MŰEGYETEM 1782

AGENT-BASED MODELS IN SPATIAL INFORMATICS

PhD thesis booklet

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INTRODUCTION

The research deals with agent-based models whose actors, the agents act in a spatial environment. Besides their attributes, they must have a spatial position, which can change in time. Consequently, the agent-models are extremely suitable in depicting space-time phenomena. Thus, I chose this actively improving topic, which I present practical models beyond the theoretical introduction. The dissertation investigates two complex phenomena, the Landscape diversity and the Evacuation simulation.

There are some traditional methods to assess and measure landscape diversity, like the area of the land cover classes, the number of land cover patches, the density of patches, the ratio of the biggest patch to class-area, the summed perimeter of the classes, the edge density, the ratio of perimeter and area, and others (Szabó, 2010).

The evacuation simulation is a method, which we can use to measure evacuating times of areas, buildings, rooms, corridors. It is based on the simulation of crowd dynamics and pedestrian motion. The evacuation of pedestrians is a complex problem, that is almost impossible to measure due to its cost, risks and other factors (Izquierdo et al., 2009; Gwynne, Galea, Owen, Lawrence & Filippidis, 1999). There are some existing models with different space-time approach, like the cellular automata models, the agent-based models, the Social Force Model (Helbing, Illés és Vicsek, 2000). Viswanathan et al. reached the conclusion that the zoned evacuation time is the metric that that can best discriminate between models (Viswanathan, Lee, Lees, Cheong & Sloot, 2014).

THE GOALS OF THE DISSERTATION

- Introduce the agent-based modelling approach
- Develop a prototype agent-based method to capture the landscape diversity phenomenon
- Apply the agent-based diversity method
- Develop a novel agent-based model in the field of evacuation simulation
- Develop a model, which captures the natural discrete element of human movement, the step
- Create a sophisticated model, that solves the spatial limits of cellular automata models
- Create a generally applicable, easily customizable agent-based model for evacuation purposes
- Create an agent-based evacuation model, which is able to compute real-time results

Overview of the developed models

Landscape diversity

The Wandering Agent Model is a numerical simulation method, which is the extended agent-scope interpretation of Buffon's Needle problem. The subject of the simulation is the agents' spatial environment, the world. With the wandering agents, we are able the estimate the border lengths of the landscape object classes. Therefore we must add a short-term memory property to the agents, where they can store the last viewed object class. Since it is short-term, it is only enough to store one object class a time. During their wandering – the simulation – they increment a common Monte Carlo integral (Metropolis, 1987) when they cross an object border. This aggregated number is in related to the summed length of borders. In order to ensure uniform sampling, I bounded the edges of the world with toroidal topology. That means that when an agent leaves the world on one side, it comes back on the opposite one.

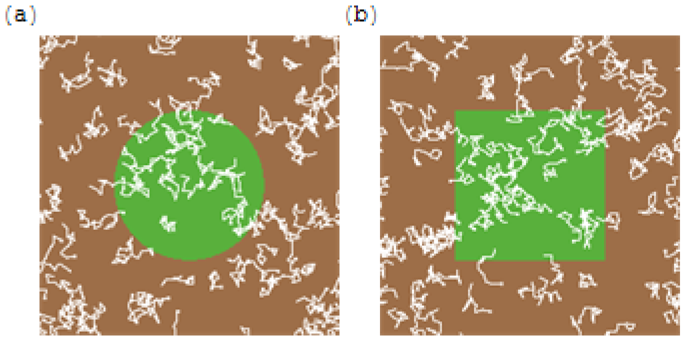

Figure 1: Hundred wandering agents register the discovery of new object classes: on a circle shaped forest (a), quadratic shaped forest (b) around arable land

With the aim of a reference measure, the value of pi (3.14) can be approximated, which validates the operability of the model. If we store the visited land covers through the simulation, then we got information about the spatial distribution of the classes as well.

