Towards a specification of behaviour models for crowds

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Abstract. Agent-based models (ABM) representing human behaviour are widely employed to simulate normal but also emergency situations. Human behaviour is heterogeneous and depends on individual properties. The properties influence motives and needs which in turn govern movement and behaviour. In this work, behaviours for humans at mass events like open-air concerts, street festivals or Christmas markets are conceptually formalised. The resulting behaviour specifications serve as input for an ABM to study crowd formation and eventually communication processes within the crowd. This work is embedded in pilot projects of the Fraunhofer Center for the Security of Socio-Technical Systems (SIRIOS) and forms a basis to realistically simulate human behaviour during mass events as well as to optimize communication strategies in case of emergencies.

Keywords: Crowd simulation · Agent-based model · Agent behaviour specification.

1 Introduction

Dangerous situations at major events can arise from human behaviour and technical faults. Simulations support the necessary plan approval implementation process. This refers both to the assessment of the risk before and during the event as well as to the security infrastructure and, in the event of a risk, to countermeasures. In this context, agent-based models (ABM) representing human behaviour can be gainfully employed to simulate normal and emergency situations, allowing organisers and authorities to manage large-scale public events.

The ABM presented in this paper is based on work in the EU project SATIE, which investigated passenger behaviour in airports under normal and disturbed conditions like distancing rules due to the Covid pandemic [7] or cyberattacks where gate information is manipulated [8]. This is further developed in the context of mass events at the Fraunhofer Center for the Security of Socio-Technical

Systems (SIRIOS). Four Fraunhofer institutes collaborate in SIRIOS to develop simulation tools to provide decision support in public crisis events [11].

The agent-based simulation tool so far incorporates modules for pedestrian movement in 2D continuous space based on a combination of the social force model [5] with Smoothed Particle Hydrodynamics [12] for agent-to-agent collision and a colliding force derived from a precalculated potential field for agent-to-wall collisions; path-finding applying the A* algorithm [4]; and a needs-based action selection mechanism for the agents. The generation of scenario-specific layouts defining the event location and of different agent types and/or behaviour is controlled via a set of specification files in a pre-defined JSON format. Our goal is to extend this framework to allow for heterogeneous agent behaviour dependent on agents' individual characteristics like age, gender or fitness level. We attempt this by mapping agent parameters to motives or needs, which in turn are mapped to available actions.

The remainder of this paper is structured as follows: First, we discuss related work, followed by the presentation of our approach in section 3. Next, in section 4 a small example simulation is presented. Finally, in section 5 the work is concluded and an outlook on future developments is provided.

2 Related Work

The concept that humans make their decisions to take action in order to fulfill needs goes back to Maslow [9]. A well-known example of needs-based action selection is the 'Sims' franchise [14]. In this series of computer games virtual agents have needs, modeled as reservoirs that can be depleted and refilled through various actions or objects in the environment.

The current version of our ABM implements a simple version of this: to find their next target, agents evaluate all possible actions and select the one which will satisfy their current needs best. A similar approach is applied by the Anthology framework [1]; it includes travel time to possible locations in the calculation of action utility. Differences between agents with regard to need reservoir decay and increase rates are not yet realised, although the authors discuss such a possibility for future versions.

The CROSS framework [13] also includes satisfaction of basic needs (stomach, bladder) in its agent decision making algorithm, combined with a cognitive component that provides an agent's knowledge and internal state (memory). The behaviour selection process then chooses the behaviour best suited to the currently most dominant goal (need). Levels of bladder and stomach decay linearly over time, the same for all agents. In contrast to Anthology, this framework is dedicated to the simulation of crowds and the authors provide an example model instantiation for a festival. However, the environment is grid-based and agent movement is therefore comparatively simple.

