may be expected in multi-temporal data analysis for the detection of localised areas of rapid changes (Brown *et al.*, 2000).

In this paper, we present early experimental results of a segmentation algorithm developed for landscape unit mapping based on computer analysis of a digital thematic map. The objective is to partition the landscape into non-overlapping units such that the characterization and the monitoring of the landscape can be performed within areas of similar (predefined) properties. In this work, we define a landscape unit as a mosaic of land cover types that comprise a logical grouping. This definition is in agreement with EPA (1994).

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2.0 RELATED WORKS

The mapping of landscape units, based in part or wholly on TM data, is generally achieved from visual inspection. For example, Davis *et al.* (1994) delineated apparent landscape boundaries from image tone and texture analysis of Landsat TM imagery. Wickham and Norton (1994) mapped landscapes according to pattern types from visual inspection of Landsat TM scenes. They mapped landscapes as '… clusters of 2 or 3 land cover types, based on their pattern within the clusters and tendency for a single type to dominate.'

3.0 COMPUTER-BASED LANDSCAPE UNIT MAPPING

Subjectivity is inevitable in drawing landscape boundaries from visual inspection. Even under well-defined rules, different mapping results may emerge from different interpreters (see, *e.g.*, the measure of repeatability reported in Wickham and Norton 1994). Consistency can be reached using computer analysis of digitized maps (note that consistency is not a guarantee of accuracy). The approach we use shares similitude with multi-scale analysis techniques developed for texture segmentation (Tuceryan and Jain, 1998). The main differences are that (i) the algorithm is applied on a thematic map instead of raw imagery, and (ii) a selective rule is chosen to fuse multi-scale information instead of an integration rule. Selective rules have been proposed in the feature-based image fusion literature (*e.g.*, Li *et al.*, 1995).

In the present work, land cover composition similarity is adopted as the logical grouping criterion. Recall that we define a landscape unit as a mosaic of land cover types that comprise a logical grouping. An overview of the proposed algorithm is shown in Fig. 1. The multi-scale approach is used (i) to establish local proportions of land cover types within different window sizes, *w*, centered around each pixel and (ii) to determine the suitability of each window size to support pattern unit candidacy. The latter is an indicator on the admissibility of the characteristics of the area enclosed within the window to conform to the adopted logical grouping convention. It is defined in terms of land cover diversity and spatial arrangement. A fusion process of the multi-scale proportion maps is then carried out at each pixel position based on pattern unit minimum acceptable size. An unsupervised segmentation algorithm is utilized to cluster the resulting fused map into homogeneous regions. A filtering process aim at removing small landscape units is finally performed. Each step is now described in more detail.

3.1 MULTI-SCALE PROPORTION MAPS

The digital thematic map is decomposed into a multi-scale representation based on local evaluation of land cover type proportions. The proportion of each land cover is computed around each pixel position within a specified window size (scale). Note that because of the partial overlap, the measures computed within each window are not statistically independent. The minimum window size is fixed to 33 pixels on a side and corresponds to about 1 km. Limits of that order have been used in previous studies (Davis *et al.*, 1994; Wickham and Norton, 1994) in order to agree with the lower limit for a landscape, as defined by Forman and Godron (1986). The window size is progressively increased by a factor 2 until it reaches a size of one-eighth the image dimension. This upper limit is imposed because a landscape unit must contain a minimum number of repetitive pattern units to be defined as such (see next section for the definition of pattern units). Each proportion map is encoded in a datacube format. At each pixel position there is a vector $P_w(p_1, p_2, p_3, \ldots, p_k)$ that gives the proportion p_i of cover type i, i=1 to k, computed within a window of size w [pixels]. There are as many proportion maps as there are windows.

3.2 PATTERN UNIT CANDIDACY BINARY MAPS

A pattern unit may be defined as '… *a collection of measurement units and/or patch units which have the property of being the minimum descriptor of a larger area*.' (EPA, 1994). Although this definition can be relatively easy to conceptualise from a human interpreter standpoint, it is more difficult to capture such a definition in mathematical terms. To determine if the land area enclosed within a given window can potentially represent a pattern unit, we formulate two simple conditions:

(1) There are at least 2 different cover types within the window; each of them having proportions greater than 10%.

(2) At least one of the two cover types (>10%) has 2 spatially disconnected patches within the window (we refer to patch as an ensemble of spatially connected pixels of a same cover type; note that patches are determined within the whole image and not within the local window). Only the two cover types having the highest proportions are checked, i. e. the two predominant cover types.

The first condition is the basic criterion required because of the 'mosaic of cover types' landscape unit definition we adopted. The minimum threshold imposed on proportions helps avoiding cases where one of the cover types consists of a few isolated pixels. The second condition helps prevent the subsampling of individual patch by taking into account the inter-patches distances of a potential pattern. It also eliminates cases where the window centre is located on the boundary of 2 large patches.

A map is generated where a value of 1 is assigned to a pixel that satisfies both conditions. Otherwise, a value of 0 is attributed. One binary map is generated for each scale.