1. thesis:

Using my "Wandering Agent Model" we can calculate the border length of any object by comparing the cumulated Monte Carlo integral of new object class discoveries on the examined object with the integral measured on a reference object with known border length.

Thesis references:
(Wirth, Czinkóczky & Szabó, 2015; Wirth, Szabó & Czinkóczky, 2016b)

The Scouting Agent Model is the further developed version of the Wandering Agent Model. Here the agents have vision, long-term memory and goal (progress toward the closest visible unvisited object class). With these attributes, we can estimate the diversity and complexity of an investigated landscape. Similarly, they store their new discoveries into a Monte Carlo integral during the scouting. The cumulated integral describes the diversity potential of the investigated area. The model has stochastic components, like the random rotation in the lack of seeing new object class.

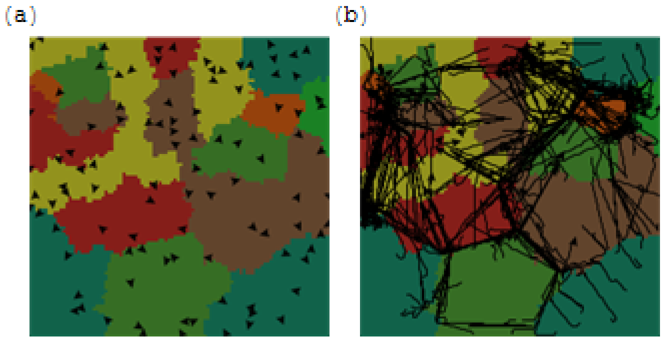

Figure 2: The movements of 100 scout agents in a tutorial world: initial state (a), after 100 steps (b)

With 100 agents we are able to map the characteristics of the landscape. There can be seen in the pattern that the scouts moved mainly on the border of land cover classes, sometimes they crossed them in the middle. The agents' distribution after the scouting is related to the distribution of the landscape objects.

2. thesis:

The further developed "Wandering Agents" called "Scouting agents" have a goal-oriented motion, vision, and a long-term memory. With these properties, they are able to estimate the diversity of an area. During the simulation, they cumulate the number of new object discoveries to a Monte-Carlo integral, which describes the estimated landscape's diversity as a potential value.

Thesis references:
(Wirth, Czinkóczky & Szabó, 2015; Wirth, Szabó & Czinkóczky, 2016a; Wirth, Szabó & Czinkóczky, 2016b)

The Scouting Agent Model was tested on the CORINE Land Cover geodatabase (Bossard, Feranec & Otahel, 2000). I randomly clipped hundreds of mezoscopic worlds from the raster model of the Great Hungarian Plain. From the evaluation of the worlds, we created an isopotential landscape diversity potential map with interpolation. This map can be the base of necessary interventions on the landscape. It can be helpful for stakeholders as a representative information product.

3. thesis:

I showed that a "Landscape Diversity Isopotential Map" is able to visually represent the potentials calculated by landscape diversity agent-models. The map is based on the interpolation of random sampled worlds' measurements.

Thesis references:
(Wirth, Czinkóczky & Szabó, 2015; Wirth, Szabó & Czinkóczky, 2016a; Wirth, Szabó & Czinkóczky, 2016b)

Evacuation simulation

The developed Spatial Step-model is a discrete, microscopic agent-based model, which keeps the step-orientation of cellular automata models, but solves its spatial and topological limitations with an agent-based approach. The mathematical background with set equations makes it capable to run simulations at any spatial resolution. Its agent character handles the waiting activity, hence it is able to investigate panic properties. This model encapsulates the essence of pedestrian movement by using steps as its basis.

