2009 IEEE Toronto International Conference
Science and Technology for Humanity
TIC-STH 2009 - September 26-27, 2009 – Toronto, Canada

Alessandro Pluchino

Department of Physics and Astronomy – University of Catania (ITALY)

Multi Agent Simulation of Pedestrian Behavior in Closed Spatial Environments

Work performed in collaboration with:

Andrea Rapisarda,

Giuseppe Inturri,

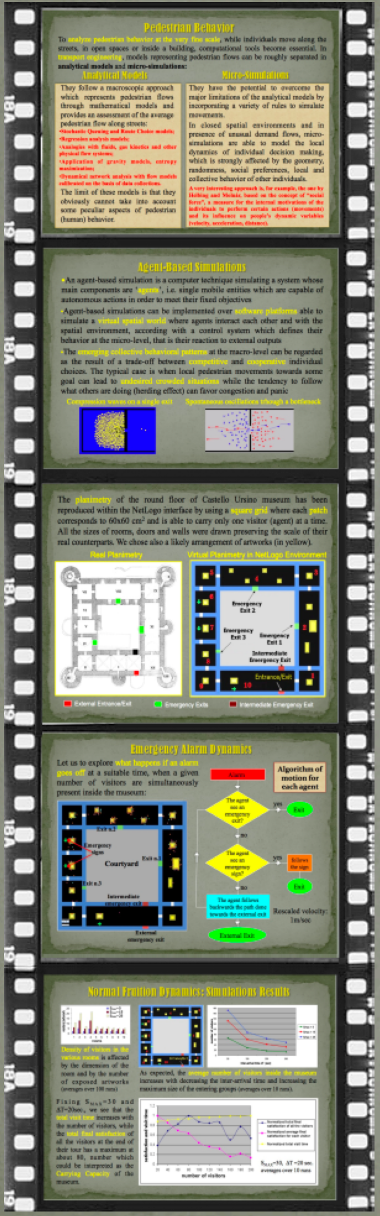
Cesare Garofalo, Salvo Tudisco,

Matteo Ignaccolo, Salvo Caprì

and Francesca Camillen

from University of Catania

Outline



Pedestrian Behavior

To analyze pedestrian behavior at the very fine scale, while individuals move along the streets, in open spaces or inside a building, computational tools become essential. In transport engineering, models representing pedestrian flows can be roughly separated in analytical models and micro-simulations:

Analytical Models

They follow a macroscopic approach which represents pedestrian flows through mathematical models and provides an assessment of the average pedestrian flow along streets:

- Stochastic Queuing and Route Choice models;
- Regression analysis models;
- Analogies with fluids, gas kinetics and other physical flow systems;
- Application of gravity models, entropy maximization;
- Dynamical network analysis with flow models calibrated on the basis of data collections.

The limit of these models is that they obviously cannot take into account some peculiar aspects of pedestrian (human) behavior.

Micro-Simulations

They have the potential to overcome the major limitations of the analytical models by incorporating a variety of rules to simulate movements.

In closed spatial environments and in presence of unusual demand flows, micro-simulations are able to model the local dynamics of individual decision making, which is strongly affected by the geometry, randomness, social preferences, local and collective behavior of other individuals.

A very interesting approach is, for example, the one by Helbing and Molnár, based on the concept of "social force", a measure for the internal motivations of the individuals to perform certain actions (movements) and its influence on people's dynamic variables (velocity, acceleration, distance).

Agent-Based Simulations

- An agent-based simulation is a computer technique simulating a system whose main components are 'agents', i.e. single mobile entities which are capable of autonomous actions in order to meet their fixed objectives
- Agent-based simulations can be implemented over software platforms able to simulate a virtual spatial world where agents interact each other and with the spatial environment, according with a control system which defines their behavior at the micro-level, that is their reaction to external outputs
- The emerging collective behavioral patterns at the macro-level can be regarded as the result of a trade-off between competitive and cooperative individual choices. The typical case is when local pedestrian movements towards some goal can lead to undesired crowded situations while the tendency to follow what others are doing (herding effect) can favor congestion and panic

Compression waves on a single exit

Spontaneous oscillations through a bottleneck

The planimetry of the round floor of Castello Ursino museum has been reproduced within the NetLogo interface by using a square grid where each patch corresponds to 60x60 cm^2 and is able to carry only one visitor (agent) at a time. All the sizes of rooms, doors and walls were drawn preserving the scale of their real counterparts. We chose also a likely arrangement of artworks (in yellow).

