WOA 2011
Dodicesimo Workshop Nazionale "Dagli Oggetti agli Agenti“
5-6 Luglio 2011, Rende, Cosenza (Italy)

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

A Cellular Automata Model for Pedestrian and Group Dynamics

S. Bandini, F. Rubagotti, G. Vizzari, K. Shimura

Crystals of Crowd: Modeling Pedestrian Groups Using MAS-based Approach

L. Manenti, S. Manzoni

CSAI COMPLEX SYSTEMS & ARTIFICIAL INTELLIGENCE RESEARCH CENTRE

DISCO DIPARTIMENTO DI INFORMATICA SISTEMISTICA E COMUNICAZIONE

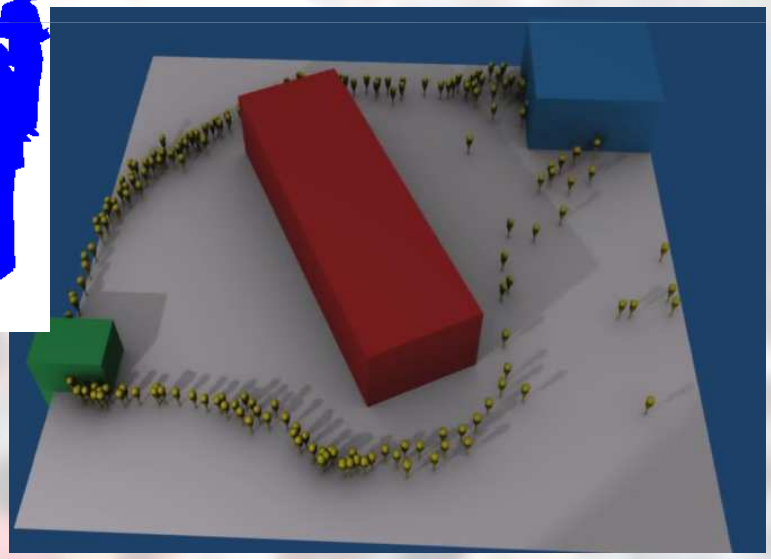
Outline of Presentation

- Goal and Motivation
- State of the Art
- GA-PED model
- Crowd Crystals Model
- Conclusions and Future developments
- References

Goals and Motivations (I)

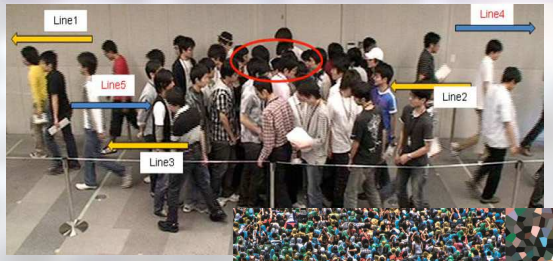
GOAL

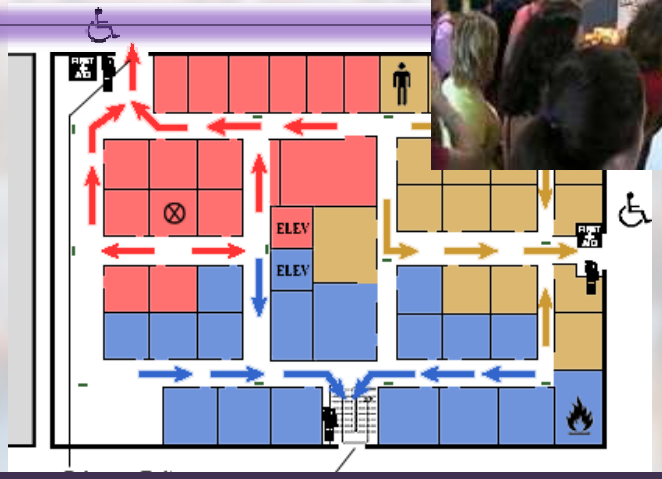
New computational **models** for the representation and the simulation of the dynamical behavior of groups of pedestrians within a crowd



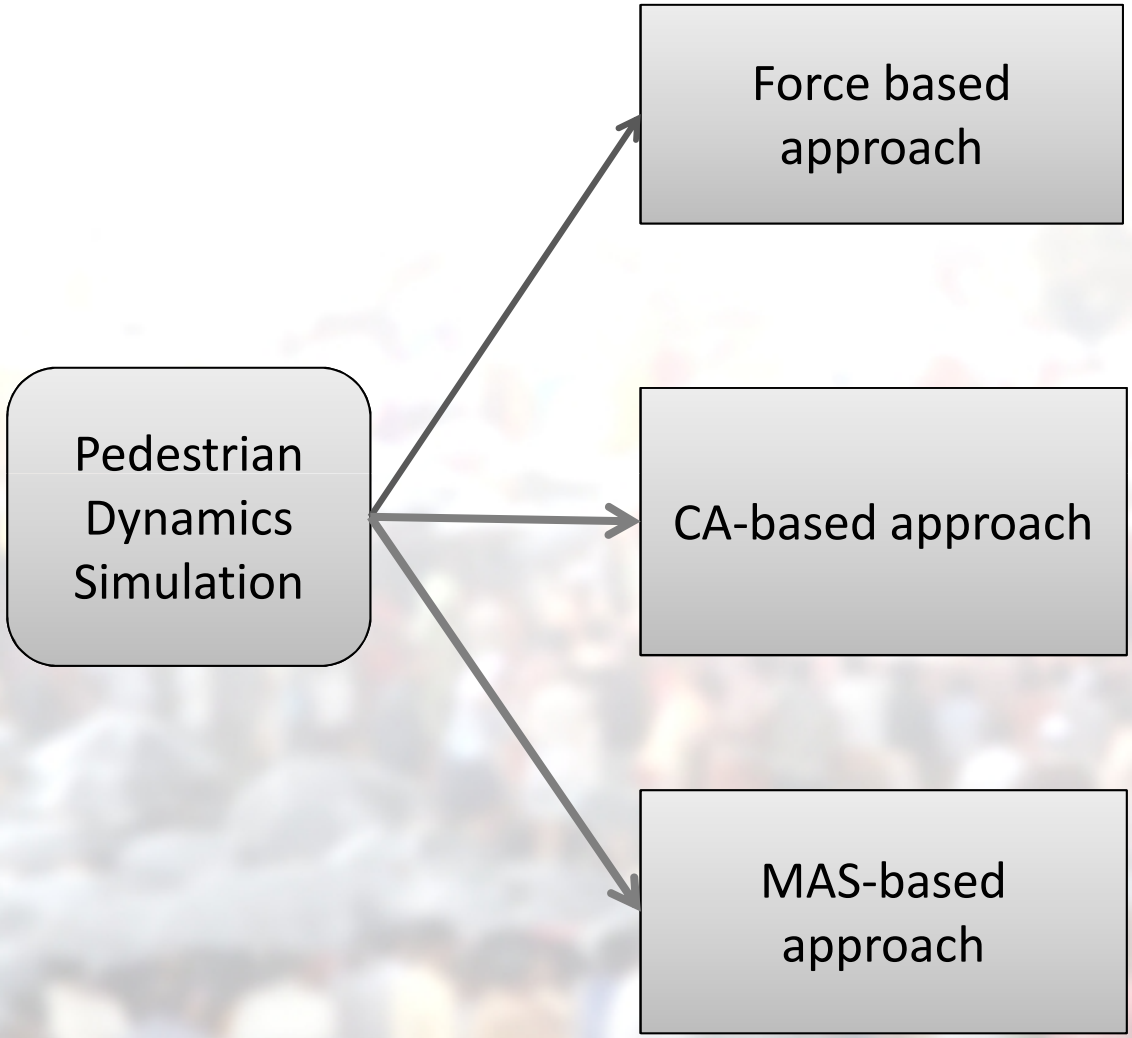
Goals and Motivations (II)

- To face challenging problems in the Pedestrian Dynamics field
- To develop computer-based systems to support crowd and collective spaces management
- To test the results on real cases through experimental and calibration activities