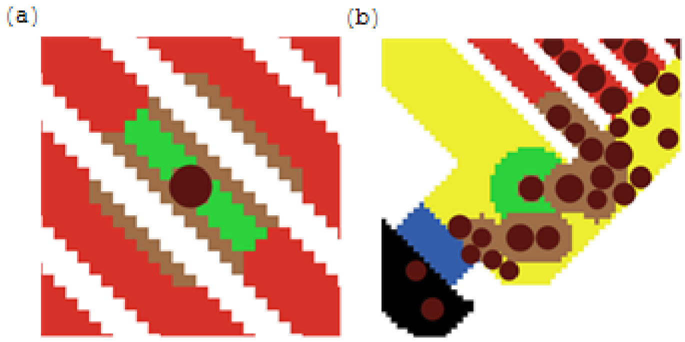

Figure 3: An agent in the lecture hall:
in a row (a), in the corridor (b) towards the blue door
The brown cells are reserved, the greens are free to step onto

The model I developed can work not only in experimental but in complex spaces as well. It handles the immobile (walls, columns), and mobile (pedestrians) obstacles. I introduced its operability in a lecture hall with different evacuation scenarios. In order to solve the navigation I implemented the potential field method.

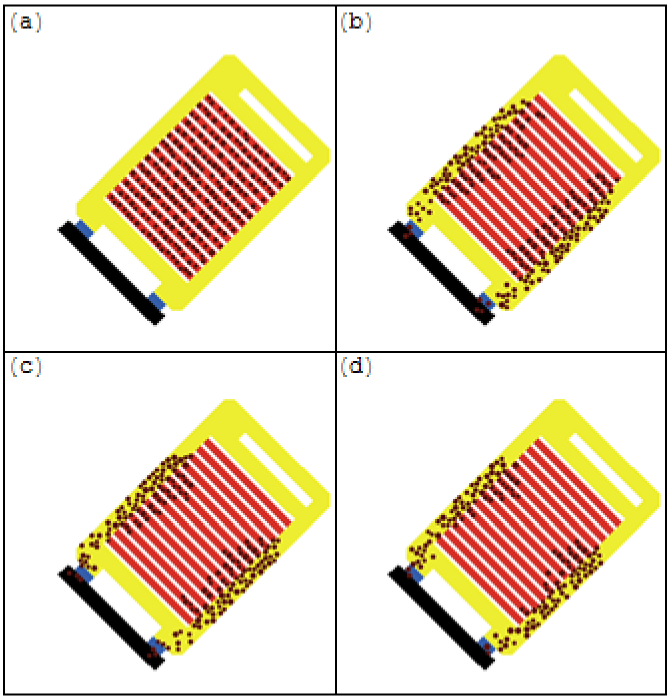

Figure 4: Evacuation with 220 agents. BME, K174 lecture hall:
in 0 (a), 10 (b), 20 (c), 30 simulation epochs (d)

4. thesis:

The "Spatial Stepmodel" I developed keeps the step-oriented character of cellular automata models and solves their spatial and topological limitations with its agent-based approach and mathematical background. The sophisticated model is able to handle any kind of spatial resolution. I showed with different scenarios that it is generally applicable for evacuation simulations.

Thesis references: (Wirth & Szabó, 2017a; Wirth & Szabó, 2017b)

I compared the discrete Spatial Stepmodel with the continuous Social Force Model. I showed that in the Spatial Stepmodel there is an apparent mix-up among agents unlike in the Social Force Model where the evacuation happens in an orderly fashion. For this experiment, I assigned a row identifier to the agents. After I observed the order of the agents leaving the room, I converted the gathered data to a stacked probability density plot. To ensure that the information is reliable I repeated the simulations 40 times.