Real Planimetry

Virtual Planimetry in NetLogo Environment

🟥 External Entrance/Exit 🟩 Emergency Exits 🟥 Intermediate Emergency Exit

Emergency Alarm Dynamics

Let us to explore what happens if an alarm goes off at a suitable time, when a given number of visitors are simultaneously present inside the museum:

Algorithm of motion for each agent

Rescaled velocity: 1m/sec

Normal Fruition Dynamics: Simulations Results

Density of visitors in the various rooms is affected by the dimension of the room and by the number of exposed artworks (averages over 100 runs)

As expected, the average number of visitors inside the museum increases with decreasing the inter-arrival time and increasing the maximum size of the entering groups (averages over 10 runs).

Fixing $S_{MAX}=30$ and $\Delta T=20$sec., we see that the total visit time increases with the number of visitors, while the total final satisfaction of all the visitors at the end of their tour has a maximum at about 80, number which could be interpreted as the Carrying Capacity of the museum.

$S_{MAX}=30$, $\Delta T=20$ sec. averages over 10 runs

Simulating Pedestrian Behavior:
Analytical Models versus Micro-Simulations

Agent-Based Model Approach:
Emerging Crowd Behavior in Closed Spatial Environments

Case Study: Agent-Based model of a Museum on the NetLogo Software Platform

Study of Normal Fruition dynamics and of Emergency Alarm dynamics

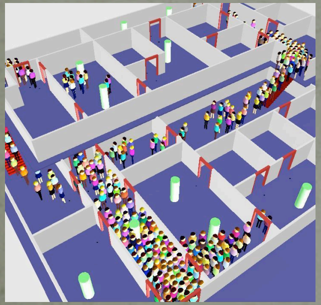
Simulation Results and Conclusions

Pedestrian Behavior

- It is important to study pedestrian behavior for several reasons: walking, the most sustainable form of transport, involves 75% of all trips under a kilometer, transport interchange facilities, commercial centers, public spaces

- However today there is still a disproportionate investment on research into motorized travel and we are not able to easily answer questions on how many people will use a new pedestrian facility or how will improvements to non-motorized travel conditions affect motor vehicle use

- Also Urban Planning, Crime Prevention, Emergency, Disaster Planning and Epidemiology are fields which need improved methods for modeling pedestrian movements



- Concepts such as crowding, personal space, territoriality, sensory overload, collision avoidance, navigation and orientation, environmental perception, evaluation and decision making, are all important ingredients which have to be taken into account when modeling pedestrian behavior

Papadimitriou E., Yannis G., Golias J., A critical assessment of pedestrian behaviour models, Transportation Research Part F 12 (2009) 242–255.

Pedestrian Behavior

To analyze pedestrian behavior at the very fine scale, while individuals move along the streets, in open spaces or inside a building, computational tools become essential. In transport engineering, models representing pedestrian flows can be roughly separated in **analytical models** and **micro-simulations:**

Analytical Models

They follow a ***macroscopic approach*** which represents pedestrian flows through ***mathematical models*** and provides an assessment of the average pedestrian flow along streets:

- **Stochastic Queuing and Route Choice models;**
- **Regression analysis models;**
- **Analogies with fluids, gas kinetics and other physical flow systems;**
- **Application of gravity models, entropy maximization;**
- **Dynamical network analysis with flow models calibrated on the basis of data collections.**

The limit of these models is that they obviously ***cannot*** take into account some peculiar ***microscopic aspects*** of pedestrian (human) behavior.

