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A simulated annealing algorithm for zoning in planning using parallel computing

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ABSTRACT

There is an increasing demand for tools that support land use planning processes, particularly the design of zoning maps, which is one of the most complex tasks in the field. In this task, different land use categories need to be allocated according to multiple criteria. The problem can be formalized in terms of a multiobjective problem. This paper generalizes and complements a previous work on this topic. It presents an algorithm based on a simulated annealing heuristic that optimizes the delimitation of land use categories on a cadastral parcel map according to suitability and compactness criteria. The relative importance of both criteria can be adapted to any particular case. Despite its high computational cost, the use of plot polygons was decided because it is realistic in terms of technical application and land use laws. Due to the computational costs of our proposal, parallel implementations are required, and several approaches for shared memory systems such as multicores are analysed in this paper. Results on a real case study conducted in the Spanish municipality of Guitiriz show that the parallel algorithm based on simulated annealing is a feasible method to design alternative zoning maps. Comparisons with results from experts are reported, and they show a high similarity. Results from our strategy outperform those by experts in terms of suitability and compactness. The parallel version of the code produces good results in terms of speed-up, which is crucial for taking advantage of the architecture of current multicore processors.

1. Introduction

The design of a land use map is a laborious task that requires deep knowledge and expertise. The development of new automatic processes and tools to help public administrations and technicians in this task is of strategic importance. In this work a novel mechanism to achieve near-optimal solutions to this problem is introduced. It is formulated in terms of a multiobjective optimization problem in which plots are allocated to the most appropriate land category for it. **Plots** are land basic elements that can be assigned one category, in our case they are cadastral plots. Fig. 1 shows a group of 15 plots that are used as an example in this paper. Objectives to be considered often include land suitability for the land category (Arentze, Borgers, Ma, & Timmermans, 2010; Cromley & Hanink, 2003; Eastman, Jin, Kyem, & Toledano, 1995). Also, some authors consider spatial criteria, especially the compactness of the regions allocated to one single category (Aerts, Eisinger, Heuvelink, & Stewart, 2003a; Duh & Brown, 2007; Janssen, van Herwijnen, Stewart, & Aerts, 2008; Nalle, Arthur, & Sessions, 2002; Stewart, Janssen, & van Herwijnen, 2004) because an irregular allocation of land categories in small, scattered, unconnected areas is usually undesirable in terms of economic and technical impact.

The problem of allocating different categories to specific land units can be established formally as a combinatorial optimization problem. A large number of alternative solutions can be usually found, and their quantitative comparison is usually important to validate the quality of the solutions and to justify them. Moreover, the number of plots involved in a municipal land use plan is usually large. Because these two factors lead to a high computational load, the search for the optimal solution usually calls for the use of heuristic algorithms capable of achieving near-best solutions in a reasonable time (Matthews, Craw, & Sibbald, 1999). As a consequence, heuristics are used to obtain near optimal solutions. In particular, a number of authors have used algorithms based on the simulated annealing technique to optimize the allocation of land uses to spatial entities (Aerts & Heuvelink, 2002; Aerts, van Herwijnen, & Stewart, 2003b; Boyland, Nelson, & Bunnell, 2004; Duh & Brown, 2007; MartÃ-nez-Falero, Trueba, Cazorla, & Alier, 1998;

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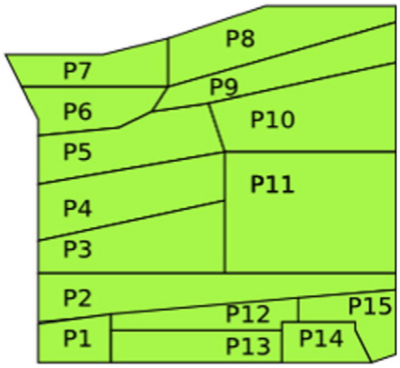

Fig. 1. Example of a set of plots.

Sante, Boullen, Crecente, & Miranda, 2008; Sharma & Lees, 2004; Watts et al., 2009). All these iterative algorithms operate on a regular raster grid. However, land use allocation based on a regular grid is usually unrealistic as it may lead to a single-land use plot allocated to several categories or, more frequently, to a group of very different plots allocated to a single category. Therefore, the use of a coarse raster grid can create areas of assumed homogeneous land that may contain variability (Stevens, Dragicevic, & Rothley, 2007). In addition, the planning laws in the study area often require land use zoning to be based on cadastral plots. We argue that the use of plot polygons instead of grid cells is more convenient but involves using complex compactness metrics based on geometric characteristics of these regions such as their area and perimeter.