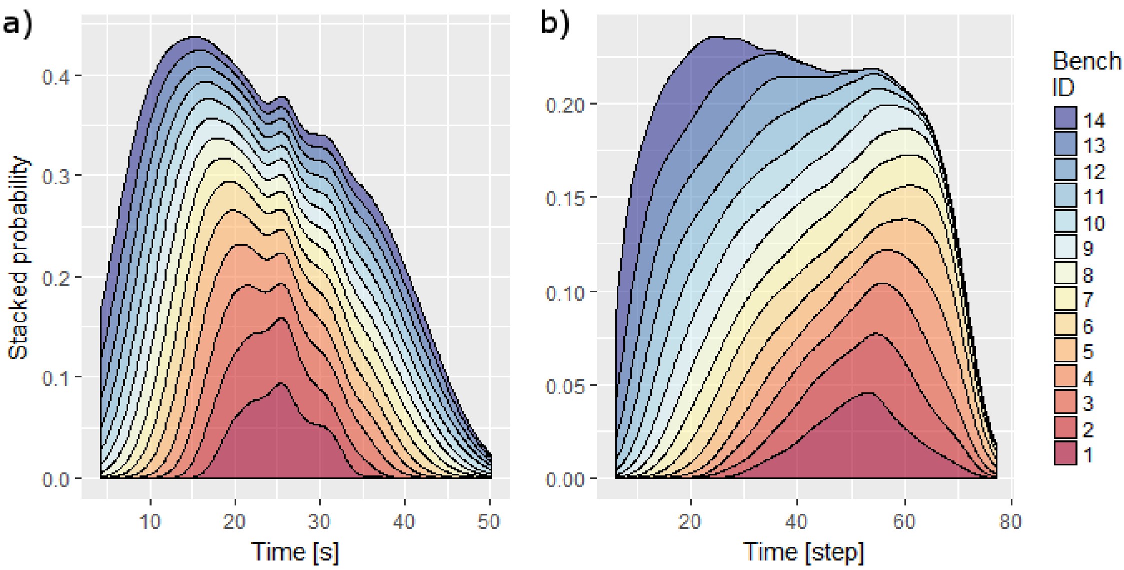

Figure 5: Mixing during evacuation:
a) with Social Force Model; b) Spatial Stepmodel

The stacked density function of the Social Force Model reveals that the mixing of agents from different rows is insignificant, the outflow is uniform: the evacuation of the rows is graduated, it starts with the first row, then comes the second, and so on. In this model the flow forces are so dominant that people cannot leave the rear rows. The reason of this is that agents from the rear rows can reach the corridor easier since no one blocks their way from rows behind them; and once the corridor is filled, it gets emptied in the front, allowing the front rows to fill up free space sooner than the middle rows.

5. thesis:

By investigating zoned evacuation times, I showed that mixing plays an important role in the "Spatial Stepmodel", in contrast with the continuous "Social Force Model" in which evacuation is regular.

Thesis references: (Wirth & Szabó, 2017a; Wirth & Szabó, 2017b)

SUMMARY

The dissertation introduces an agent-based Monte Carlo method, which is capable to estimate the lengths of borderlines of the spatial objects' classes. The method bounds the investigated world – containing the object classes – along their edges with a toroidal topology, thus the sampling remains uniform. I showed the application of the method by estimating the approximate value of pi (3.14) with the registered border crossing on a quadratic and round shaped object.

The developed Scouting Agent Model approaches the landscape diversity problem in its real complexity. The simulation method is generally applicable on any classified geodatabase; the estimated landscape diversity potential aggregates well the fragmentation and distribution of different land cover classes. The method can be easily parameterized, it is able to satisfy unique viewpoints. The measurements of an area can be interpolated to create a continuous cover, and an isopotential landscape diversity map can be derived. This map can be used to identify locations where an intervention is necessary.

In the field of evacuation simulation, the developed Spatial Stepmodel integrates the advantages of agent-based and cellular automata (CA) models. It keeps the step-oriented approach of CA models, but solves their spatial limits. The topological limitation is solved by the agent-based approach, the resolution one is solved by the mathematical background. Consequently, the Spatial Stepmodel is a sophisticated model, which handles all kinds of cellular resolutions. By the introduction of step sizes, reaction times and velocities the model became capable of computing real-time results.

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