State of the Art: Group Modeling in PED

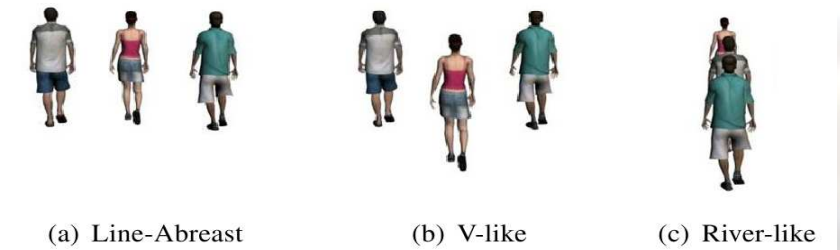


Group modeling and cultural differences among pedestrians within a crowd are **open issues** in the Pedestrian Dynamics field

State of the Art: Group Modeling in PED

First proposals exploiting traditional models:

- Holonic multiagent multilevel model [Gau07]
- Group dynamics in social force model [Mou09]
- Group dynamics in CA-based approach [Sar09]
- Groups dynamics by means of utility function and social comparison theory [Qiu10a]



Other proposals focusing on the concept of group:

- Group dynamics considering group morphology starting from observation [Mou10]
- Group dynamics by means of weighted matrices modeling inter and intra relationships [Qiu10b]

Multidisciplinary approach

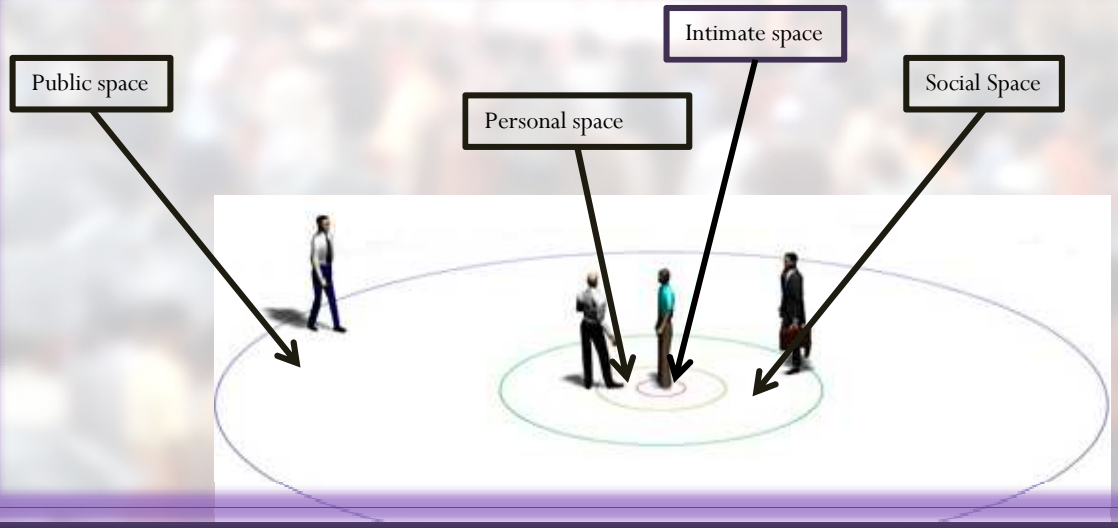
"A number of things or persons being in some relation to one another"
[Wikipedia]

GROUP

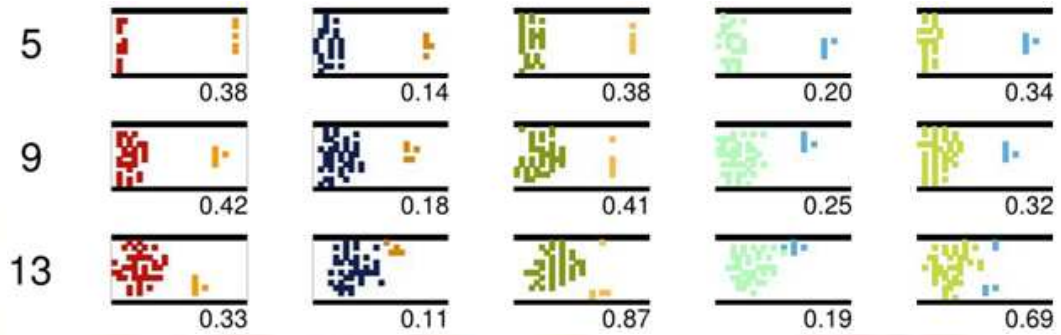
"An arrangement of relationships between components or individuals which produces a unit or a system "
[Ferber, 99]

"A number of individuals assembled together or having some unifying relationship"
[Webster Dictionary]

"A whole of individuals with a common goal and/or a common perceived identity "
[Social Science Encyclopedia]



Our Proposals



GA-Ped Model
based on CA-approach

Crowd Crystals Model
based on MAS-approach

CRYSTALS Project

GA-Ped Model

It is our first attempt to deal with the simulation of groups of pedestrians using a discrete approach.

This model is influenced by:

- Cellular Automata Models for Traffic Simulation;
- Cellular Automata Floor Field Models for Pedestrian Simulation;
- Agent-based Models for Pedestrian Simulation.

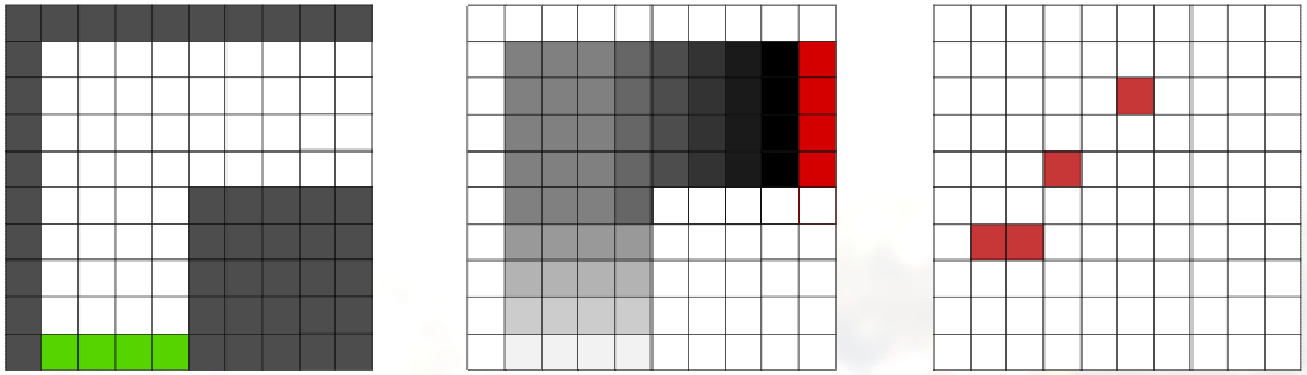
GA-Ped: Features

- Discrete space;
- It is possible to introduce groups of pedestrians with different sizes and behaviors;
- The movement of pedestrians is influenced differently by the presence of pedestrians belonging to the same group or by the presence of strangers;
- Pedestrians have a realistic perception model;
- Discrete-time dynamical system;
- Update rules are applied to all pedestrians following the *shuffled sequential update* method (necessary due to a reservation mechanism).

GA-Ped: Space

- Mutuated from the Cellular Automata theory: the space is discretized into squared cells with fixed width (two dimensional grid);
- In the primary version of the model the cell size is 40by40cm^2 (the typical space occupied by a pedestrian in a dense crowd);
- Modeled using a three-layer structure.

