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A multi-resolution approach towards point-based multi-objective geospatial facility location

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ABSTRACT

The placement of certain facilities, such as radars and wind turbines, requires careful planning according to very specific geographical and spatial requirements. Such placement problems are often solved by metaheuristics which find near-optimal solutions within a fraction of the time required to solve these problems exactly. The use of high-resolution representations of the feasible search space generally ensures a high level of solution quality and accuracy, but involves evaluation of a larger number of candidate solutions than lower resolution representations, and is therefore more time-consuming. A trade-off between solution quality and time requirements must therefore be achieved when choosing an appropriate resolution of data to include in geospatial facility location models. In this paper, we propose a novel explore-and-exploit, multi-resolution solution approach that takes advantage of the reduced computational requirements associated with lower resolution terrain data, while simultaneously benefitting from the quality of solutions returned at higher resolutions. Our multi-resolution approach is capable of outperforming analyses in which only highest resolution data are considered, both in terms of solution quality and solution time requirements.

1. Introduction

Research into the optimal placement of facilities according to geographical and spatial criteria — henceforth referred to as *geospatial facility location problems* (GFLoPs) — are well-documented and wide-ranging in solution methodology and practical application. A large portion of GFLoPs are suitability analyses that are region-based and aim to find generally large, contiguous areas of terrain destined for the placement of a number of facilities within their borders, *e.g.*, regions identified for the development of wind farms (Sliz-Szkliniarz & Vogt, 2011; Van Haaren & Fthenakis, 2011) or solar farms (Sanchez-Lozano, Teruel-Solano, Soto-Elvira, & Socorro Garcia-Cascales, 2013; Uyan, 2013). This paper, however, is concerned with point-based problems in which the aim is to find precise, discrete facility site locations for *networks* of facilities which generally include one type of facility, *e.g.*, watchtowers (Agarwal et al., 2005), transmitters (Akella, Delmelle, Batta, Rogerson, & Blatt, 2010; Krzanowski & Raper, 1999; Lee & Murray, 2010), surveillance sensors (Bao, Xiao, Lai, Zhang, & Kim, 2015; Kim, Murray, & Xiao, 2008; Murray, Kim, Davis, Machiraju, & Parent, 2007) and wind turbines (Emami & Noghreh, 2010; Kwong et al., 2014; Serrano-Gonzàlez, Burgos-Payàn, & González-Longatt, 2013). Point-based analyses may often follow ones that are region-based.

The space of location decisions in point-based facility location problems is generally categorised as continuous or discrete (ReVelle & Eiselt, 2005). In continuous problems, the points to be sited can generally be placed anywhere on the plane, while in discrete problems the facilities can be placed only at a limited number of pre-selected candidate sites (eligible points) on the plane. We solve GFLoPs as discrete facility location problems in this paper — for which raster data are used to provide the pre-selected candidate sites. Raster data represent the earth's surface and environmental information as uniformly spaced sample points, called *gridposts*, across the terrain surface. Gridposts that lie within feasible facility placement regions, such as those identified in region-based analyses, may be considered for facility site placement and are called *candidate sites*. Raster data are employed extensively in the literature for solving point-based GFLoPs due to its ease of implementation — examples include the placement of wind turbines (Kwong et al., 2014; Serrano-Gonzàlez et al., 2013), radar and weapon systems (Ghose, Prasad, & Guruprasad, 1993; Tanergüclü, Maras, Gencer, & Aygüneş, 2013), and other *line-of-sight* (LOS)-dependent facilities (Franklin, 2002; Kim, Rana, & Wise, 2004; Heyns & Van Vuuren, 2015a; Lee & Murray, 2010).

A natural approach towards solving a point-based GFLoP is to select a single resolution of geospatial data to include in the model, after which a search algorithm may be employed to find suitable candidate site combinations based on these data. Higher resolution data include more candidate sites spaced closely together, whereas lower resolution data include fewer candidate locations spaced further apart. The use of

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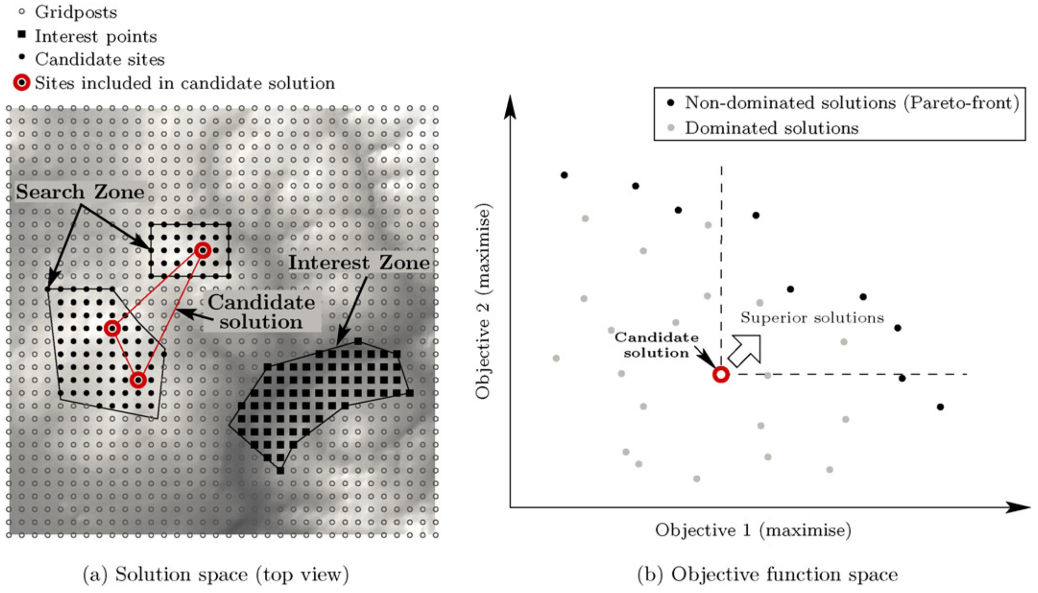