Coming from the computer graphics community, the crowd simulation system HiDAC on the other hand provides realistic animations of crowd movement by combining a social and physical forces model with geometric and psychological rules [10]. To avoid homogeneous crowds and ease the definition of different agent types the authors suggest a mapping of personality factors to low-level parameters of the HiDAC model [2]. Agents' personality types are defined as a vector of five elements (the so-called 'Big Five' personality traits: openness, conscientiousness, extroversion, agreeableness and neuroticism) and traits are assigned to agents based on normal distributions with user-defined values for means and standard deviations. The focus here is on integrating different mental states of agents during the evacuation of buildings.

3 Methodology

The objective of our approach is to find an efficient and effective way to generate heterogeneous agents representing participants at mass events like big open-air concerts or street festivals. Since such events can last from several hours to several days, it is necessary to not only model the participants' movement on the micro level including path-finding and collision avoidance but also their decision-making with regard to where to go and what to do next.

The basic idea is that an agent's individual properties influence their needs and resulting motives. We propose mapping properties to needs by specifying empirically determined or plausible functions which are applied to modify the decrease rate of motives and/or changes an action induces on a motive for each agent. For example, a person with low extroversion could have different effects from certain socially related actions than someone with a more outgoing personality; or children and old people typically need to go to the toilet more often than young to middle-aged adults. This correlation of age with urination frequency could be modelled as an inverse Gaussian curve or a step-wise linear function for different age groups. It can then be used to supply an age-related factor ω_{age} to feed into the agent's toilet need update as follows:

$$value_{t_{i+1}} = value_{t_i} - decreasePerMinute * \omega_{age}/60 * \Delta t \tag{1}$$

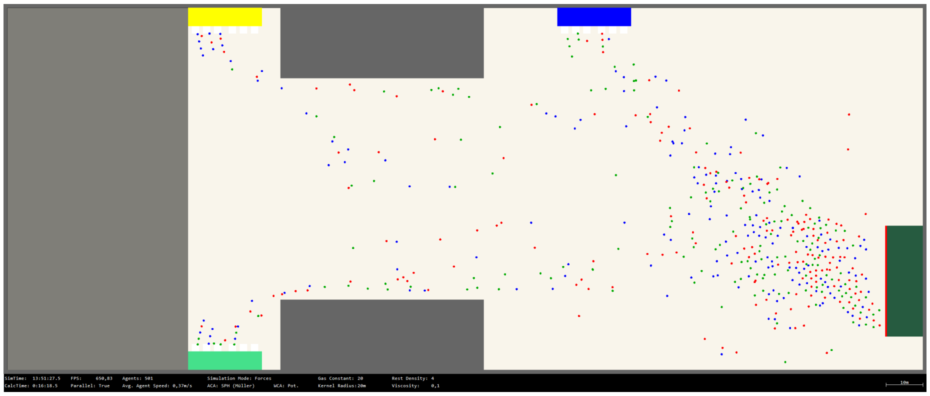
Table 1. Needs vs Actions table.

Need / Action	Eat	Drink	Watch stage	Walk	Queue
Thirst	+	−−	++	++	+
Hunger	−−	−	+	+	+
Toilet	+	++			
Entertainment			−	+	+

While needs influence the choice of actions, actions in turn can have an influence on an agent's current need levels. When thirst drives an agent to get something to drink, this intake of fluids will increase their need to go to the toilet. Table 1 shows an example of the general correlation between needs and actions that we included in the model; a + (−) sign indicates positive (negative) correlation. The strength of the correlation is expressed by the number of signs.

4 Application

As proof of concept we simulated an artificial public event and different types of visitors over several hours. The layout (see Fig. 1) consists of a festival area with a stage on the right, stalls for drinks (light green) and food (yellow) on the left, and toilets (blue) at the top. The grey rectangles are walls or other obstacles. Agents enter from the left and visit the stage to fulfill their need of entertainment or wander off to one of the stalls or the toilets when the respective need becomes dominant.