GA-Ped: three Layers Structure



1. Layer 1
   Details about the environment are saved into this layer (e.g. walls, obstacles, …);

2. Layer 2
   Contains information about the values of the floor field into each cell;

3. Layer 3
   Stores the position of each pedestrian
   Each cell can be occupied by only one pedestrian.

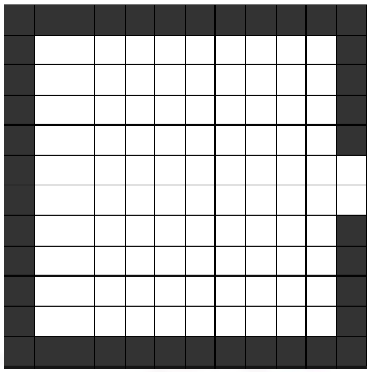
GA-Ped: Generating Spots

A generating spot consists in a group of cells, located in the same area, that can generate pedestrians following the same set of rules of generation, based on these parameters:

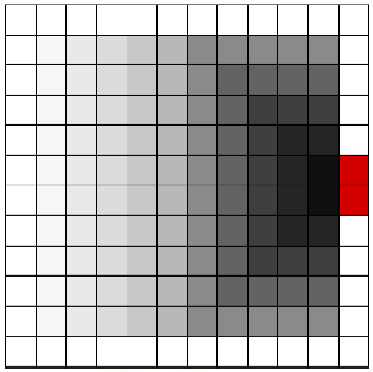
- max pedestrians
- group classes
- itineraries
- frequency of generation
- max population size

The density of the system may not be an input parameter: it is possible to determine the size of the population, but it is also possible to influence its value by determining the frequency of generation of new pedestrians in each spot.

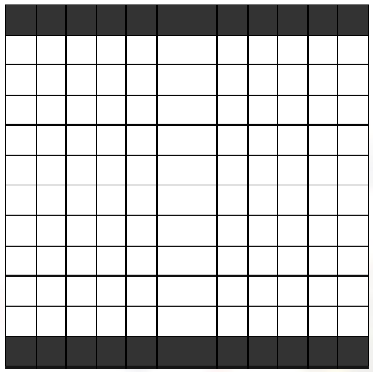
GA-Ped: Floor Fields



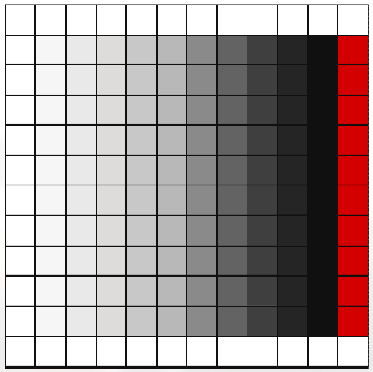
(i) Structure of the room



(ii) Floor field to the exit



(iii) Structure of the corridor



(iv) Floor field to walking east

- floor fields can be thought of as a grid of cells underlying the primary grid of the environment;
- they contains information suggesting the shortest path to reach the destination;
- in our model floor fields are static;
- one floor field for each target.

GA-Ped: Pedestrian Characterization

Elementary characterization of pedestrians:

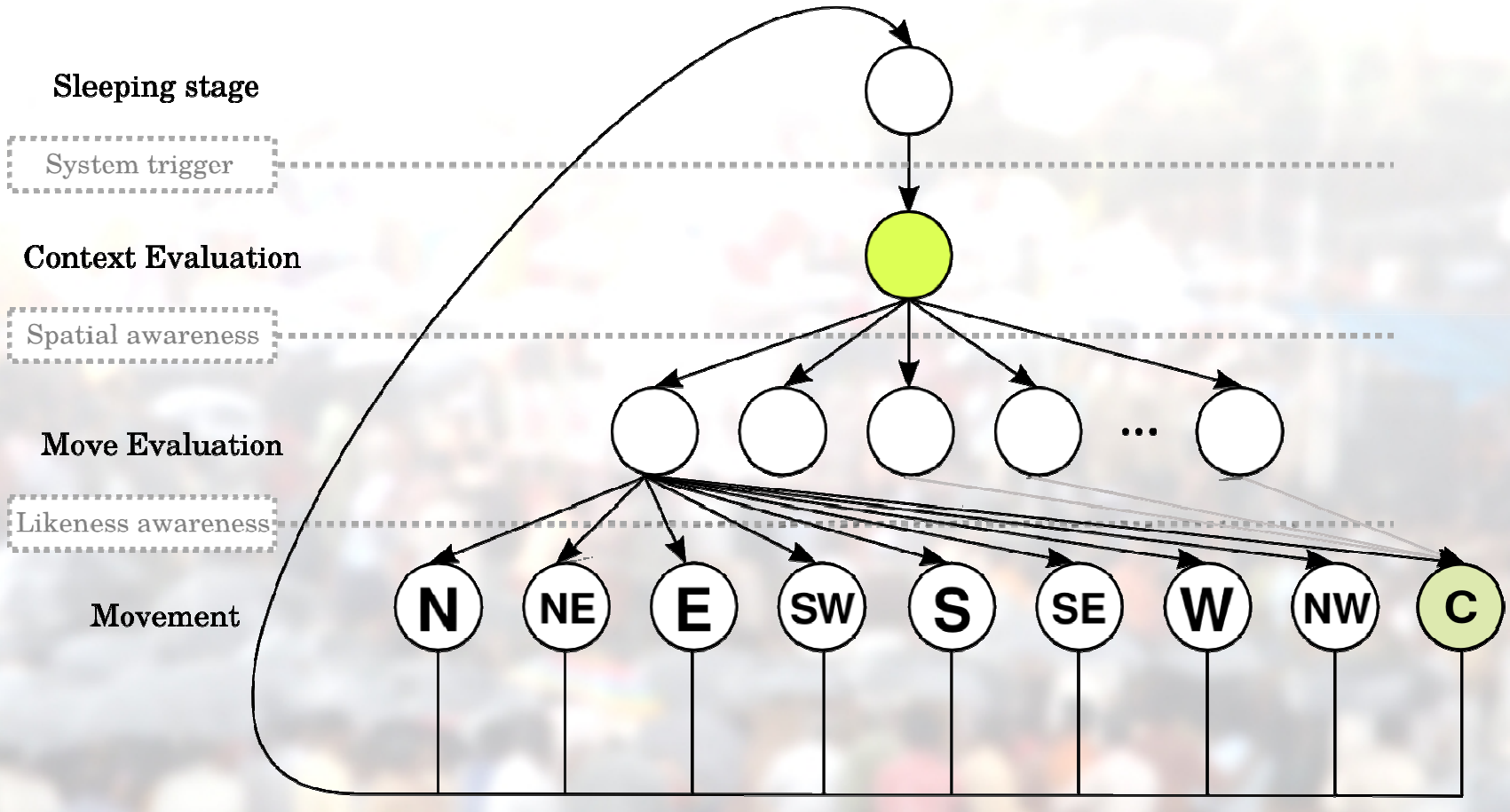
- pedID;
- Primary group;
- Schedule/itinerary.

In the future may be extended, e.g.:

- Stress index;
- Gender;
- Age;
- Ethnicity;
- …;

