# MAKKSim: Dealing with Pedestrian Groups in MAS-based Crowd Simulation

Lorenza Manenti<sup>1,2</sup>, Sara Manzoni<sup>1,2</sup>, Giuseppe Vizzari<sup>1,2</sup>

<sup>1</sup>Complex Systems and Artificial Intelligence Research Center Dipartimento di Informatica, Sistemistica e Comunicazione Universita' di Milano–Bicocca viale Sarca 336/14, 20126 Milano

<sup>2</sup> Centre of Research Excellence in Hajj and Omrah, Umm Al-Qura University Makkah, Saudi Arabia {manenti, manzoni, vizzari}@disco.unimib.it

*Abstract*—The paper presents MAKKSim, an agent-based tool for pedestrian dynamics simulation. The software is a second generation tool in which the presence of pedestrian groups and some cultural elements are explicitly modelled and can be set by the end-user.

In this work, an overview on the MAKKSim model and software architecture is presented, by means of the definition of agent behaviours and the analysis of UML diagrams and enduser interface.

# I. INTRODUCTION

The simulation of pedestrians and crowd dynamics is a consolidated field of application for agent-based models: successful case studies can be found in the literature and offthe-shelf simulators are commonly employed by end-users, decision makers and consultancy companies.

However, these tools are the result of a first generation of research efforts considering individuals, their interactions with the environment and among themselves, but generally neglecting or treating in a simplistic way aspects like (i) the impact of cultural heterogeneity among individuals and (ii) the effects of the presence of groups and particular relationships among pedestrians. The last point is, in fact, an open topic in the context of pedestrian modelling and simulation approaches [1] [2]: the implications of particular relationships among pedestrians in a crowd (e.g. the presence of groups) are generally not considered by current approaches.

In this work we present *MAKKSim* (MAKKa pedestrian and crowd Simulator), a second-generation platform for pedestrian dynamics simulation based on an agent-based model in which groups of pedestrians and cultural attitude are explicitly considered. MAKKSim and its relative model are the results of CRYSTALS project, a multidisciplinary research between the Center of Research Excellence in Hajj and Omrah (Saudi Arabia) and Complex Systems & Artificial Intelligence Research Center (Italy): the main focus of this project is the adoption of an agent-based pedestrian and crowd modelling approach to investigate meaningful relationships between the contributions

of anthropology, cultural characteristics and existing results on the research on crowd dynamics, and how the presence of heterogeneous groups influences emergent dynamics in the context of the Hajj (i.e. the Pilgrimage toward Makka). In the specific context of the Hajj, the yearly pilgrimage to Makka that involves over 2 millions of people coming from over 150 countries, the presence of groups and the cultural differences among pedestrians represent two fundamental features of the reference scenario.

Modelling groups and cultural aspects were the main requirements for MAKKSim development: with MAKKSim, we try to consider and explicitly model the impact of cultural heterogeneity among individuals by means of the introduction of proxemic-driven behaviour based on the theories by E.T. Hall [3] and by E. Canetti [4]: moreover, groups can be directly managed by the user by means of the definition of parameters related to group cohesion. Beyond groups and cultural attitude, other requirements were the integration of existing data specifying the spatial structure of the environment in which simulations must take place (e.g. CAD files), the possibility to export data about the simulations for analyses carried out by means of external programs, the possibility to provide an effective 3D visualization of the dynamics generated by the simulator.

In the following, an introduction to MAKKSim platform is proposed, with an explanation of the model of pedestrians by means of agent behaviours and the description and management of the environment. Then, an analysis of software architecture and relatives modules is presented, in order to show relationships among different elements of the model which the platform is based on.

# II. MAKKSIM

MAKKSim is a software simulation platform developed by Complex Systems and Artificial Intelligence Research Center (CSAI) that supports the development of what-if scenarios about pedestrian dynamics within structured environments. MAKKSim allows end-users to simulate and visualize crowd dynamics in open and closed structured spaces. The underlying modeling approach employed by MAKKSim is based on agent-based approach, according to which pedestrians and groups of pedestrians within a crowd are represented by individual behavioural and perception rules that drive agents within the structured environment. MAKKSim agents are able to perceive and avoid spatial elements that represents obstacles and to follow paths throughout environmental elements. Moreover, MAKKSim agents are able to perceive other agents and to recognize those that belong to their group and to behave, according to proxemic behavioral rules by maintaining differently spatial distances in case of group members and not group members.

