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Towards realistic and effective Agent-based models of crowd dynamics

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ABSTRACT

The authors propose a new methodology for creating realistic and effective models of crowd dynamics, which takes into account the Agent-based approach combined with non-homogeneous and asynchronous Cellular Automata. The proposed methodology makes it possible to model pedestrians' dynamics in complex environments, like stadiums or shopping centers, and enables mimicking of the pedestrians' complex decision making process on different levels: strategic and tactical/operational. On the other hand, the use of the Agent-based approach makes it possible to apply different scenarios and situational contexts, namely competitive and non-competitive evacuation or free movement of pedestrians. The proposed approach was tested in large-scale test cases, namely the evacuation of the Allianz Arena football stadium in Munich and other stadiums like Wisla Krakow Stadium or GKS Tychy Stadium, as well as AGH University facilities.

1. Introduction

Nowadays, one can observe two main approaches to crowd simulations, depending on the purpose of modeling and simulating [1].

On one hand, one can distinguish models and simulations of crowd behavior dedicated for the entertainment industry (e.g. video games, movies, commercials and special effects), mixed reality and general modeling of complex crowd behaviors. In such an approach, the main emphasis is placed on impressive, high quality visualization. Traditionally, researchers interested in this approach look to define a wide range of behaviors and to incorporate some cognitive aspects of agents' decision-making.

On the other hand, the second group of crowd simulations is devoted for specialized aims like safety engineering, architectural optimization and organization of mass events, etc. In this case, the most important aim is to use reliable models, including thorough calibration, as well as qualitative and quantitative validation, including fundamental diagrams (relationship between flow and crowd density). The most important issue is the final compatibility of physical parameters, proper flow characteristics and realism of behavioral aspects.

The authors considered applying a cognitive crowd model. However, the vast majority of "fully" cognitive models can be applied only for several agents, not for hundreds or thousands of them [2]. Thus, finally, the authors decided to apply a concept of Agent-based modeling using the Cellular Automata approach [3]. According to Allen Newell's classification [4,5], with such an approach we are not able to represent, in an accurate manner, all levels of abstraction of an entity's decision-making process, namely social, rational, cognitive, reactive and physical layers.

The paper raises the following question: *Can we represent in a reliable and an effective way, the dynamics of pedestrians using agents with reduced autonomy and a relatively simple structure*?

The authors found this issue very important during the FP7 SOCIONICAL Project,[1] where 70,000 pedestrians in the Allianz Arena Munich football stadium, had to be simulated on-line, in the "All stadium" stage of complex simulation scenario.

The paper is a continuation of our previous work [6] devoted for basic concepts of applied Cellular Automata. The current paper is focused on Agent-based modeling of pedestrians and is organized as follows. Section 2 reviews related work on microscopic crowd modeling. Section 3 describes the proposed approach using Agent-based modeling combined with non-homogeneous Cellular Automata.[2] Sample results are presented and discussed in Section 4, while Section 5 concludes the paper.

2. Motivation and background

Realistic and effective modeling of crowd dynamics and behavior is actually a great challenge. Paris and Donikian noted in their article that currently the possibility of crowd behavior simulation using complex cognitive behaviors "boils down to simulating a few

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[1] FP7 ICT Project no. 231288 of EU SOCIONICAL.

[2] In non-homogeneous Cellular Automata, all cells are not qualitatively identical and different transition rules are applied [7].

people…” [5]. On the other hand, as noted by Friedman and Kaminka, a lot of complex, cognitive crowd models “represent often only qualitative description and do not easily permit algorithmic replication” [2].

Agent-based modeling (ABM) is a very useful concept in crowd modeling. According to Bonabeau [8], one defines such a system as “a collection of autonomous decision-making entities called agents” and it is assumed that “each agent individually assesses its situation and makes decisions on the basis of a set of rules”.

One can distinguish different points of view in pedestrian behavior modeling. On one hand, some researchers [9] rightly point out: “Humans have enormous heterogeneity (…) each human is different from another” and “it is absolutely impossible to introduce as much heterogeneity in behavior as we observe in daily life.” [9]. On the other hand, in some situations agents' behavior can be reliably reproduced using well-defined classes of behaviors and limited behavioral autonomy [5]. The classification of behavioral pattern modeling according to the ISO 13387-8 standard is presented in Fig. 1.

From a general point of view, the abilities of a particular agent can be divided into the groups presented in Table 1. It should be stressed that Agent-based models of human activities represent different levels of heterogeneity [10].