GA-Ped: Pedestrian Behavior

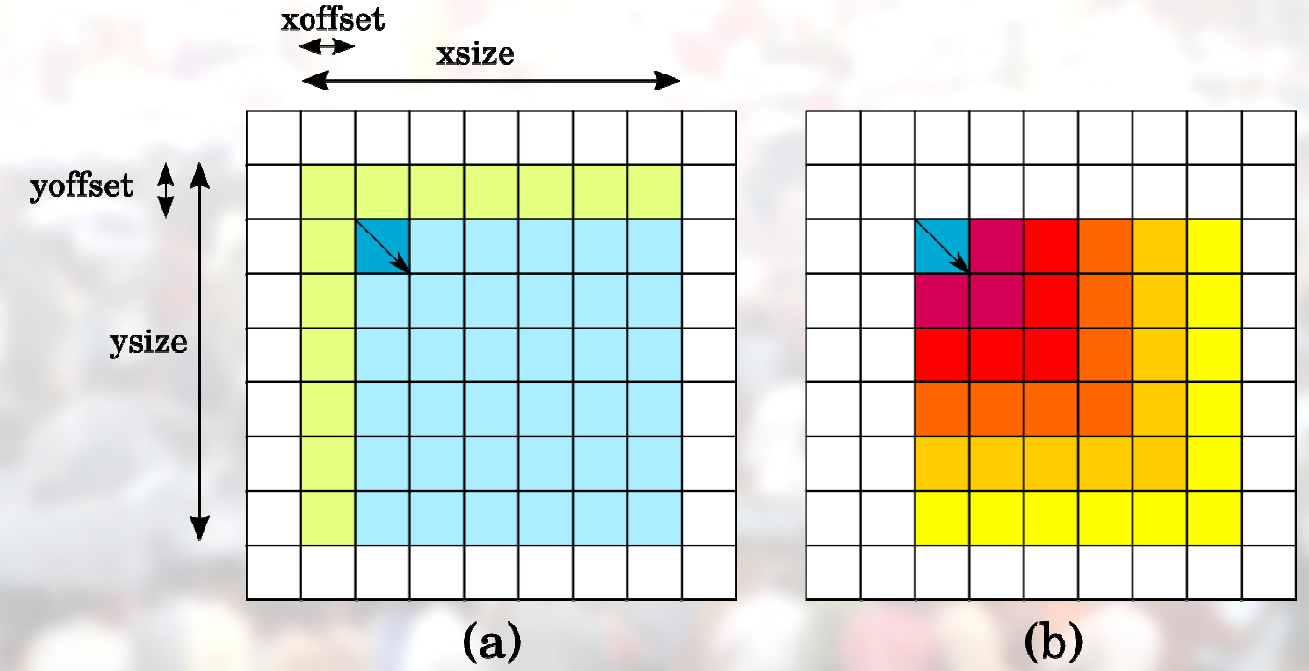
The behavior is modeled using a Deterministic Finite Automaton



GA-Ped: Pedestrian Perception Model

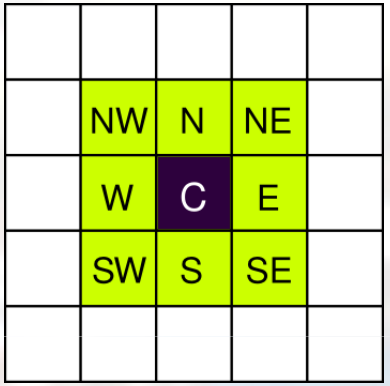
The main idea for the perception model consists in the use of *perception fans*.

A *perception fan* determines how far a pedestrian can see and how he evaluates different objects according to their distance.



GA-Ped: Pedestrian Movement Evaluation

Movements are possible along eight directions (cells with Tchebychev distance = 1), it is possible to keep the current position



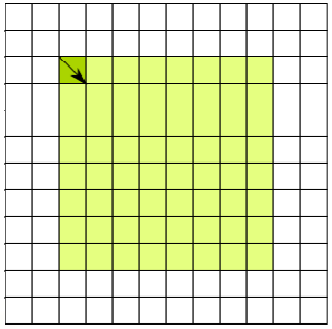
We defined the *likability* of a movement, as influnced by:

1. goal driven component (least effort theory) (**+**)
2. group cohesion (**+**)
3. geometrical repulsion (walls, obstacles, …) (**-**)
4. proxemic repulsion (**-**)
5. stochasticity (**+**)

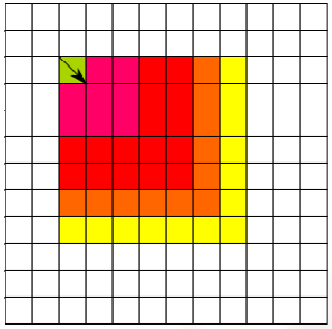
A pedestrian will choose a movement that maximizes the *likability*, i.e. the benefits obtained travelling into that particular position

GA-Ped: pedestrian movement evaluation

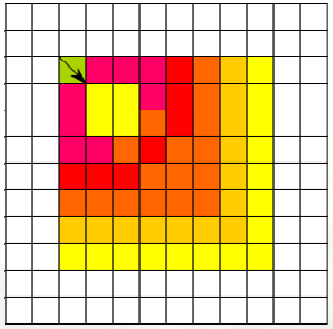
Observation fan: perceptive capabilities for a pedestrian walking south-east, with fan dimension 7, and three weight matrices for walls, pedestrian belonging to the same group and to other groups.



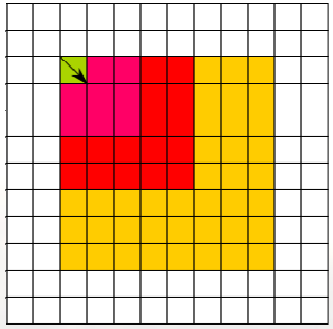
(i) Fan size



(ii) Weight matrix for walls

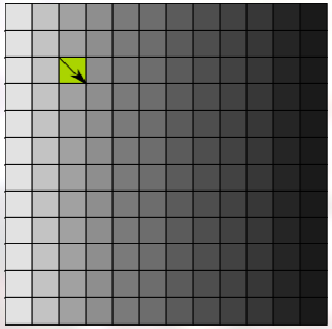


(iii) Weight matrix for same group

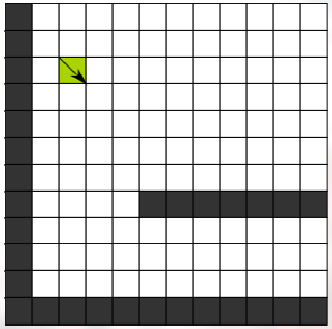


(iv) Weight matrix for different group

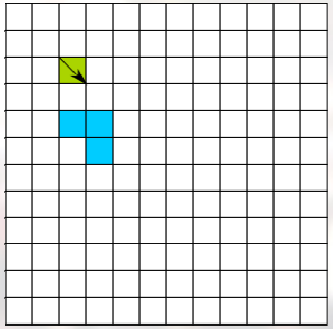
Sample scenario: pedestrian walking south-east, in a west-east corridor, with walls, 3 friends and 9 pedestrians belonging to other groups



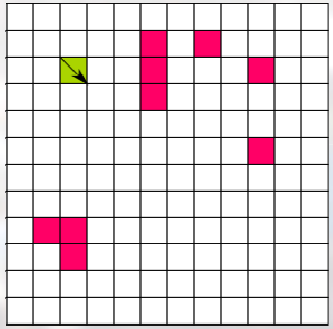
(v) Floor field



(vi) Walls

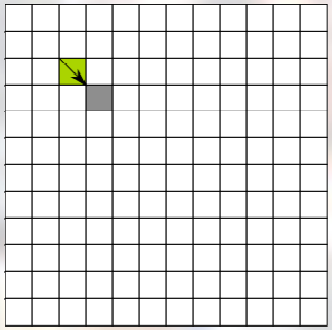


(vii) Pedestrians, same group

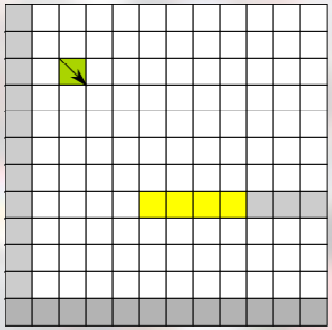


(viii) Pedestrians, other groups

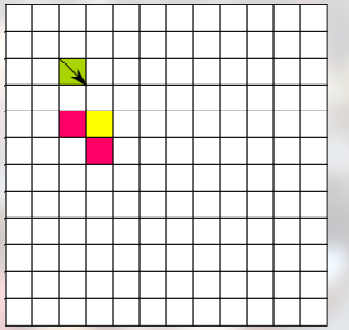
Scenario evaluation: pedestrian evaluates the floor field, the presence of walls, friends and other pedestrians according to the weights of the observation fan.