Micro-Simulations

They have the potential to overcome the major limitations of the analytical models by incorporating a variety of rules to simulate ***individual features*** at a microscopic scale.

In closed spatial environments and in presence of unusual demand flows, micro-simulations are able to ***model the local dynamics of individual decision making***, which is strongly affected by the geometry, randomness, social preferences, local and collective behavior of other individuals.

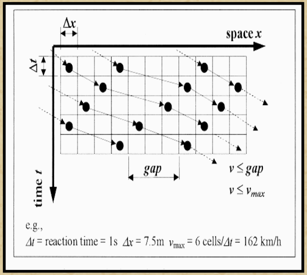
A very interesting approach is, for example, the one by Helbing and Molnár, based on the concept of "*social force*", a measure for the internal motivations of the individuals to perform certain actions (movements) and its influence on people's dynamic variables (velocity, acceleration, distance).

Micro-Simulations approach to Pedestrian Behavior

Due to the rapid increase in computational speed and to the availability of rich data sets, micro-simulations approaches have had a huge development in recent years:

Cellular Automata approach

Tries to model the behavior of pedestrians by means of a ***limited set of rules*** describing their individual features.

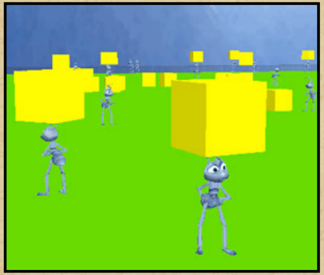


V. J. Blue, J. L. Adler (2001) "Cellular automata micro-simulation for modeling bi-directional pedestrian walkways", Transportation Research Part B 35, pp. 293–312;

S. Sarmady, F. Haron, A. Z. Hj. Talib, "Multi-Agent Simulation of Circular Pedestrian Movements Using Cellular Automata", Second Asia Intern. Conf. on Modelling & Simulation, pp. 654-659, IEEE 2008 .

Agent-Based models approach

Allows to treat pedestrians as ***fully autonomous entities (agents)*** with cognitive and sometimes also learning capabilities.



D. Helbing, P. Molnár (1995) "Social force model for pedestrian dynamics", Physical Review E, Volume 51, Number 5.

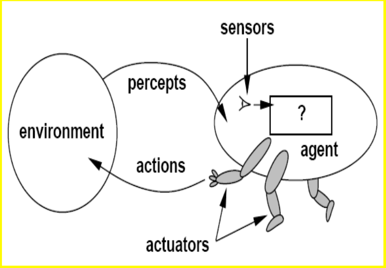
W. L. Koh, L. Lin, S. Zhou, "Modelling and simulation of pedestrian behavior", Proc. of the 22nd Workshop on Prin.of Adv. and Distr.Simulation, IEEE 2008;

M. Batty (2003) "Agent-Based Pedestrian Modelling", P. A. Longley and M. Batty (Eds.), Advanced Spatial Analysis, ESRI Press, Redlands, CA.

Gwynne et al., Building and Environment 34 (1999) for a good review of these methodologies

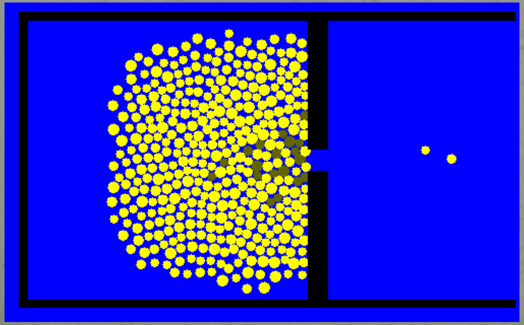
Agent-Based Simulations

- An agent-based simulation is a computer technique for simulating a system whose main components are 'agents', i.e. "*single mobile entities which are capable of autonomous actions in order to meet their fixed objectives*" (Woolridge, 2002)