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SimTime:  13:51:27.5   FPS:     650,83   Agents: 501                Simulation Mode: Forces           Gas Constant: 20      Rest Density: 4
CalcTime: 0:16:18.5    Parallel: True    Avg. Agent Speed: 0,37m/s  ACA: SPH (Müller)     WCA: Pot.   Kernel Radius:20m     Viscosity:    0,1
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Fig. 1. Example simulation with agents of three different age groups (blue: young, green: adult, red: senior).

In this first trial of our approach, we focus on basic and domain-related needs (thirst, hunger, toilet, entertainment) and investigate the effect of one agent property (age) on the manifestation of agent behaviour. To aid the visibility of effects we differentiate only three age groups (young, adult and senior) and apply simple step functions to modify the needs according to age group. These functions are not based on any data but have solely been defined to demonstrate the applicability of our approach. The resulting age-related factors are given in table 2. Table 3 lists the factors used to model the effects of actions on needs; a positive value indicates that the action increases the need whereas a negative value results in the action decreasing the need.

We conducted simulations with 600 agents (200 per age group) over a time period of 8 hours with two model variants: the original ABM version (M1) and the updated version with behaviour modifications in place (M2). Both model variants apply the impact factors listed in table 3. M2 also varies the desired speed of the agents according to their age: whereas young people and adults move with the same speed seniors are a little slower (see table 2). At the beginning of the simulation, the agents gradually enter the festival area and then stay until the end. Their needs are initialised with random values following a normal

Table 2. Age-related factors influencing agents' needs and desired walking speed.

Need / Age group	Type 1	Type 2	Type 3
Thirst	1.3333	1	0.6667
Hunger	0.8333	1	1.6667
Toilet	0.6667	1	1.3333
Entertainment	1.3333	1	0.6667
Speed	1	1	0.875

Table 3. Impact factors of actions on needs.

Need / Action	Eat	Drink	Walk	Watch	Queue
Thirst	0.25	-1	2	1.5	0.75
Hunger	-1	-0.1	2	1.3	1
Toilet	0.3	0.5			
Entertainment			1	-0.5	1.1

distribution with mean 0.5 and standard deviation 0.15. This means that while some agents will head straight to the stage, others will first get something to eat or drink, or visit the toilets.

To compare results we recorded the total number of visits to drink and food stalls and the toilets over time. Figures 2, 3 and 4 show resulting time series from a typical run for M1 (type 0, black) and M2 (type 1-3, blue, green and red lines). After an initial settling phase, the effect of the stronger thirst assigned to the young agents (type 1) is clearly visible as they visit the drink stalls significantly more often (Figure 2), while the senior agents (type 3), who have been assigned a lower than average thirst, fall behind. The adults (type 2) show practically no deviation from the default behaviour (type 0). This is as expected given their thirst factor of 1.

The attendance at the food stalls (Figure 3) is more interesting. While the general shape coincides with the assigned age-related factors, so that the senior agents eat more often than the younger agents, the gap between the senior and younger agents' food stall visits is significantly larger than suggested by these factors. This might be explained by a combination of the younger agents filling part of their hunger need through drinking (see impact factor of -0.1 in Table 3) and the senior agents exacerbating their hunger through more walking and queueing.

The toilet visits (Figure 4) also demonstrate such overlapping effects of age-related need modification with action-related impacts. Even though the younger agents were assigned a lower toilet need, their elevated drinking behaviour leads to them having to go to the toilet more often than the adult agents whose age-related toilet need is higher.

