Interactive calibration of a land-use cellular automata model

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Abstract

This paper describes a semi-automated interactive method that has been implemented to calibrate a cellular automata (CA) model developed to simulate land-use changes in the Elbow river watershed in the Calgary region, Alberta. CA models have five main characteristics: 1) they have a regular discrete lattice of cells in one or two dimensions, 2) they have an internal clock representing a discrete time and cells are updated at each predefined temporal step, 3) each cell has a finite set of possible states, 4) transition rules are applied uniformly through time and space, and 5) the outcome of the transition rules, which is the new state of the cells, depends on the value of the cells in a local neighborhood. In most CA models applied to land-use changes, the transitions rules are programmed into the model and the user has to find the numerical values of each parameter. Often, a single transition rule is used to describe a land-use change. Moreover, commonly used automated calibration methods relying on logistic regression, brute force computing or neural network are either a black box, are not reproducible, or consider average neighborhood configurations consequently assuming that only one process is responsible for a land-use change. A novel calibration method to overcome these limitations is presented in this paper.

Background and Relevance

This paper describes a semi-automated interactive method that has been implemented to calibrate a cellular automata (CA) model developed to simulate land-use changes in the Elbow river watershed in the Calgary region, Alberta. CA models have five main characteristics: 1) they have a regular discrete lattice of cells in one or two dimensions, 2) they have an internal clock representing a discrete time and cells are updated at each predefined temporal step, 3) each cell has a finite set of possible states, 4) transition rules are applied uniformly through time and space, and 5) the outcome of the transition rules, which is the new state of the cells, depends on the value of the cells in a local neighborhood. In most CA models applied to land-use changes, the transitions rules are programmed into the model and the user has to find the numerical values of each parameter. Often, a single transition rule is used to describe a land-use change. Moreover, commonly used automated calibration methods relying on logistic regression, brute force computing or neural network are either a black box, are not reproducible, or consider average neighborhood configurations consequently assuming that only one process is responsible for a land-use change. A novel calibration method to overcome these limitations is presented in this paper.

Methods

This novel procedure involves the use of a spatio-temporal GIS database that integrates land-use maps, and physiographic and socio-demographic data collected in the study area over the last 25 years. First, five historical land-use maps that have been produced from Thematic Mapper images are read, and factors responsible for driving the land-use changes (distance to the road network, distance to downtown Calgary, and distance to a main river) are identified. Then, for each type of land-use change, the model selects in the historical data all the cells that adhere to this change and a frequency histogram is produced for each land-use state present in the neighborhood and for each driving factor. If particular driving factor values or neighborhood configurations were often present in the historical data, the histograms will display a normal curve with a peak value. The user selects ranges of values on each histogram that represents the coefficients of the model parameters. This information is then analyzed to automatically create the transition rules that can be applied for the simulation. This calibration procedure offers several advantages. It is highly flexible in terms of study area, number and types of land uses and driving factors; it is interactive and allows a user to dynamically display the influence of each driving factor on past land-use changes and to select how this factor will be taken into consideration in the CA model to forecast future land-use development. In addition, multiple processes driving a land-use change can be identified and independently simulated. This model was calibrated and applied to simulate land-use changes from the past (1985) to the present (2006). The simulation results obtained for the year 2006 were compared with an independent land-use map of the same year. . Then, the model was used to simulate land-use changes from the present (2006) to 2031. Three simulations were performed over this period. First, the model forecasts land-use changes based solely on observed historical trends. Then, the number of cells that should become urbanized is specified according to population growth estimations for the next 25 years. Third, a virtual new town is integrated in the initial conditions and a new parameter is added to the model to take into account the distance to that new town.

Results

Results obtained by simulating the land-use changes from the past to the present reveal that the model adequately reproduces the land-use dynamics in the watershed. Several hundreds of transition rules were identified by the model to reflect the diversity of processes having an impact on land-use changes. The transitions rules can be displayed to the user in an easy to understand way, allowing a better comprehension of the dynamics affecting the territory. The model was validated by a group of 15 experts (mostly planners and land managers) from the Calgary Regional Partnership, the City of Calgary and Alberta Environment. They confirmed that new urban developments predicted by the model were corresponding to planned developments and that the transition rules provided realistic land-use forecasting. Comments from the group of experts confirmed that this simulation model could be used as a decision support tool to investigate the impact of various management scenarios on future land development.