Ecological Modelling 363 (2017) 1–7

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Configurational changes of patchy landscapes dynamics

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ARTICLE INFO

Article history:
Received 26 January 2017
Received in revised form 8 August 2017
Accepted 9 August 2017
Available online 5 September 2017

Keywords:
Landscape modeling
Vectorial mosaics
Minkowski sum
Forest
Savanna

ABSTRACT

This paper introduces dynamic configurational changes for patchy mosaics, parameterizable dilation and/or erosion processes of units in a vectorial landscape. Patchy-based models are rare although this conceptual framework could yield insights to the functioning and dynamics of agricultural and natural landscapes. Compared to common raster-based models, they are more parsimonious and intuitive, but their algorithmic computations are challenging. The aim of this study is to implement polygon dilation throughout Minkowski sum on polygons, along with their associated formal grammar, in the DYPAL modeling platform. This computation is a challenging open-problem and this paper provides a first working approach along with the methodology for a generic implementation framework. As an example, this paper illustrates configurational changes on a complex forest-savannah dynamics in a tropical biodiversity hotspot, New Caledonia. Finally, perspectives for configurational changes in landscape modeling are discussed.

1. Introduction

Landscape ecology aims at understanding how and why the composition and configuration of landscapes influence ecosystem functions and habitat quality in spatially heterogeneous areas (Wu and Hobbs, 2002). Understanding configurational changes remains challenging due to the diversity of the landscape unit (patch) natures and their intricate interactions. Landscape modeling is of capital interest for this purpose and, consequently, to be able to make reliable predictions on their dynamics, whatever their urban, agricultural or natural types. The main objective of this study was to implement configurational changes of patches in vectorial landscapes. This study then exemplifies configurational changes in a complex forest-savannah mosaic in a tropical hotspot in New Caledonia.

Most landscape models rely on a set of mechanisms driving the evolution and the interaction of landscape units in a spatiotemporal framework (Costanza and Voinov, 2004; Houet et al., 2014; Verburg et al., 2006). To model the dominant driving forces, be they natural or anthropic, is a first critical step towards understanding the landscape dynamics. Simulation of such mechanistic models then allow exploring applied questions, such as which policies should be adopted to minimize habitat destruction or which mosaic would favor flagship species (Butler et al., 2007; Fahrig and Nuttle, 2005).

A typical landscape mosaic is composed of several two-dimensional units that can be described through their *configuration*, *i.e.* their spatial arrangements such as their shape or topology, and their *composition*, *i.e.* their type of land cover and land use (Li and Reynolds, 1994). Two complementary paradigms can be used to model such mosaics, depending on how their constitutive units are handled, namely vectorial and raster landscapes (Gaucherel et al., 2006; Longley et al., 2005). In vectorial landscapes, patches are described by the exact coordinates of their bounding vertices, and associated with a uniform compositional (land cover) type. Although conceptually coherent with the inherent nature of observed patches, this approach is, by far, less explored than raster

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http://dx.doi.org/10.1016/j.ecolmodel.2017.08.007
0304-3800/

landscapes. Indeed, most models convert patchy or vectorial landscapes into pixel or raster landscapes according to a regular grid through the process of "rasterization". This approach is very common for at least two reasons: i) remote sensing instruments also use such grid-based format, and ii) modeling is more straightforward, since neighboring pixels and their geometries are constrained by this matricial representation. These raster models, pretending to mimic real landscapes such as the game of life (Conway, 1970), or much more sophisticated such as the SME (Maxwell and Costanza, 1997) and CLUE (Verburg et al., 2002) platforms, can reproduce observed landscape patterns and sometimes bring deep insights on the underlying processes.

Conversely, patchy-based models are still rare, although their conceptual framework could reveal insights on the functioning of agricultural and natural landscapes. From a functional point of view, vectorial models are more parsimonious and meaningful (see Gaucherel et al., 2014, 2006 for a more exhaustive discussion; Levin et al., 1993). In patchy-based models, natural/agricultural units are not decomposed into a set of neighboring non-autonomous pixels sharing the same composition but are directly handled as autonomous patch entities. In other words, the vectorial modeling of a mosaic is object-oriented. While such a vector mode is quite inappropriate for point-patterns, vector mode provides the framework to handle polylines, such as rivers, roads or hedgerows (Gaucherel, 2008; Gaucherel and Salomon, 2014). This allows the development of a formal grammar that governs the landscape dynamics, *i.e.* a formalization based on a set of grammatical rules (Gaucherel et al., 2012), revealing that the number of possible changes is relatively low and generic: any heterogeneous mosaic can be modeled and understood with only eight operations (Fig. 1).