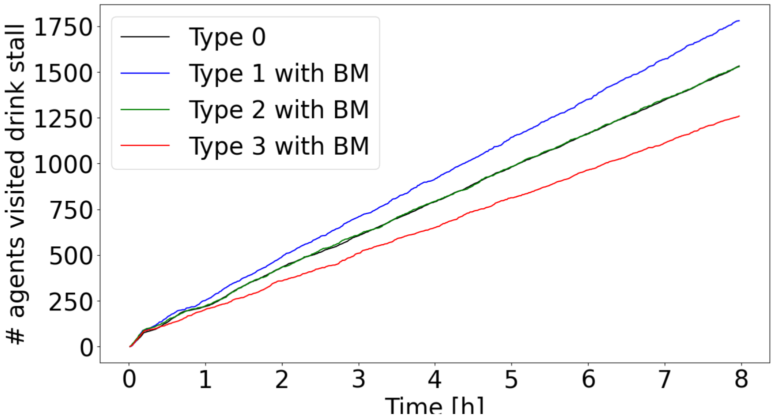

Fig. 2. Comparison of overall drink stall visits: results from a simulation with the three different age groups (type 1-3) vs. results from a simulation without behaviour modification (type 0).

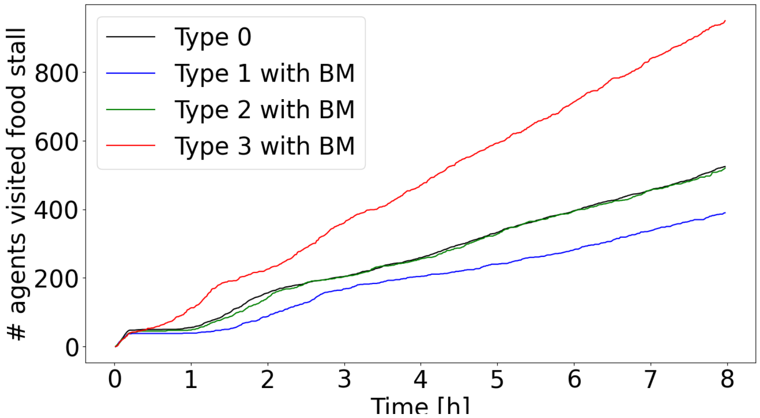

Fig. 3. Comparison of overall food stall visits: results from a simulation with the three different age groups (type 1-3) vs. results from a simulation without behaviour modification (type 0).

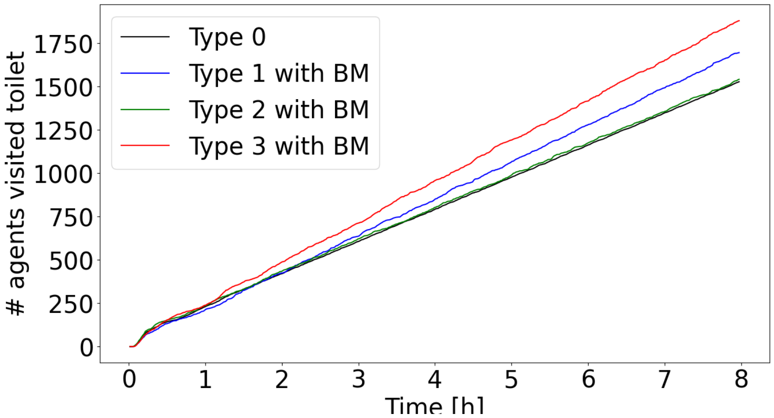

Fig. 4. Comparison of overall toilet visits: results from a simulation with the three different age groups (type 1-3) vs. results from a simulation without behaviour modification (type 0).

5 Conclusion and Outlook

The results discussed above are encouraging. The first trial implementation demonstrates that our approach is feasible and worth pursuing. We will work next on generalising the format to allow for the flexible inclusion of new functional relationships between parameters, actions and needs.

This is needed in preparation for a planned extension regarding emergency communication. The dissemination and effectiveness of warning messages are central in emergency interventions. For instance, it is known that in the case of evacuation, this phase is mainly responsible for evacuation delays [6]. Therefore, we plan to extend our framework to encompass this aspect. Most emergencies at large-scale events are acute, and existing communication and psychological frameworks are only partially applicable [3] . Our future work will not only focus on physical needs but also address emotional, social, and safety motives. This will enable us to include emergency-related behaviour such as information seeking, sharing, and compliance. In this context, introducing heterogeneous agents into our model is crucial to accurately simulate the diverse range of reactions in emergency scenarios.

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