3.3 FUSION OF PROPORTION MAPS

In the fusion step, a composite proportion map is constructed at each pixel position from the selection of one of the feature vectors P_{33}, P_{65}, …, or P_{wmax}. The fusion rule consists in selecting the land cover proportion vector computed within the minimum window size for which the corresponding pattern unit candidacy index is equal to 1. If none of the window sizes support pattern unit candidacy, then the feature vector from the minimum window size is selected, in the present case P_{33}.

3.4 UNSUPERVISED CLUSTERING

The goal of the clustering step is to partition the fused proportion map into groups of homogeneous land cover composition (logical grouping criterion). We adopt an unsupervised approach since the different landscape unit categories are unknown. In the present experiment, the k-means algorithm has been used to perform this task. Cluster aggregation may be performed at this step (recall that landscape units are scalable entities).

3.5 LANDSCAPE UNIT FILTERING

The purpose of this step is to re-label landscape units of small extent that are embedded in larger ones, in a way somewhat similar to a majority filter applied after a per-pixel image supervised classification process. This operation is particularly appropriate when the goal is landscape monitoring from landscape index measurements. This topic will be further discussed in the next section.

4.0 EXPERIMENTAL RESULTS

Results are presented for a 10-class land cover thematic map. The map was derived from gaussian-based maximum likelihood supervised classification of a Landsat TM subset forest scene acquired on 4 July 1988 (Path-Row No. 8-23). The pixel size is 30m and the image subset size is 1024 by 1024 pixels (~30 km x 30 km).

The multi-scale proportions maps were computed for three different window sizes, w = 33, 65 and 129 pixels (~1, 2 and 4 km). The k-means clustering algorithm implemented in PCI was run, using default parameters, on the fused proportion map. The resulting k-means output contained 7 clusters. Each cluster may be assimilated to a landscape unit category. Visual inspection of the segmented image as well as the individual cluster statistics revealed that some of them were composed of the same main cover types but in different proportions. These clusters were merged (recall that landscape units are scalable entities), reducing the number of landscape unit categories from 7 to 5. Moreover, landscape units smaller than 4096 pixels (equivalent to a square unit of 64 x 64 pixels) have been re-labelled to the unit category they are embedded in. In the context of landscape monitoring, the computation of landscape indices within such small units is not convenient. Figure 2 shows the final boundary map (black contour lines corresponding to vector data describing the boundaries of polygons in the segmentation map) overlaid on the thematic map.

5.0 DISCUSSION

The experimental results shown in Fig. 2 indicate that, generally, similar cover types mixtures are enclosed within distinct landscape units. However, the segmentation result is not totally satisfying. For example, (i) the large water body in the middle-right portion of the map is not accurately delimited by the computed boundaries, (ii) some patches are split between two different landscape units, and finally, (iii) the contour shapes are not always smooth (specially around the large water body where there are blocking effects). We also noticed during the experimentation that the final results are sensitive to the clustering algorithm used (*e.g.* isodata vs. k-means, number of requested clusters).

Like unsupervised segmentation of textured images, landscape partitioning is a difficult and challenging computer problem. Although the present study is restricted to an experiment conducted on one single map of small dimension, this preliminary result indicates an interesting direction for landscape unit mapping from computer analysis. Further work is required regarding the adequacy of the pattern unit candidacy criterion, the clustering algorithm step (e.g. how to determine the number of clusters), and the elimination of blocking effects. The approach needs also to be tested on different types of landscape of larger extent.

6.0 ACKNOWLEDGMENTS

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7.0 REFERENCES

D. Brown, J. -D. Duh and S. Drzyzga, 'Estimating Error in an Analysis of Forest Fragmentation Change Using North American Landscape Characterization (NALC) Data,' *Remote Sensing of Environment*, Vol. 71, pp. 106-117, 2000.

D. H. Cain, K. Riitters and K. Orvis, 'A Multi-Scale Analysis of Landscape Statistics,' *Landscape Ecology*, Vol. 12, pp. 199-212, 1997.

F. W. Davis, P. A. Stine and D. M. Stoms, 'Distribution and Conservation Status of Coastal Sage Scrub in Southwestern California,' *Journal of Vegetation Science*, Vol. 5, pp. 743-756, 1994.

Environmental Protection Agency (EPA), *Landscape monitoring and Assessment Research Plan*, EPA 620/R-94/009, Office of Research and Development, Washington, D.C. 1994.

R. T. T. Forman and M. Godron, *Landscape Ecology*, John Wiley and Sons, New York, 619 p., 1986.

E. J. Gustafson, 'Quantifying Landscape Spatial Pattern: What Is the State of the Art?,' *Ecosystems*, Vol. 1, pp.143-156, 1998.

H. Li, B. S. Manjunath and S. K. Mitra, 'Multisensor Image Fusion Using the Wavelet Transform,' *Graphical Models and Image Processing*, Vol. 57, pp. 235-245, 1995.

K. McGarigal and B. J. Marks, FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. *General Technical Report PNW-GTR-351, USDA Forest Service, Pacific Northwest Research Station*, Portland, OR. 1995.