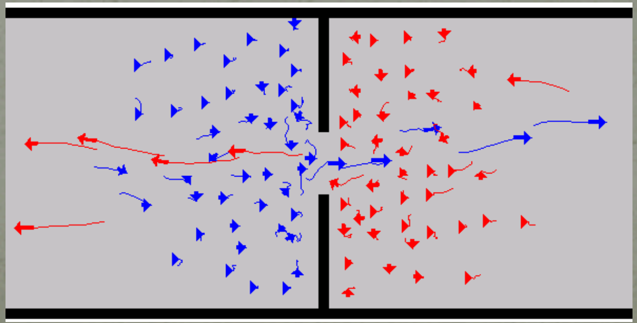
- Agent-based simulations can be implemented over software platforms able to simulate a virtual spatial world where agents interact each other and with the spatial environment, according with a control system which defines their behavior at the micro-level (*bottom-up approach*), that is their reactions to external outputs
- The emerging collective behavioral patterns at the macro-level can be regarded as the result of a *trade-off* between competitive and cooperative individual choices at the micro-level. The typical case is when local pedestrian movements towards some goal can lead to undesired crowded situations while the tendency to follow what others are doing (herding effect) can favor congestion and panic

Compression waves on a single exit



http://www.panics.org/

Spontaneous oscillations through a bottleneck



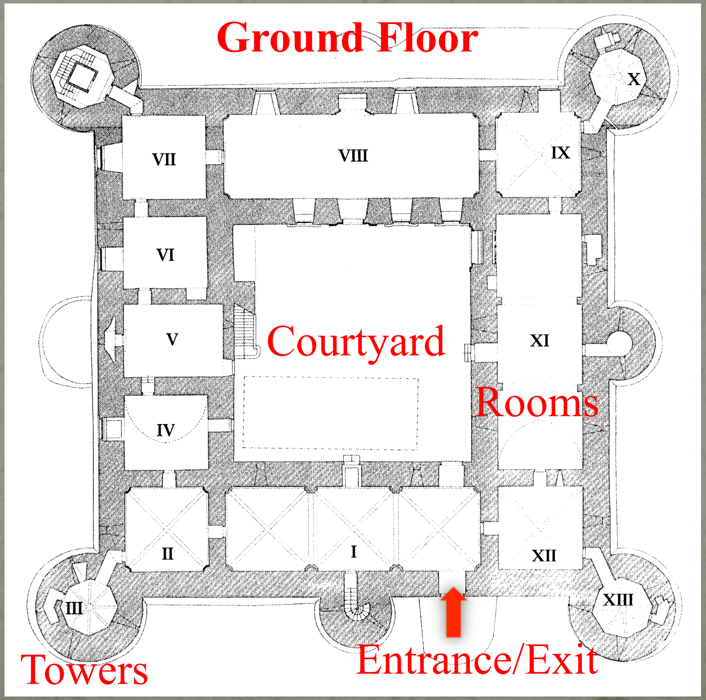
http://www.trafficforum.org/somsstuff/pedapplets/Corridor.html

Case Study

Agent-Based Model of Castello Ursino (Catania, Italy)

We realized an agent-based simulation of people visiting and evacuating a museum, located inside the Castello Ursino in Catania (Italy), which offers an excellent test environment for showing the potentiality of this technique.

Castello Ursino was built by order of Federico II between 1239 and 1250, as part of a much larger scheme of fortresses spread out over the Sicilian territory from Enna to Messina, right up to Siracusa.



The **planimetry** is square, with four towers placed around a central courtyard. It has **only one entrance** but many rooms and corridors containing paintings, sculptures and other works of art (more than 8000 pieces).

Pedestrian Dynamics inside Castello Ursino Museum

The general aim of our work is to show how an agent-based simulation of pedestrian walking dynamics in a given bounded environment, in this case the Castello Ursino museum, can be important in exploring rising crowd behavior which can affect, in turn, the level of service and the safety of a building.

In order to do this we will concentrate on two main dynamical regimes:

Normal Fruition Dynamics

In the first part of the simulation, visitors start their tour and visit each room in a fixed sequence, enjoying as many artwork is possible.