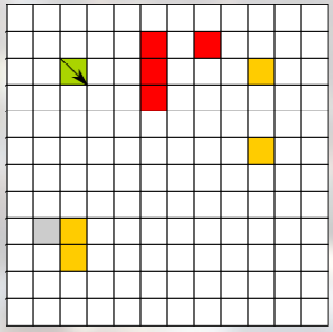
(ix) Foor field evaluation



(x) Walls evaluation



(xi) Pedestrians evaluation, same group



(xii) Pedestrian evaluation, other groups

GA-Ped: pedestrian movement evaluation

1. goal driven component ($\rightarrow$ floor field value)

$$l_2(c_{x,y}, t)$$

2. group cohesion ($\rightarrow$ presence of other members of the same group)

$$\zeta(group, d, (x, y), g) = \sum^{c_{i,j} \in \zeta_{x,y,d}} w^{\zeta}_{i,j} \cdot l_3(c_{i,j}, g)$$

3. geometrical repulsion ($\rightarrow$ presence of obstacles)

$$\zeta(walls, d, (x, y)) = \sum^{c_{i,j} \in \zeta_{x,y,d}} w^{\zeta}_{i,j} \cdot l_1(c_{i,j})$$

4. proxemic repulsion ($\rightarrow$ presence of strangers)

$$\zeta(strangers, d, (x, y), g) = \sum^{c_{i,j} \in \zeta_{x,y,d}} w^{\zeta}_{i,j} \cdot (1 - l_3(c_{i,j}, g))$$

Likability formula:

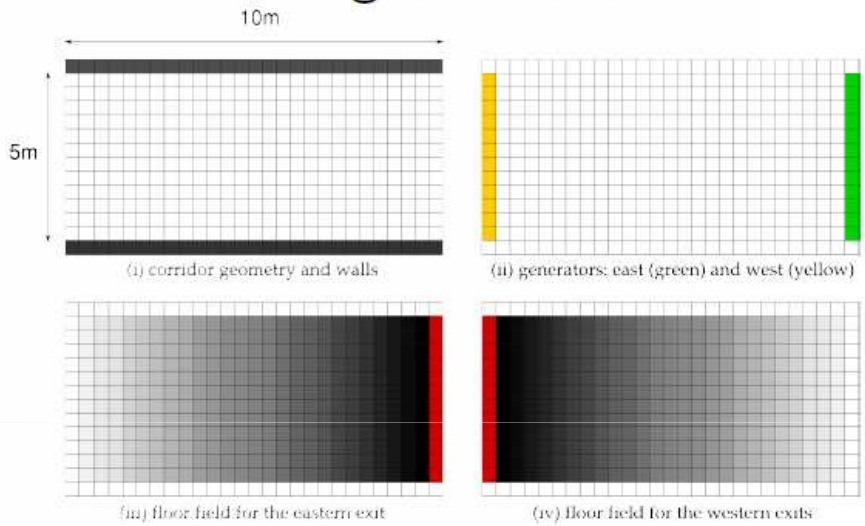
$$li(c_{x,y}, d, g, t) = j_f \cdot field(t, (x, y)) + j_g \cdot \zeta(group, d, (x, y), g) - j_w \cdot \zeta(walls, d, (x, y)) - j_n \cdot \zeta(strangers, d, (x, y), g) + \epsilon$$

GA-Ped: implementation

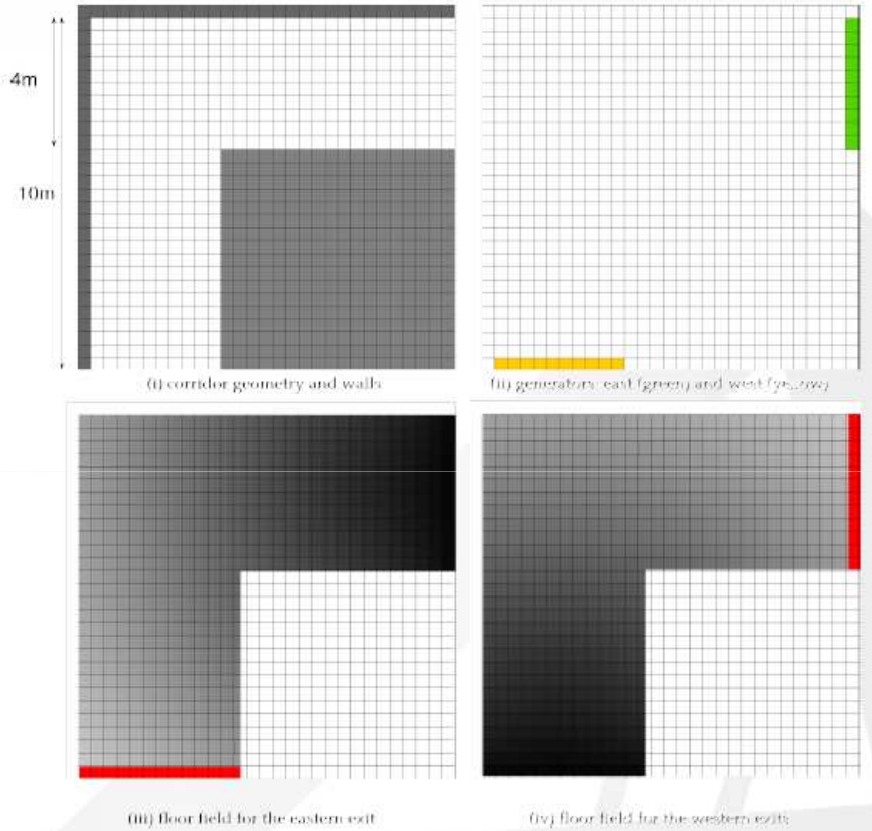
- Python 2.6;
- SQLite;
- multiprocessing module (built-in);
- PIL Python Imaging Library;