Such patchy-based modeling has been successfully implemented, mostly on compositional changes. For example on agricultural landscapes, farmers create, maintain, and manage the composition of patches: for example, farmers decide to shift half of their crop fields into fallows and after one year, start a new cycle of cultivation (Gaucherel et al., 2009). In these so-called "land cover rotations", patch shapes and arrangements are unchanged. Depending on the landscape dynamics being modeled, configurational changes may simultaneously be required. Some recent attempts to manage simple configurational changes such as patch (field or farm) merges can be found in the literature (Houet et al., 2014). As a more challenging issue, the modeling of a forest-savannah mosaic, such as the one used as a case study here, shall integrate two antagonistic configurational changes: the forest dilation (forest colonization) over savannah patches, and the savannah dilation (burn) over forest patches and due to fire. To our knowledge, this study present the first attempt to model and formalize such realistic landscape dilations which opens a new avenue for a comprehensive understanding of landscape dynamics.

The main objective of this paper is to report the implementation of dilation configurational changes in a patchy landscape, using the free open-source DYPAL modeling platform (http://amap-collaboratif.cirad.fr/pages_logiciels/index.php?page=dypal) dedicated to patchy landscape dynamics (Gaucherel et al., 2009, 2006). With this configurational change added, it now gathers all possible operations on patches (Fig. 1) and combines them into a coherent mathematical framework, based on a formal grammar. It consists of a set of rules inspired from linguistic and computer-based developments to handle complex 2D graphs, which translates any spatial ecological process into algorithmic operations on the studied mosaic. In other words, this grammar handles and rigorously formalizes composition and configuration changes of patches across the modeled landscape (Gaucherel et al., 2012). The second objective was to show the application of such configurational changes through the case study of a forest-savannah mosaic driven by gradual processes that should be best handled by the dilation operation. Finally, we discuss the interest and genericity of such landscape dynamics using configurational changes, and their potential interest for landscape modeling.

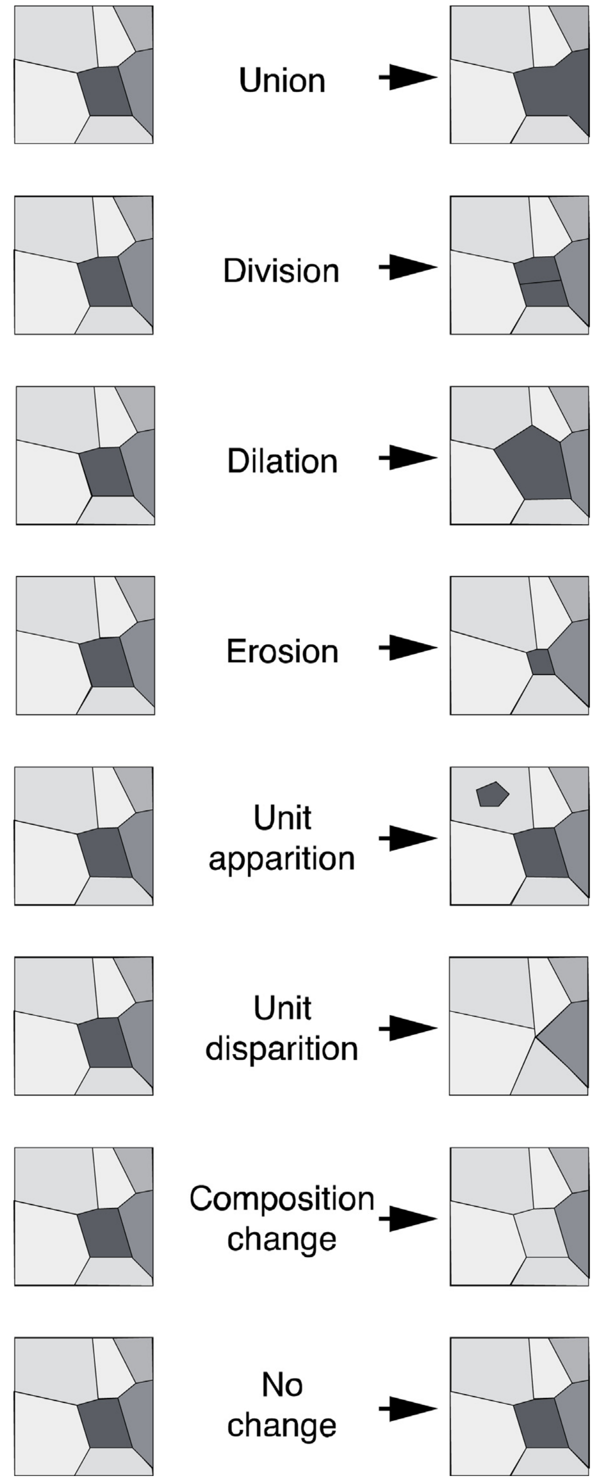

Fig. 1. The eight possible changes for a patch unit. Changes are illustrated by the fate of the central dark grey patch, a "word" in the modelling formalization. These modelling operations correspond to grammatical "rules" (called rewriting/production rules) in the definition of DYPAL equations.