Considering the necessity to introduce and describe the environment of the simulation, MAKKSim provides to endusers design tools for the effective and efficient development of what-if scenarios by allowing the import of a set of CAD and 3D file formats: the use of these latter allows to simulate populated spaces and the generation of effective 3D visualization of crowd dynamics and to export of simulation data for analytical aims. The integration within 3D formats is supported by the use of Blender<sup>1</sup>: it is a free, open source 3D environment that can be used for modeling, animating and rendering 3D scenes, and provides a Python scripting engine and a set of primitives to support 3D drawing and 2D/3D interactive views.

MAKKSim first exploitation has been within CRYSTALS project, in which MAKKSim has been employed for the development of a set of what-if scenarios within Arafat I railway station in order to demonstrate how agent-based approach and the modeling of crowd of pilgrims taking into account multidisciplinary issues (e.g. multicultural setting) can effectively be employed to support decisions and operations of organizers and crowd managers devoted to the yearly pilgrimage at Makka.

## A. Pedestrians and environment

As previously written, MAKKSim is based on agent-based approach: pedestrians are modelled as agents situated in a structured environment. The environment is managed in a discrete way: MAKKSim is able to work on 3D images in which relevant elements for the simulation have to be presented. Starting from these images, MAKKSim elaborates 2D-images and creates a grid of the environment with cells with a size of 40x40 cm according to [5].

In this discrete environment, the dynamics of agents is based on two behaviours:

- the *goal-driven behaviour*, that represents the tendency of a pedestrian to move toward its target;
- the *proxemic-driven behaviour*, based on Proxemic theory and consisting of two different rules:
  - *separation rule*, that represents the tendency of a pedestrian to preserve a certain distance from other

<sup>1</sup>Blender website: http://www.blender.org/

pedestrians which belong to a different group;

- *cohesion rule*, that represents the tendency of a pedestrian to stay close to its group members.

In order to support these rules, every agent is characterized by a state representing individual properties of pedestrian:

- *group membership*: every agent belongs to a group, defined as a set of agents (groups of size equal to 1 are allowed);
- *goal*: every agent has only one goal to reach during the simulation;
- *goal, cohesion and separation degrees*: every agent is characterized by multiplicative coefficients to manage personal attitude related to goal-driven and proxemic-driven behaviour;
- *cohesion and separation radius*: every agent is characterized by values which identify how much space has to be considered in the management of proxemic-driven behaviour. In fact, these values identify the largeness of the neighbourhood interested by separation and cohesion rules.

All these values can be set by the user to obtain different plausible simulations.

Thanks to the discretization of the environment, the goaldriven behaviour is managed by means of floor field method: considering the set of goals in a scenario, for every target a 2D-image of the environment of the simulation is created (see Fig. 1). Starting from the image and considering the walkability of the environment, a weighted matrix in which every cell represents a pedestrian position is created. Every cell has an own weight assigned starting from the target area (in which the weight is equal to 0): cells more distant from the target have a greater weight respect to the others (Fig. 2(a)).

Proxemic-driven behaviour works in a similar way: for every agent, separation and cohesion rules are verified considering neighbourhoods and according to values specified by the user before the simulation.

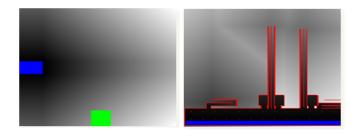


Fig. 1. 2D-images created by MAKKSim with floor field representation: figure on the left shows a simple environment in which the goal area is represented by the blue object on the left. Figure on the right shows part of the scenario of Arafat I station: red lines represent non-walkable space and the target area overlaps with the internal part of the station.

The overall dynamics of a pedestrian is the result of the weighted sum of the three vectorial components representing goal-driven behaviour and separation and cohesion rules (Fig. 2(b)):

```
ped_direction = g_direction *W_g+
s_direction *W_s+ c_direction *W_c
```

where  $W_g, W_s, W_c$  are respectively the goal, cohesion and separation degrees presented before.

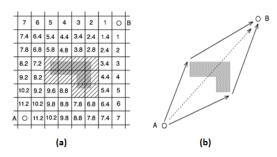


Fig. 2. These figures represent the weighted matrix and the vectorial components related to an agent a with a target b. Figure (a) shows the weighted matrix: you can note that the values increase starting from b. Figure (b) represents the suggested paths to agent a to reach its goal b.

## B. MAKKSim Software Architecture

In this section an overview on software architecture and an analysis of relevant modules to manage the environment, the scenario and the agents is presented.

The software architecture of MAKKSim is composed by potentially reusable modules to build personalized decision support systems and it can be further extended by means of scripts written in Python language.