Simulation: scenario

Rectangular Corridor

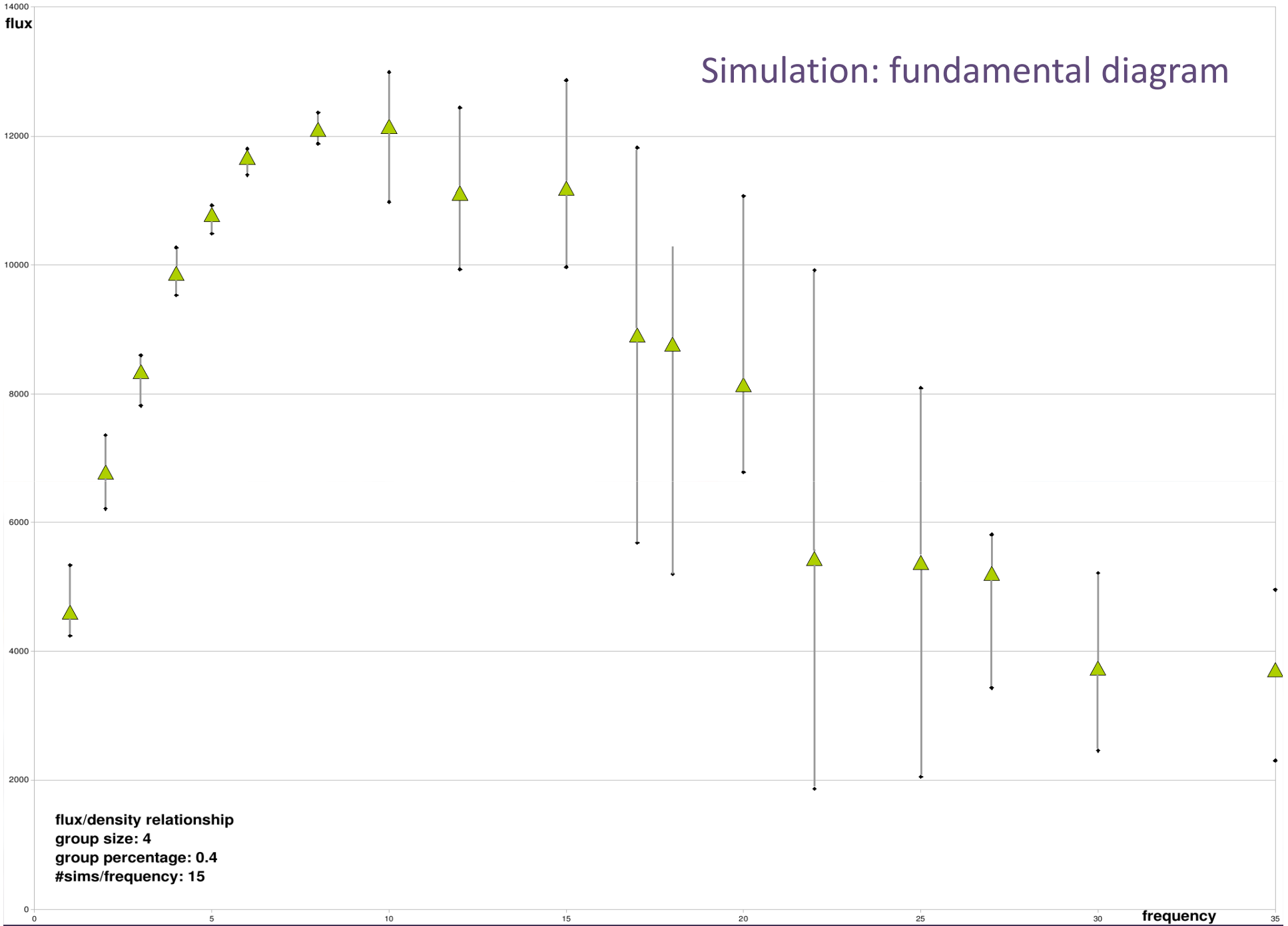


L-shaped corridor

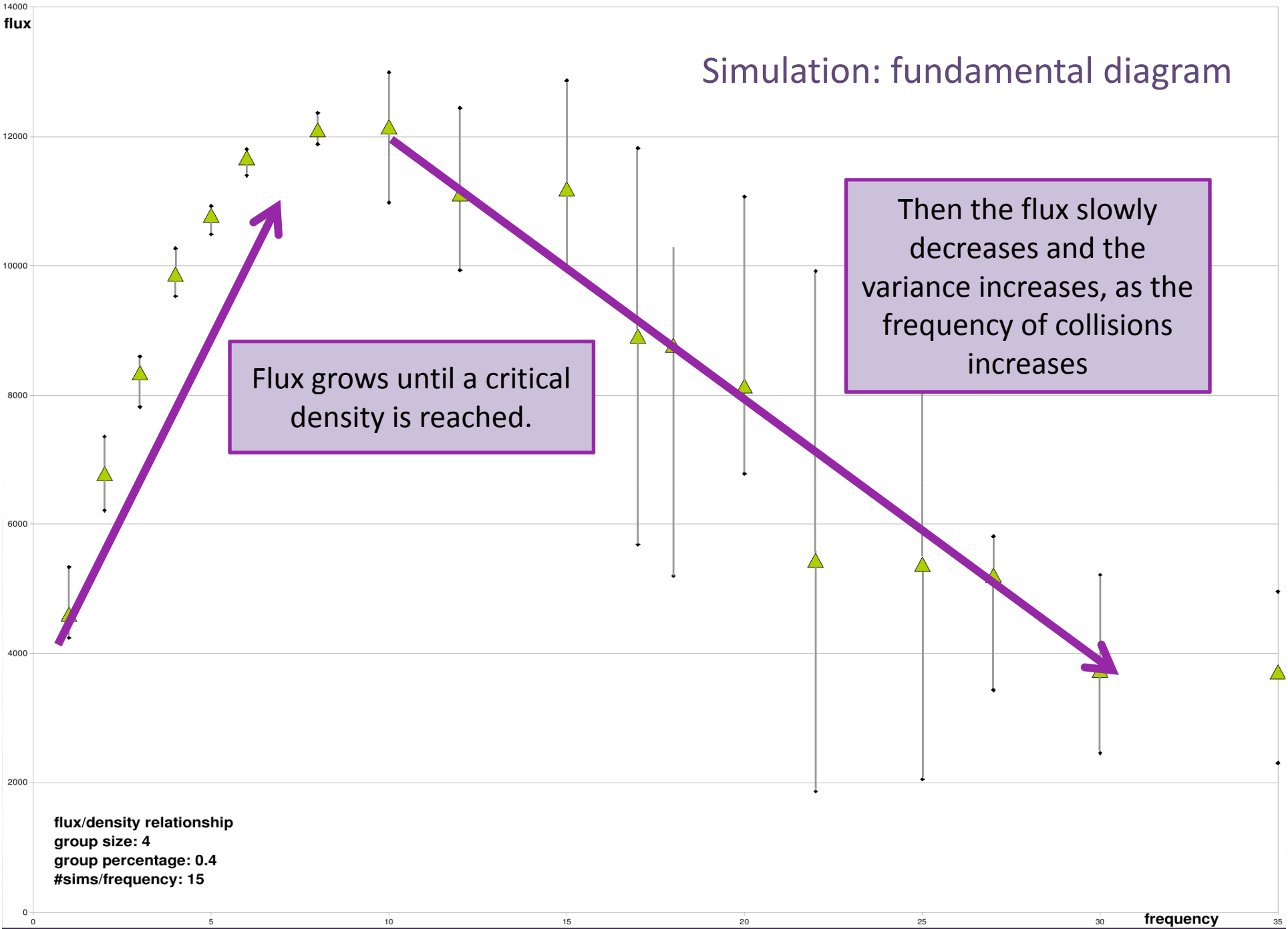


Why? We have data empirically collected on these two particular configurations

Simulation: fundamental diagram



Simulation: fundamental diagram



Other interesting results

- lane formation at high densities;
- group dispersion tends to grow with larger groups;
- group dispersion is higher in crowded environments;
- the higher is the number and the size of the groups into the environment, the less will be the total flow, due to the higher degree of friction between different groups;
- the presence of small groups (size 2) often improves the overall flow, because they limit turbolences and conflicts around then bend, allowing the formation of relatively stable lanes (L-curve scenario);

Crowd Crystals Model

Features of the Crowd Crystals Model:

- Agent-based approach;
- Explicit representation and modeling of groups (i.e. crystals);
- Derived from sociological theories and empirical studies;
- General and platform-independent model without an explicit description of space, time, perception functions;
- Formal description of the main elements of the system;
- Behavioral functions of pedestrians inside and outside groups;
- Analysis of internal states of agents;

Definition of the Main Elements (I)

- A crowd can be seen as a set of crystals, according to the theory of Elias Canetti;
- We define a crowd as a system:

$$S = \langle \mathrm{A}, G, R, O, C \rangle$$

  - *A*={a_1,…,a_n} is the population of agents;
  - G={G_1,…,G_n} is a finite set of groups;
  - R={r_1,…,r_l} is a finite set of static binary relationships defined on the system;
  - O={o_1,…,o_k} is a finite set of goals present in the system;
  - C={C_1,…,C_s} is a family of features defined on the system regarding the groups where each C_i is a set of possible values that the i^{th} feature can assume;

Definition of the Main Elements (II)

- Main aspects in group definition:
  - relationship among members;
  - shared goal;
- We define a crystal as:

$$G_i = \langle A_i, z_i, r_i, o_i \rangle$$

  - $A_i \subseteq A$ is a finite set of agents belonging to G_i;
  - $z_i \in C_1 x \ldots x C_s$ is a vector with the values of features related to G_i;
  - $r_i \in R$ is a static irreflexive, symmetric relationship among agents in G_i such that for all $a,b \in A$ with $a \neq b$ (a,b) is the transitive closure of r_i;
  - o_i is the goal associated to G_i;

Definition of the Main Elements (IIb)

- Considerations on the population of agents:

$$A_i \bigcap A_j = \varnothing \; \forall i,\; j = 1,\ldots,m \;\; \text{and} \; i \neq j$$

$$\mathrm{A} = \bigcup_{i=1}^{m} Ai$$

- Graph $GA_i=(A_i,E_i)$ where:
  - A_i is the set of agents belonging to $G_{i;}$
  - E_i is the set of edges given by the relationship $r_{i;}$
- GA_i is a non-oriented and connected graph;

Definition of the Main Elements (III)

