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Simulation Modelling Practice and Theory 12 (2004) 307–326
SIMULATION MODELLING PRACTICE AND THEORY
www.elsevier.com/locate/simpat

A unified simulation framework for spatial stochastic models

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Received 30 September 2002; received in revised form 24 September 2003; accepted 17 February 2004
Available online 19 March 2004

Abstract

For spatial stochastic models, a lot of programs exist which deal with the simulation of specific models. But, combining them is not that easy and usually requires greater effort. This paper presents an object-oriented framework, i.e. a set of collaborating abstract and concrete classes, dealing with the simulation of such models. The selected fundamental models are only illustrating examples for the general concept. From the Java implementation of this framework, two code examples are shown, which could also be implemented similarly in any other object-oriented programming language. All interfaces and a lot of concrete classes can be implemented dimension-independent. The design and implementation problems arising in the context of static and dynamic plus sampling are specifically discussed.

Keywords: Simulation; Spatial stochastic models; Java; Stochastic geometry

1. Introduction

Spatial stochastic–geometric models are random geometric structures, such as random configurations of points, overlapping (random) geometric objects at random locations, and random mosaics among others. They can be used to model global patterns and have proven useful in various fields, such as communication networks [1], materials science [15], medicine [9,10], physics [12], and astrophysics [13].

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1569-190X/$ - see front matter
doi:10.1016/j.simpat.2004.02.001

The combination of the existing simulation programs (cf. e.g. [15,16]) is not an easy task if possible at all. Furthermore, those implementations depend on the dimension of the simulated model. So, to simulate the model (for which a simulation program is given) in a higher dimension, at least changes are required, or a new program has to be developed.

The framework for the simulation of spatial stochastic–geometric models presented in this paper gives a possible solution to these problems and provides an unified approach. There are several orthogonal models in the framework which can be arbitrarily combined. This leads to combinatorial complexity of possible applications. All models are designed as interfaces, which are dimension-independent. Therefore, the framework is basically independent of the dimension. Only for a part of the concrete classes it would be much more complicated to give a dimension-independent implementation. So, for such classes a separate implementation has to be provided for each dimension. The framework is implemented in Java [3]. It could, however, be implemented similarly in any object-oriented programming language. Two code examples of concrete models are presented, demonstrating the advantages of the framework design. All parts of the framework are explained using UML class diagrams [20].

The paper is organized as follows. Section 2 contains a brief description of fundamental spatial stochastic–geometric models considered as illustrating examples in the presented framework. Related work and common problems occurring during the combination of existing simulations are addressed in Section 3. The framework is described in Section 4, where sample implementations for two models are shown, followed by the summary and conclusions in Section 5.

2. Spatial stochastic–geometric models

In this section, several fundamental spatial stochastic–geometric models are described, which are considered as illustrating examples in the present paper. The description is only as detailed as necessary for the design and non-formal—besides the little paragraph on basic morphological operations. The main focus is on the simulation of these models, but also not more precisely than required for the framework. The description is for the two-dimensional case, but can be extended to higher dimensions. An overview of spatial stochastic–geometric models is given, for example, in [19].

2.1. Basic morphological operations

For simulation without edge effects, some basic operations from the field of mathematical morphology are necessary, which are described here shortly according to [15,18]. The *Minkowski addition* $A \oplus B$ of two sets A and B is the pointwise addition of the elements of both sets,

$$A \oplus B = \{x + y : x \in A, y \in B\}.$$