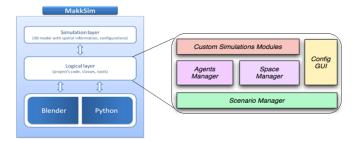


Fig. 3. The three layers software architecture

Currently, MAKKSim is based on a three layers software architecture (Fig. 3):

- Low level layer, that is the foundation of the software, composed by Pithon virtual machine that runs the code and the Blender 3D environment that is used to produce an easy-to-read visual response;
- 2) *Logical layer*, that is the core of the project and of the simulation engine;
- 3) *Simulation layer*, that supports end-users in the creation of simulations, and includes the 3D model of the environment and the configurations of the simulation (e.g. groups, agents, targets and so on).

These layers are not stand-alone modules: interactions among layers are necessary and allowed in order to exchange information and data from simulation to low level and vice versa.

As previously written, the logical layer represents the core of the simulation engine, in which the code of the project, the classes and the tools are located. This layer is composed of five modules (Fig. 3):

- 1) *Scenario manager*, that is devoted to the management of the configuration file for the scenario. Moreover, it generates logs and statistics about the simulation;
- 2) *Space manager*, that is devoted to the management of the space;
- 3) *Agent manager*, that is devoted to the management of agent behaviour;
- 4) *Custom Simulations Modules*, with the scope to allow the customisation of the simulation by the end-user;
- 5) Configuration GUI, to support user interface.

All these modules are connected with each other and with Blender environment, in order to exchange information and data in the same and different layers.

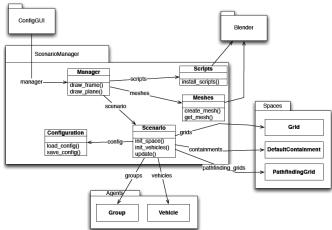


Fig. 4. The UML diagram related to Scenario Manager Package

A more detail explanation of Scenario Manager, Agent Manager and Space Manager packages is now presented by means of UML diagrams.

1) Scenario Manager: This module contains information to manage the configuration of the simulation and to create log and statistic files (Fig. 4). In order to perform these tasks, an interaction with Blender environment is guarantee to support animation and pedestrian 3D models set-up. Moreover, the module allows the configuration of simulation parameters and provides the mechanism to update the scenario of the simulation. Actually, this module works with Agent Manager in order to redesign frames of the simulation after the updating of the states of all the pedestrians involved in the scenario.

Agent Manager: This module is devoted to the management of agents (called vehicles in the follows) and groups (Fig. 5). The class *Vehicle* that implements agents can be overridden in order to adopt different pedestrian simulation models. Class

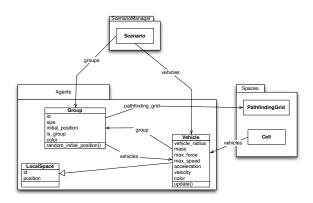


Fig. 5. The UML diagram related to Agent Manager

Vehicle is connected to the Space Manager module to manage the path with the relative pathfinding algorithm. Every vehicle belong to a group, identified by a set of features like id, size, initial position and so on. In particular, every group has only one goal, that is shared among all the group members.

3) Space Manager: This module is devoted to the management of the environment by means of the definition of the grid, the cells and the pathfinding algorithm (Fig. 6). The environment is divided into cells of 40x40 cm: the algorithm analyses the position of pedestrians in the environment and computes the path for the pedestrians using floor field method. Pathfinding algorithm also uses the grid for the agent neighbourhood calculus to develop the cohesion rule related to groups: in this case, every cell has a dimension of 10x10 m.

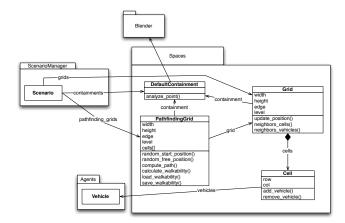


Fig. 6. The UML diagram related to Space Manager

#### C. The end-user interface

MAKKSim shows a simple and user-friendly interface composed of two main parts (Fig. 7): on the left a window in which the scenario of the simulation is proposed. The user can modify the environment adding spatial constraints and relevant elements in order to define target areas. On the right, all the utilities to set up simulation, pedestrians and groups are presented.