- Definition of agents: every agent represents a pedestrian within a crowd;
- $L=\{L_1,\ldots L_q\}$ is a family of agent features where Li is a set of possible values that the i^{th} feature can assume;
- Every agent is defined as

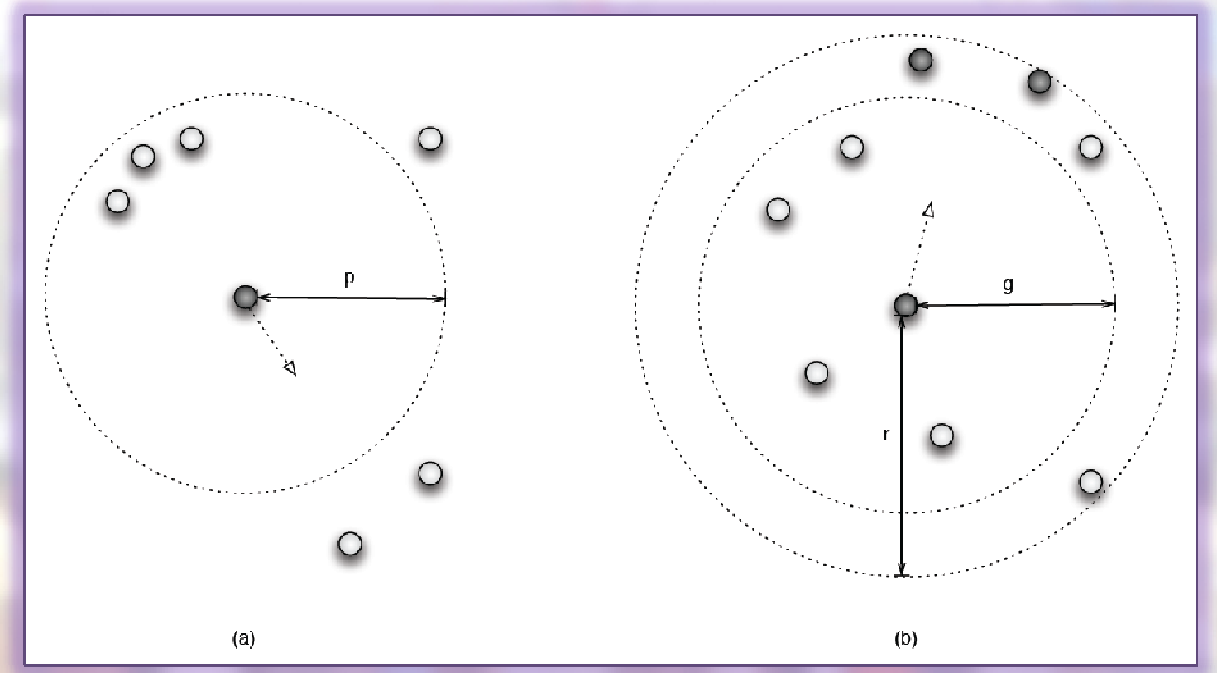
$$a = \langle \ w_a \rangle$$

where:

- $w_a \in L_1 x \ldots x L_q$ is a vector with the values of features related to agent a;

Behavioral Rules

- Two main rules:
  - To maintain a minimum distance from pedestrians belonging to the other groups;
  - To keep a maximum distance from other agents belonging to the same group;



Distance Function

- We define a pseudo-semi-metric:

$$p = \mathrm{A} \times \mathrm{A} \mapsto D$$

that is a function that measures distances between agents, such that, given two agents a, b ϵ *A* p(a,b)=p(b,a) and p(a,a)=0_D

- D is a domain of distances described as a totally ordered set with 0_D as minimal element;
- We can reduce the complexity of D and admit $D \subset \Re^+$

Safe Proxemic Rule

- Every agent a ϵ *A* belonging to a group G_i is characterized by a personal distance $d_a \epsilon D$:

$$da : \left(\prod C \right) \times \left(\prod L \right) \mapsto D$$

Features of group

Features of agent

- An agent a ϵ G_i is in a safe proxemic condition iff:

$$\neg \exists b \in A \setminus A_i : p(a,b) \leq d_a$$

Safe Group Rule

- Every group G_i is characterized by a private distance $\delta_{Gi} \in D$:

$$dg : \left(\prod C \right) \mapsto D$$

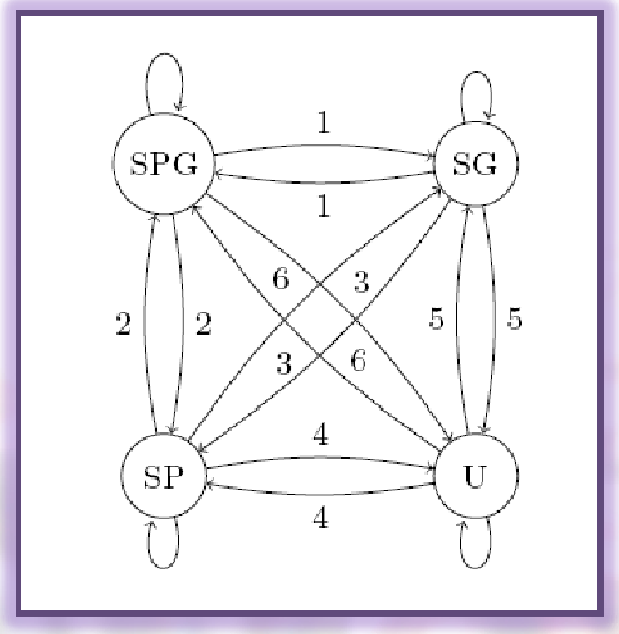
- We introduce a dynamic relationship **r** such that $\mathbf{r_t}$ is a dynamic irreflexive and simmetric relationship among agents in G_i at a particular time t:

$$\forall a, b \in G_i, (a,b) \in r_t \text{ iff } p(a,b) \leq \delta_{Gi}$$

- Considering the graph structure given by $\mathbf{r_t}$ we can define the safe group condition considering the whole history of the graph and the function:

$$\Gamma\left(\langle rj \mid j \leq t \rangle\right) \in \{0,1\}$$

Internal States of Agents

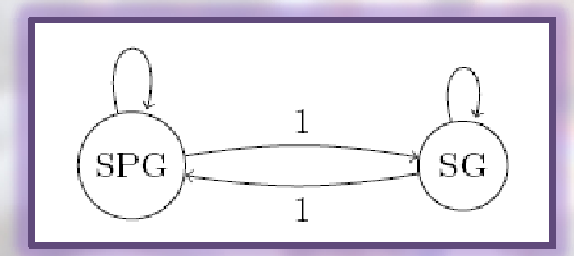


SPG= Safe Proxemic and Group state;

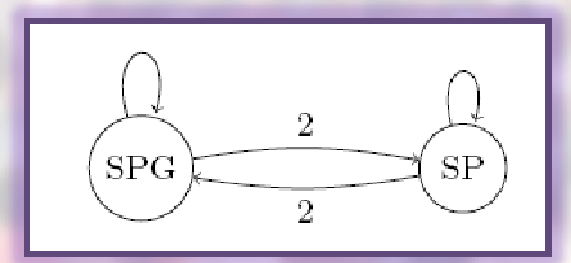
SP= Safe Proxemic state;

SG= Safe Group state;