We are interested in evaluating the so called "Carrying Capacity" of the museum, that is the total number of visitors the building can tolerate keeping maximum the global level of satisfaction.

Emergency Alarm Dynamics

In the second part of the simulation an emergency alarm randomly goes off at a given time.

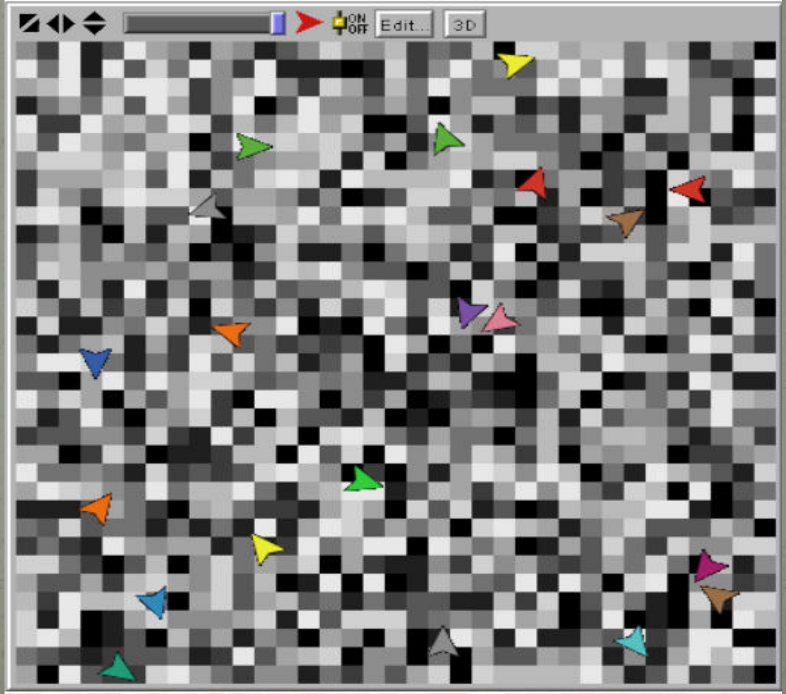
We are now interested in observing the visitors' reaction to the alarm and in calculating their evacuation time in correspondence of different arrangements of the emergency exits and different evacuation strategies.

NetLogo

For our simulations of Castello Ursino museum we chose NetLogo platform, which is a simple but powerful multi-agent simulation environment written in Java and fully programmable in an owner intuitive meta-language of higher level. NetLogo is freeware, direct and friendly, and allows the designer to focus directly on the agents' properties rather than to be drowned in complex code.

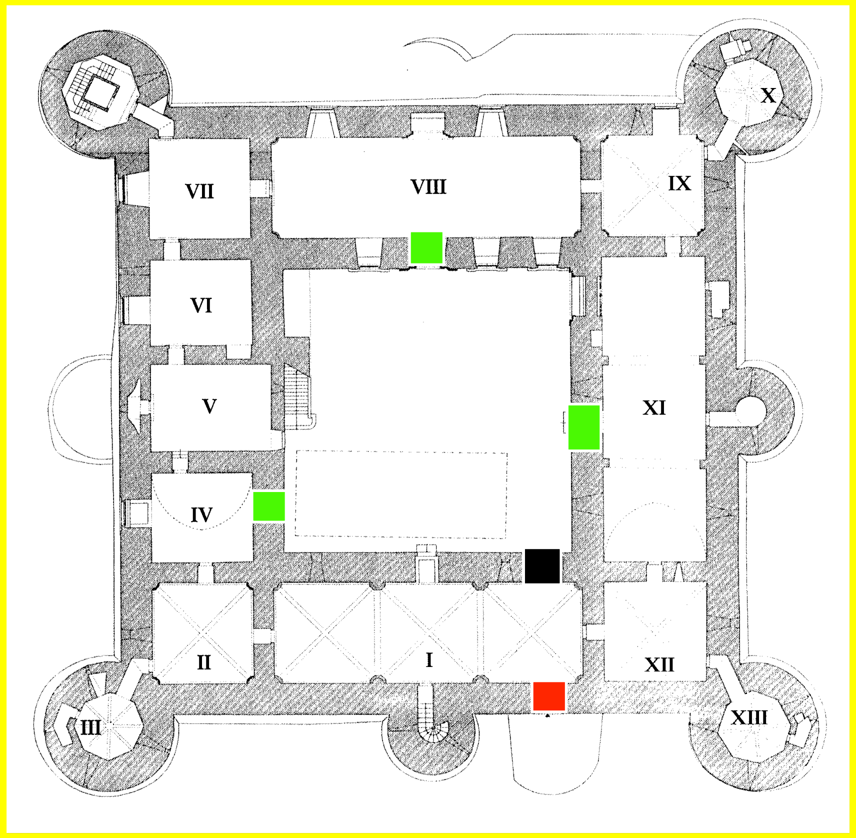
U. Wilensky (1999) – NetLogo – http://ccl.northwestern.edu/netlogo. Center for Connected Learning and Computer-Based Modeling. Northwestern University, Evanston, IL