(a) Solution space (top view)

(b) Objective function space

Fig. 1. (a) Terrain represented by raster data and its application to GFLoPs in solution space. (b) The notions of solution domination and of a Pareto-front of non-dominated solutions in objective function space.

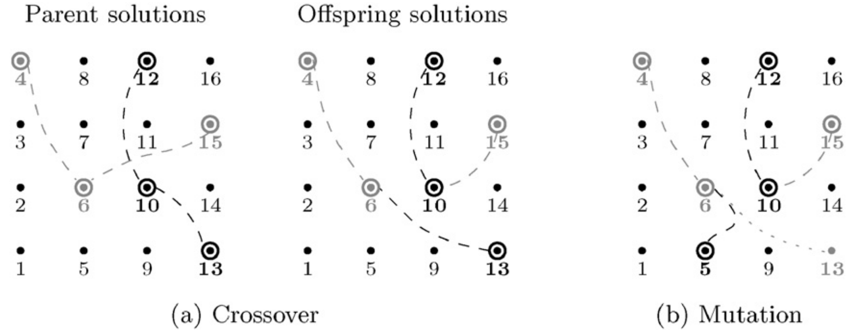
high-resolution data therefore involves a larger number of candidate sites and associated evaluations than lower resolution representations to arrive at (near-)optimal solutions and are therefore more time-consuming, but this generally ensures a high level of solution quality and accuracy. Lower resolution representations of the data may be extracted from high-resolution data with the aim of reducing the number of candidate sites and the computational complexity associated with solving the problem — ultimately resulting in shorter computation times. This, however, typically comes at a loss of solution quality due to the potential loss of good candidate sites from the higher resolution data. A trade-off between solution quality and computation time requirements must therefore be achieved when choosing an appropriate resolution of terrain data to use in geospatial facility location models.

In this paper we present a new *multi-resolution approach* (MRA) towards reducing the computational burden of solving the problem by reducing the number of candidate sites that are evaluated during the optimisation process, while the superior solution quality typically associated with higher resolution analyses is maintained. In fact, the solution quality of the new approach is consistently superior to that of the traditional *single-resolution approach* (SRA) in which only the highest resolution data are considered. Both approaches followed in this paper employ the popular *Non-dominated Sorting Genetic Algorithm-II* (NSGA-II) (Deb, Pratap, Agarwal, & Meyarivan, 2002) to search for solution alternatives for a visibility-related implementation of the bi-objective *backup coverage location problem* (BCLP) (Hogan & ReVelle, 1986; Kim et al., 2008; Murray et al., 2007).

The paper opens with a discussion on important concepts and background information related to the work presented. Descriptions of the SRA and MRA solution approaches towards solving raster-based GFLoPs follow in Section 3.1 and Section 3.2, respectively. A scenario involving a visibility-related BCLP is introduced in Section 4 for the purpose of illustrating the two approaches and comparing their results. The paper closes with a brief conclusion and proposals for future work in Section 5.

2. Background

An illustration of a raster data representation of terrain is provided in Fig. 1(a). The section of terrain surface shown in this figure is, in fact, a graphical representation of sampled elevation data at the gridposts (the empty grey dots). *Search zones* (SZs) are feasible facility placement regions specified on the terrain surface and envelop the candidate sites that may be considered for facility placement (the solid dots). A candidate solution is a specific configuration of a number of facilities (three for the example in the figure) at candidate sites in the SZ. Depending on the type of facilities and criteria considered for the placement problem, candidate sites may be evaluated with respect to gridposts enveloped within specified *interest zones* (IZs), called interest points (the black squares). A significant portion of GFLoPs that involve IZs are visibility-related and require LOS analyses (Agarwal et al., 2005; Goodchild & Lee, 1989; Heyns & Van Vuuren, 2013,2015a; Kim et al., 2004; Lee, 1991; Nagy, 1994; Tabik, Zapata, & Romero, 2013; Zhao, Padmanabhan, & Wang, 2013).



(a) Crossover

(b) Mutation

Fig. 2. Crossover and mutation operations performed on candidate solutions.