Chapter 39
A Short Presentation of SLEUTH

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Abstract This chapter summarizes information about SLEUTH, a popular cellular automaton model that simulates urban growth and land use change. The model is supported in the public domain and all source code is open, including extensive documentation and discussion fora. The input data for SLEUTH are listed, the model's behavior and its control parameters explained, and methods described for model calibration, use in simulation, and for validation. Pointers to review papers are given as starting points for the reader to find SLEUTH applications, and the operating system and computer requirements are given. This volume includes a paper by the author that makes a substantial improvement to SLEUTH's calibration procedures.

Keywords SLEUTH · Cellular automaton · Land use change model · Urban growth · Simulation · Model calibration

1 Introduction

SLEUTH is a simulation model consisting of computer code written in the C programming language. Its purpose is to simulate urban growth over time, and to propagate change across a range of land use classes specified by the user. The model consists of two tightly coupled cellular automaton (CA) models: the Urban Growth Model and the Deltatron land use change model. Three main versions of the model exist, with three variants. Version 1 was experimental, version 2 used dynamic memory allocation, while version 3 adopted the Cray flat memory model and included support for the Message Passing Interface to allow parallel processing. SLEUTH-r used SLEUTH but changed some of the road handling routines to speed up the model, and simplified the calibration process (Jantz et al. 2010). SLEUTH*

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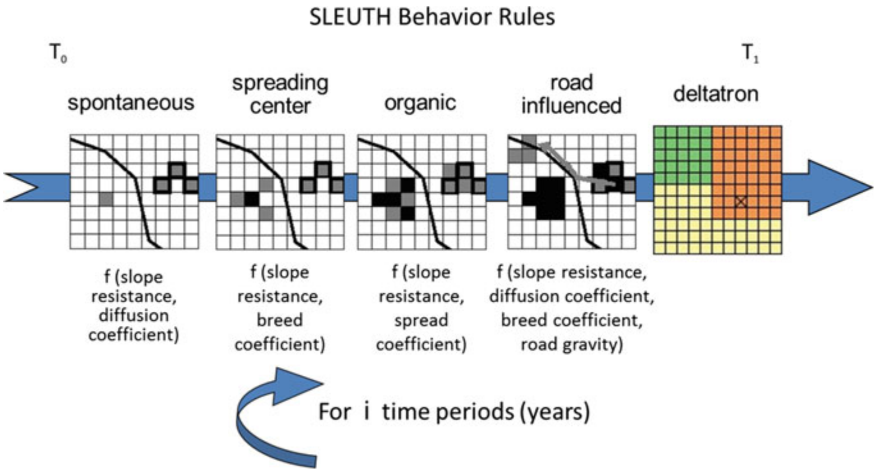

Fig. 1 SLEUTH behavior rules

included a user interface to support decision-making and scenario planning (Houet et al. 2016). The model ingests data in the form of raster images that give the model its name, topographic slope, land use, exclusions, urban extents, transportation and a hillshade layer for visualization. At a minimum, the model needs one GIS data layer at different periods of past time for slope, exclusion and hillshade, two or more transportation and land use layers, and four or more urban extent layers.

The model uses four types of CA behavior rules: diffusive growth, new spreading centers, organic growth and road influenced growth (Clarke and Gaydos 1998). These behaviors are determined by the values of five control coefficients that take integer values between 0 and 100 (Fig. 1). At zero, the behavior type is disabled, while at 100 it is uninhibited by probabilities determined by the input data and the other coefficients. To allow non-linear feedbacks in the model, the coefficients are also subjected to self-modification, in which the state of the entire system changes the values during a run. During the automated calibration process a single run starts at the earliest year for which data is available, and runs to the last year or “present.” Thirteen performance metrics are then used to evaluate the coefficient values, averaged over a series of Monte Carlo iterations. Calibration consists of selecting the best five coefficients using brute force, i.e. trying combinations and permutations to select the one that best simulates the known data (Silva and Clarke 2002). These settings are then used for forecasting. More recently, the brute force calibration method has been replaced with a genetic algorithm (Clarke-Lauer and Clarke 2011, Clarke this volume). The land use change model uses four phases: initiate change, cluster change, propagate change, and age deltatrons respectively (Clarke 2008a, b). This ensures that spatial and temporal autocorrelation exists in the land use change patterns.

2 Description of the Methods Implemented in the Model

Calibration: The brute force calibration process is described in detail in Silva and Clarke (2002). The fact that so many coefficient combinations must be tried, with Monte Carlo iterations further increasing the computational time, means that the model calibration process can take days, weeks or even months of CPU time. While the speed of processors has taken up much of this burden, parallel computing has also decreased the calibration time (Guan and Clarke 2010; Clarke 2003). Most recently, SLEUTH-GA has simply replaced brute force with a genetic algorithm that "breeds" coefficient combinations that evolve toward a best solution (Clarke, this volume). Calibrations have for some time focused on the Optimal SLEUTH metric as the single best goodness of fit parameter to maximize during calibration (Dietzel and Clarke 2007).

Simulation: SLEUTH requires calibration to give reliable scientific results (Clarke 2004). Once the best coefficient values have been determined, the model is run over the calibration period with a large number of Monte Carlo iterations and the coefficients averaged at the end of the period, i.e. the start date for simulation. The model then takes the most recent data as inputs, and runs as far into the future as is desired. Model outputs include reports, accuracy statistics, maps, animations and uncertainty estimates. If no land use data are present, the model simply simulates urban growth. By varying the parameters and input data simulations of different scenarios can be created (Xiang and Clarke 2003). Others have used the exclusion layer, including incorporating other methods such as Multi-Criterion Evaluation into the scenarios (Mahiny and Clarke 2012).

Validation: SLEUTH is among the most validated of land use change models. Not only has the model been subjected to sensitivity analysis, its accuracy has been reported for about 100 different applications. In many cases its reported accuracy during calibration has been in the 80–90% range. At least one study has returned to areas forecast in the past to fully validate the model (Manca and Clarke 2012). Others have investigated temporal sensitivity (Akin et al. 2014; Chaudhuri and Clarke 2014; Peiman and Clarke 2014) and other factors. A full survey of these studies is contained in Chaudhuri and Clarke (2013).

3 Applications

Survey articles that cover a majority of the applications are Clarke et al. (2007, 2008a, b) and Chaudhuri and Clarke (2013). The Gigalopolis project website, cited in these publications, contains a more complete application survey and an inventory of data and results. To the author's knowledge, there have been over 100 applications on 6 continents, at a range of spatial scales and geographic extents and covering western cities, favelas, informal settlements and many other fields.

4 Final Considerations and Technical Summary

SLEUTH research remains active, with new applications and model refinements continuously appearing. The author thanks in remembrance Dr. Leonard Gaydos, who first funded the model's development at USGS and who remained a colleague and friend for two decades. His unfortunate death in a snorkeling accident in 2015 was a great loss to Geography.

SLEUTH is open source and available for free at: http://www.ncgia.ucsb.edu/projects/gig/. The model requires a UNIX-like operating system (such as Linux, Ubuntu or Cygwin). Test data with results are available on the website. A discussion forum exists that can answer the majority of questions users may have. Documentation is fully online at the Gigalopolis website.

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