The proposed objective function that guides the simulated annealing combines two subobjectives: maximization of land suitability and maximization of compactness. This approach complements a previous work (Suarez et al., 2011) in which a first approach to the proposed objective function is established with preliminary results. In (Porta et al., 2013) genetic algorithms are used to deal with this problem based on the former objective function. In this paper we present an objective function that is a generalization of the ones presented in the mentioned couple of papers. The data structure was also modified to improve the performance of memory accesses and computations. In this paper the problem is generalized, and a different heuristic is used that requires fewer control parameters. We show that the results are close to the solutions produced by experts. Two spatial metrics are proposed to evaluate compactness: a function based on **patches**, which are groups of adjacent plots with the same category, and another function based on categories, in which the plots are grouped into categories. Both metrics were introduced in (Suarez et al., 2011). The zoning solutions provided by the algorithm are better than or, at least, similar to the solutions provided by experts in terms of the objective function. These solutions also increase the rationality in the development of the zoning map. The algorithm was applied to land use zoning in the municipality of Guitiriz, Galicia, NW Spain, as a case study. This case study was also used in (Porta et al., 2013; Suarez et al., 2011).

The large number of plots involved in municipal land use implies that the whole search space is usually huge. Therefore, the number of possible feasible solutions can be large. For this reason, the use of parallel computing has been considered as the only reliable alternative. In (Suarez et al., 2011), message passing was used to parallelize the proposal in distributed memory systems. In contrast, this paper focuses on shared memory paradigm that takes advantage of the fine grain parallelism, and complements message passing. Nowadays, parallel solutions are needed because of the presence of multicore processors in the market, and therefore shared memory implementations are more demanded. Celmatis, Mineter, and Marciano (2003) and Mineter and Dowers (1999) pointed out that the impact of parallel computing in Geographical Information Science is slight and that there is a need to develop parallel geoprocessing algorithms. Li (2011) proposed parallel computation as one of the priority research lines in land use simulation and optimization models that can solve real-world application problems. Many proposals for parallelization can be found in the literature (Czech, 2010; Liu & Wang, 2015; Onbasoglu & Ozdamar, 2001). In this paper, a geometric parallelism, according to the classification of Ding and Densham (1996), has been used to reduce execution time. This kind of parallelism is based on the partition of the spatial domain into sub-regions (Schiele, Moller, Blaar, Thurkow, & Muller-Hannemann, 2012) that can be currently handled by different processes.

A parallel simulated annealing algorithm for land use spatial allocation that uses an irregular spatial structure based on a cadastral parcel map is presented in this paper. The shared memory paradigm was used to implement the parallel code because it suits perfectly multicore systems. This strategy complements the message passing approach introduced in (Porta et al., 2013). Typically, this kind of problems cannot be solved analytically, and no unique solutions can be found. The use of plot polygons implies that the geometric characteristics of these regions must be recalculated at each iteration of the algorithm, which is a high time-consuming task. Our approach deals with this problem by decreasing the cost of this task by reducing the computations to those plots that change this category in each iteration. In addition, we propose a spatial parallelization to reduce execution time, by balancing the partition of the area under study into a number of so-called clusters that can be processed in parallel.

The paper is organized into three more sections. The first one defines the features of the optimization problem, the design of the simulated annealing algorithm, the implementation of the parallel version of the algorithm and the experimental results. The next section is devoted to the application of the proposed algorithm to a particular case study. Finally some conclusions and ideas for future work are presented.

2. Problem statement and methodology

Land use planning laws define a set of land use categories and the restrictions enforced in each category. For some categories, spatial allocation is completely and uniquely determined by legal restrictions. We will refer to this group of categories as fixed categories. For example, in the study area the law establishes that water protection land corresponds to buffer zones around the waterways. Accordingly, land use allocation comprises two stages: the application of law restrictions for the delimitation of fixed categories, and the making of decisions by planners for the allocation of non-fixed categories.

For the first stage, a preprocessing module was used to allocate the fixed categories which are allocated by applying the planning laws using geometric operations (buffers, intersections, differences, etc.). This stage is the same as the one used in (Suarez et al., 2011). This stage is presented in Section 2.1.

For the second stage, a heuristic algorithm based on simulated annealing is proposed to delimit the non-fixed categories. A number of parameters are introduced to guide the process. In this way, by tuning these parameters, the user has the possibility of focusing the final result

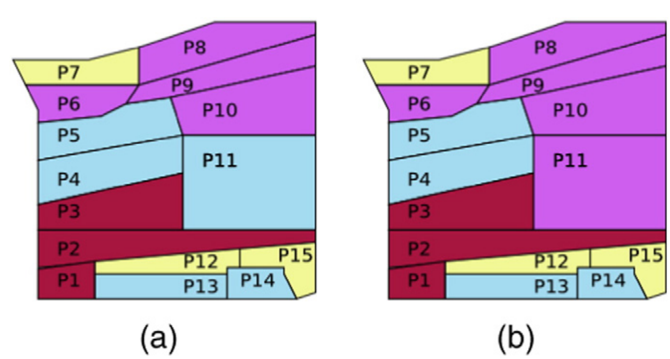

Fig. 2. Examples of a set of plots assigned to 4 categories that define 6 patches.