D. Pan, G. Domon, S. de Blois and A. Bouchard, 'Temporal (1958-1993) and Spatial Patterns of Land Use Changes in Haut-Saint-Laurent (Quebec, Canada) and their relation to landscape physical attributes,' *Landscape Ecology*, Vol. 14, pp. 35-52, 1999.

PCI, ImageWorks, Version 6.3 (October 1998), Richmon Hill, Ontario.

M. Tuceryan and A. K. Jain, 'Texture analysis.' In *The Handbook of Pattern Recognition and Computer Vision*, 2nd ed., C. H. Chen, L. F. Pau, and P. S. P. Wangs, Eds. World Scientific Publishing, Chap. 2.1, 1998.

M. G. Turner, R. V. O'Neil, R. H. Gardner, and B. Milne, 'Effects of Changing Spatial Scale on the Analysis of Landscape Pattern,' *Landscape Ecology*, Vol. 3, pp.153-162, 1989.

J. D. Wickham and D. J. Norton, 'Mapping and Analyzing Landscape Patterns,' *Landscape Ecology*, Vol. 9, pp. 7-23, 1994.

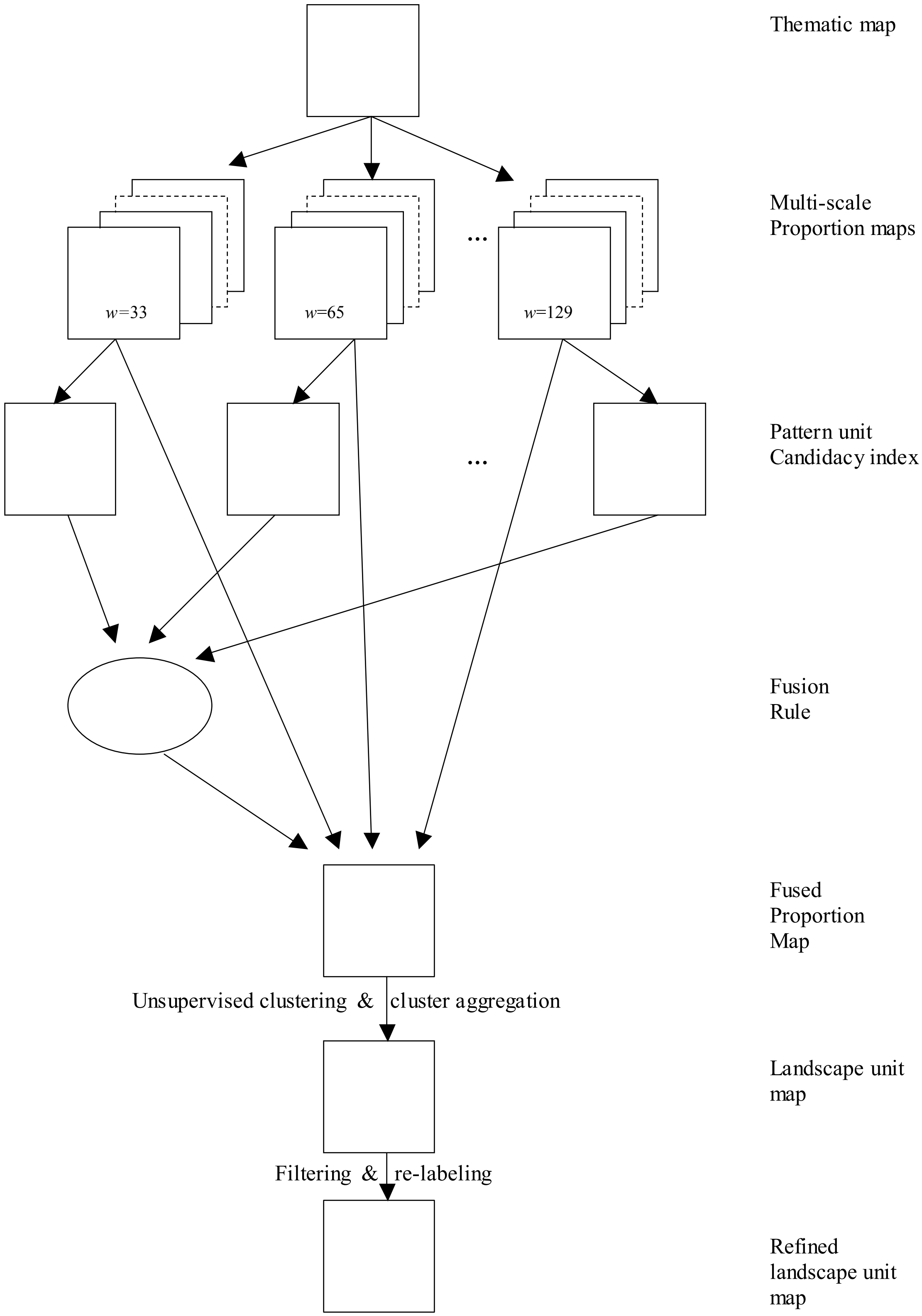

Figure 1. Schematic view of the segmentation algorithm.

Figure 2. 10-classes land-cover thematic map. The landscape unit boundaries correspond to the black contour lines.