The spatial environment in NetLogo is represented by a two dimensional grid of discrete cells, called '**patches**' (gray scale squares). Over the grid hundreds or thousands of **agents** (colored arrows) can move, all operating independently and programmed in terms of how they interact with each other and with the environment.

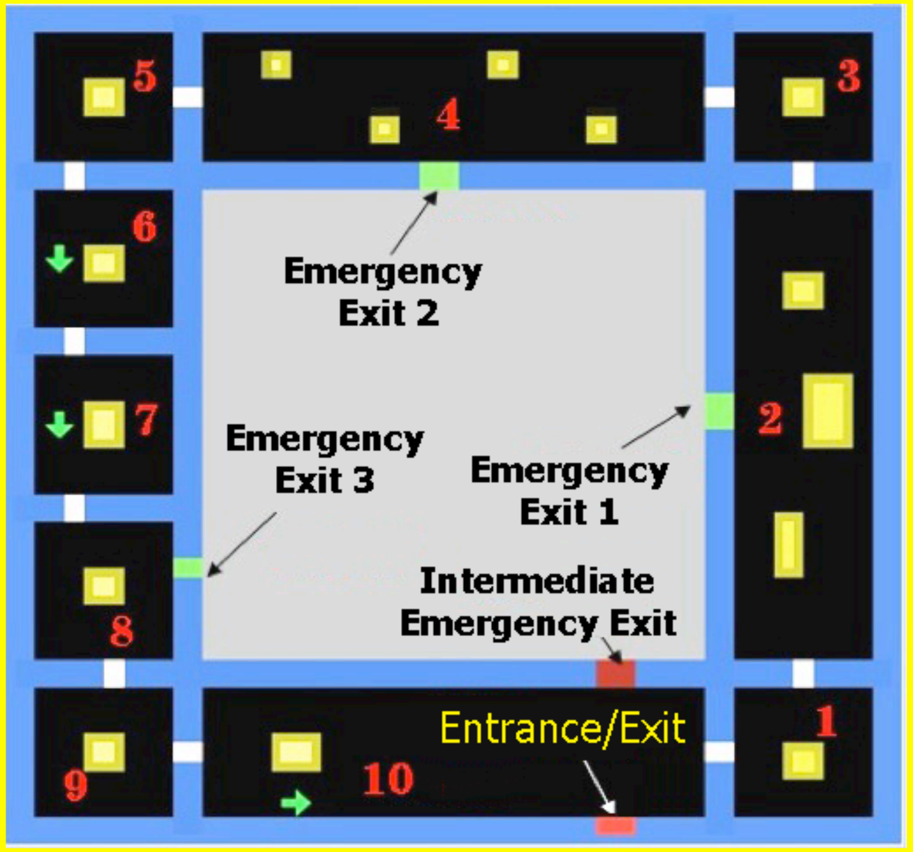


The planimetry of the ground floor of Castello Ursino museum has been reproduced within the NetLogo interface by using a square grid where each patch corresponds to 60x60 cm^2 and is able to carry only one visitor (agent) at a time. All the sizes of rooms, doors and walls were drawn preserving the scale of their real counterparts. We chose also a likely arrangement of artworks (in yellow).