U= Unsafe state



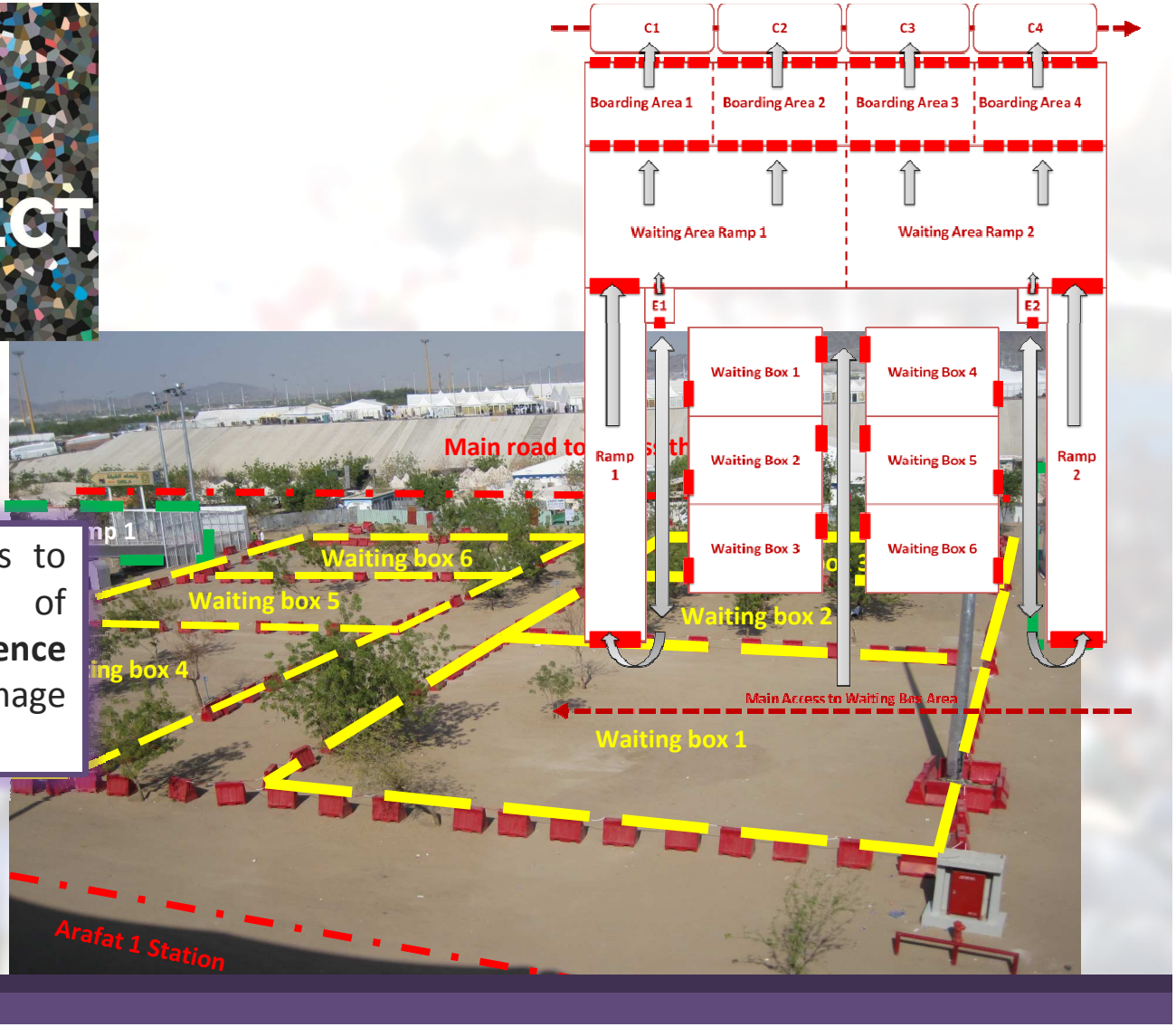
Every agent is a singleton



Only one group

Case of Study: CRYSTALS Project

The main focus of **CRYSTALS** is to investigate how the presence of **heterogeneous groups influence emergent dynamics** in Hajj (pilgrimage towards Makka).



Case of Study: CRYSTALS Project

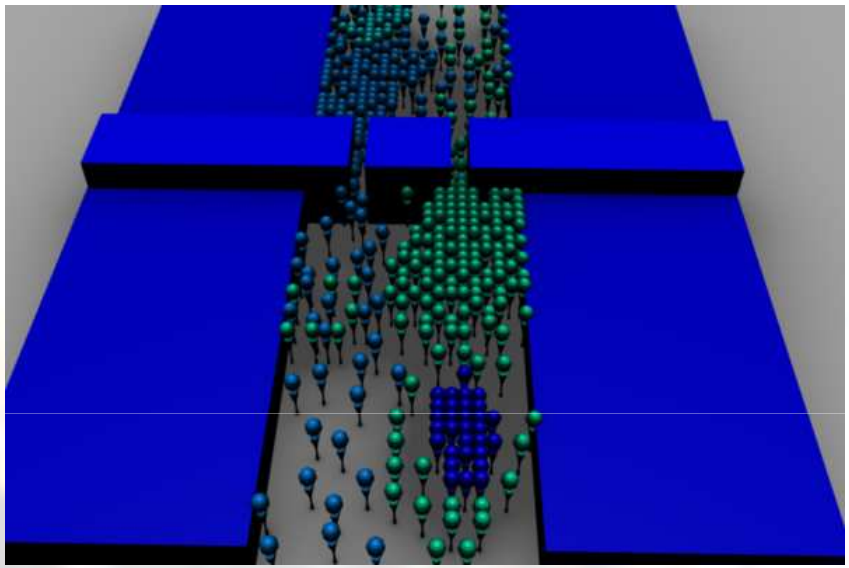
- Analysis on types of groups during Hajj:
  - Primary group;
  - Residential group;
  - Kinship group;
  - Functional group.

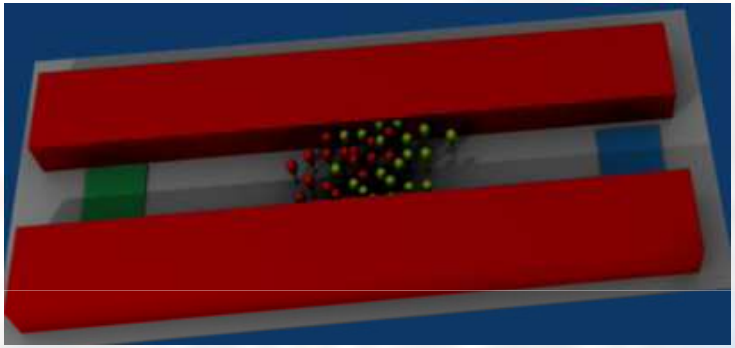
Modeling Groups in the Scenario of Arafat I Station

- The system can be defined as:
  - $A=\{a_1,\ldots,a_{52}\}$;
  - $G=\{G_1,\ldots,G_4\}$;
  - $R=\{p,k,r,f\}$;
  - $O=\{C\}$;
  - $C=\{\text{country, language, social rank}\}$.
- The four groups are defined as:
  - $G_1=<A_1,(\text{Saudi Arabia, Arabic, low}), k, C>$;
  - $G_2=<A_2,(\text{Saudi Arabia, Arabic, medium}), p, C>$;
  - $G_3=<A_3,(\text{Saudi Arabia, Arabic, medium}), p, C>$;
  - $G_4=<A_4,(\text{Saudi Arabia, Arabic, high}), p, C>$;

- Family of feature L={gender, age, marital status, impaired status}
  - a_i=<male, adult, married, not impaired>

MAKKSim: Dealing with Pedestrian Groups in MAS-based Crowd Simulation (DEMO SESSION)





- Tool based on Blender;
- Provides design tools for what-if scenarios;
- Generates effective 3D visualization of crowd dynamics;
- The platform includes some aspects of Crowd Crystals Model;
- The environment processing and the management of agents movement are based on GA-Ped Model.

Conclusion and Future developments

- What we got:
  - Original models to face the problem of representing pedestrian groups within a crowd;
  - A CA-based model tested on simple scenarios, gathering results that are in tune with the existing literature;
  - An agent-based abstract model to propose guidelines to include the concept of group in previous pedestrian dynamics model.
- Future directions:
  - A deeper analysis and extensions of the notion of group and the related dynamics;
  - Calibration and testing of MAKKSim and the alignment with the agent-based model.

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WOA 2011
Dodicesimo Workshop Nazionale "Dagli Oggetti agli Agenti“
5-6 Luglio 2011, Rende, Cosenza (Italy)

Thank you!

Lorenza Manenti

manenti@disco.unimib.it