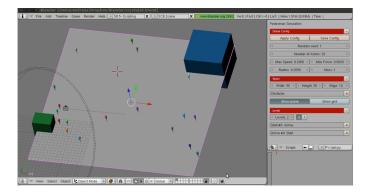


Fig. 7. An overview of MAKKSim interface: on the left the environment of the simulation is shown while on the right utilities to set up simulation, pedestrians and groups are presented

Utilities support end-users in the tree main steps necessary to create the simulation:

- 1) the definition of the environment of the simulation: thanks to the integration with Blender environment, MAKKSim is able to import 3D files in order to extract and draw the scenario. The end-user can import 3D and 2D file formats of the environment: working on 3D model file from CAD software, they can be directly imported in MAKKSim. An annotation and selection of spatial structure is then required in order to identify the main elements of the scenario which have to be considered in the simulation (e.g. the raw geometry of the roads, obstacles, corridors, gateways, and so on). Differently, considering 2D-file (in vector or bitmap format), after the importing in MAKKSim, a map redraw and some basic extrusion operations of relevant spatial structure are required, to turn the map into a proper 3D model:
- 2) the definition of pedestrians and groups: the user interface (Fig. 8) allows to define the number of pedestrians involved in the simulation and their features. It is also possible to define parameters related to the proxemicdriven behaviour (i.e. cohesion and separation degree) and to the goal-driven behaviour (i.e. goal degree);
- 3) the definition of the parameters of the simulation: the user interface (Fig. 9) allows to save and apply new configurations of the parameters related to the simulation, to create, load and save walk-ability and pathfinding grid. The interface also allows the requests for log and statistic files about pedestrian movements and simulations.

# III. THE SCENARIO OF ARAFAT I STATION ON MASHAER Line

In this section we refer to the use of MAKKSim for the study of affluence on Arafat I station of new Mashaer train line during Hajj 2010.

4	Random seed: 10	Þ
4	Number of Actors: 50	•
4	Max Speed: 0.3000 🔺 Max Force: 0.5000	Þ
4	Radius: 0.5000 🕨 🔍 Mass: 1	Þ
٩C	ohes: 0.4000 🔄 🗧 Sep: 0.2000 🕨 🔍 Goal: 0.0000	•
Ve	hicle class: woa.Avoider	
S	pace	+
G	roups	+
	patial Constraints	-

Fig. 8. User interface dedicated to the definition of pedestrians, groups and targets in the environment



Fig. 9. User interface dedicated to the definition of simulation parameters

After the representation of the scenario of Arafat I station by means of the importing of CAD file, several simulations related to the entrance of pilgrims in the station from waiting boxes were developed.

Figure 10 represents a real situation in the area of waiting box in Arafat I: it is possible to note the presence of groups moving from the waiting box towards ramps. In Figure 11, the same situation is presented using MAKKSim software.

First results related to a qualitative analysis of simulations are promising: simulations are quite similar to situations detected in the station during Hajj2010 and allows to study how the presence and the position of groups of pilgrims influence in different ways the overall dynamics of the Pilgrimage.

## IV. FUTURE INTEGRATIONS AND DEVELOPMENTS

Future works are related to the integration of MAKKSim with tools for simulation output analysis and for simulation input. From this point of view, the integration with PiGro (Pilgrim Groups granulometric distribution tool) which provides plausible configurations of group distribution in the environment is an ongoing work. PiGro is a tool in which it is possible to specify the initial configuration of the simulation specifying group features (kind, dimension, number, shape) in a given environment.



Fig. 10. A real situation representing pilgrims moving from a waiting box towards the entrance of the Arafat I station

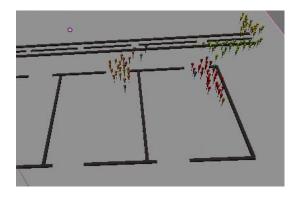


Fig. 11. Simulation related to the situation shown in Fig. 10

### ACKNOWLEDGMENT

This research was fully supported by the Center of Research Excellence in Hajj and Omrah, Umm Al-Qura University, Makkah, Saudi Arabia, grant title "Crystal Proxemic Dynamics of Crowd & Groups". Authors would like to thank Dr. Andrea Bonomi for his work in the development of the platform.

#### REFERENCES

- C. C. Challenger, R. and R. M., Understanding Crowd Behaviours. Cabinet Office, 2009, vol. 1.
- [2] C. Rogsch, W. Klingsch, and A. Schadschneider, *Pedestrian and evacu*ation dynamics 2008. Springer Verlag, 2010.
- [3] E. Hall, The hidden dimension. Doubleday New York Ed., 1966.
- [4] E. Canetti, Crowds and Power. Victor Gollancz Ed., 1962.
- [5] U. Weidmann, "Transporttechnik der fussgänger," Institut füer Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau IVT an der ETH Zürich, ETH-Hönggerberg, CH-8093 Zürich, Literature Research 90, March 1993, in German.