2.1. Related works

Probably, the most popular approach applied to crowd dynamics modeling is now represented by a group of Newtonian force models, especially the Social Force Model [11] originally proposed by Helbing and Molnar and actually developed and profiled by different teams, for instance [12,13]. Although the Social Force Model is termed as Agent-based due to its microscopic nature, the representation of a wide range of agents' abilities or “describing discontinuity in individual behavior” [8] are considerably limited. Moussaid et al. stated in [14] that such models are “not fully consistent with empirical observations and are sometimes hard to calibrate”. They propose another approach based on the combination of pedestrian heuristics with body collisions. This approach combines some cognitive elements, namely perception of the environment (visual information in decision-making) [14]. Anyway, the level of agents' autonomy is still limited.

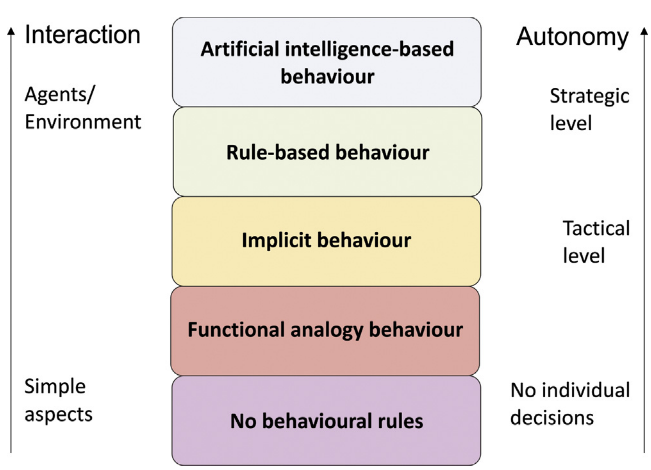

Fig. 1. Behavior pattern modeling according to the ISO 13387-8 standard.

Table 1
Agent abilities in pedestrian modeling.

Type	Level	Characteristic	Example
Strategic	Knowledge-based	Decision making	Target selection
Tactical	Rule-based	Stereotypical reaction	Lane formation
Operational	Skill-based	Automatic reaction	Avoiding obstacles

One of the most popular discrete models of pedestrian dynamics is the Cellular Automata Floor Field Model [15], where pedestrians are represented as a state in a cellular automaton lattice with static (defined targets) and dynamic floor fields (defined influence of other pedestrians on navigation). In [9] parallel implementation of fine-grained simulation of evacuation on a city scale is proposed, while the idea of applying scenario-based modeling was proposed in [16,17].

The combination of Cellular Automata with the multi-agent system termed as *Situated Cellular Agents* (SCA) is proposed in articles by Bandini et al. [3]. SCA is defined by the triple $\langle Space, F, A \rangle$, where *Space* represents an environment, where the set A of agents is situated, acts autonomously and interacts through the propagation of the set F of fields.

Another approach is proposed in the article by Musse and Thalmann [18], where the concept of BDI architecture (Beliefs–Desires–Intentions) is applied and the proposed model is based on a hierarchical approach and different levels of behavioral autonomy: programmed behavior (an innate and scripted crowd behavior), reactive behavior (a function of triggered events) or guided behavior (an interactive process during simulation).

Viswanathan and Lees have proposed some additions to general motion planning algorithms, namely group sensing for motion planning and filtering of perceptions to speed up decision making [19]. Whilst Mazzon and Cavallaro have proposed combination of pattern recognition methods with simulations [20].

3. Proposed approach

The aim of our work is to provide a reliable and effective Agent-based tool dedicated for specialized aims, namely simulation of crowd dynamics in large facilities for chosen scenarios. We decided to use the ABM (Agent-based modeling) approach combined with non-homogeneous Cellular Automata. The Agent-based approach is already used in crowd modeling, for instance Vizzari and Manenti [21] used such an approach for the modeling of groups in a crowd, Banerjee et al. [22] propose the concept of a layered approach for crowd simulations dedicated mainly for the game industry, while Szymanezyk et al. [23] propose simulation dedicated for safety control in airport terminals by applying layers (physical, occupation or navigation, etc.).

Based on the practical requirements of our projects, we have created a new *holistic methodology* including the definition of different components of the environment and setup of agents. We believe that our methodology can be helpful for the range scope of crowd simulations. In this paper, we also propose sample configurations, which have been helpful in the modeling of complex stadium scenarios in our projects: Allianz Arena Munich, Wisla Krakow and GKS Tychy. The starting point was the Social Distances model[3] described in [25].

Contrary to existing “classical” works using Cellular Automata [15,26], we propose to use a finer grained lattice (for instance 25 cm instead 40 cm) and completely different representation of pedestrians (ellipses placed on the lattice of a cellular automaton [6]), different cost functions and transition functions, and finally different handled classes of the situation including normal movement, competitive evacuation and non-competitive evacuation. In this paper, we have used the Social Distances model adapted to mass evacuation [6] combined with the Agent-based approach as a basis.

[3] The model is also applied in visual crowd analysis in combination with pattern recognition methods [24].