Real Planimetry



Virtual Planimetry in NetLogo Environment



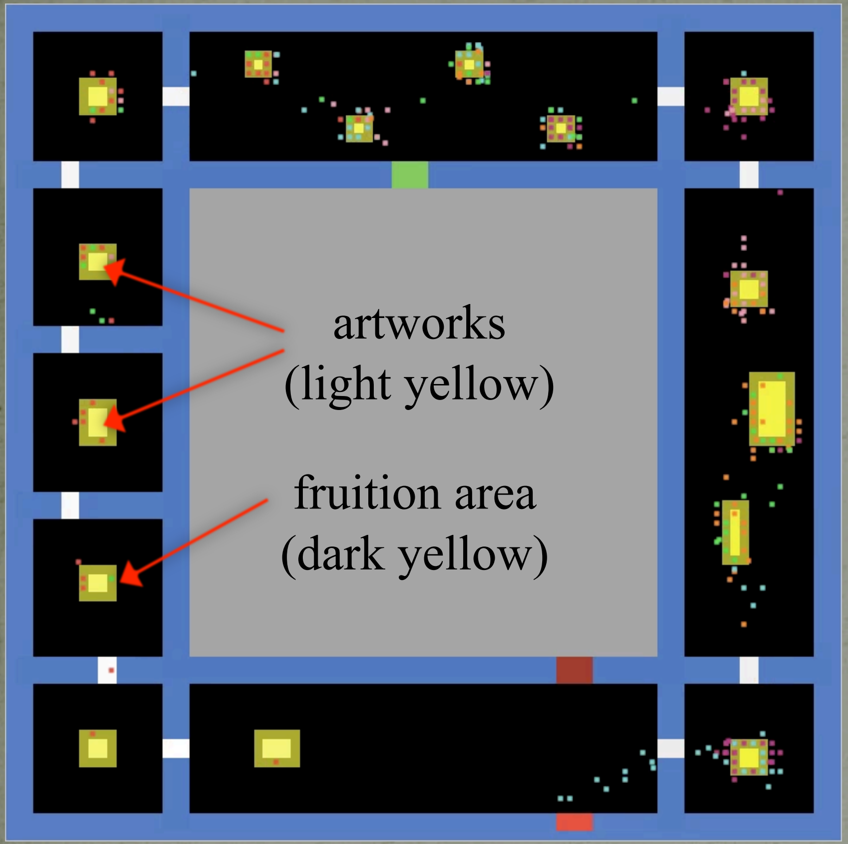
🟥 External Entrance/Exit

🟩 Emergency Exits

🟫 Intermediate Emergency Exit

Normal Fruition Dynamics

Normal Fruition Dynamics



- In the normal fruition dynamics, visitors access the museum in groups of randomly selected sizes S (between 1 and S_{MAX}) separated by random intervals of time uniformly distributed around the quantity ΔT (inter-arrival time);

- Visitors move counterclockwise along one patch in one time-step (=1sec), so they have an average velocity of 0.6 m/sec, which well approximates the normal pace (0.75 m/sec);

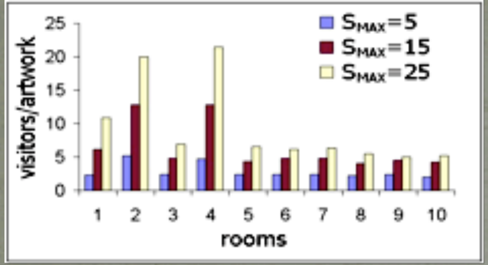
- Each agent possesses a radius of vision and is attracted by doors or artworks around him;

- In absence of obstacles, each agent moves towards his target, doors or artworks, which are dynamically stored in an individual memory; in presence of obstacles, walls or other people, agents try to avoid them going around;

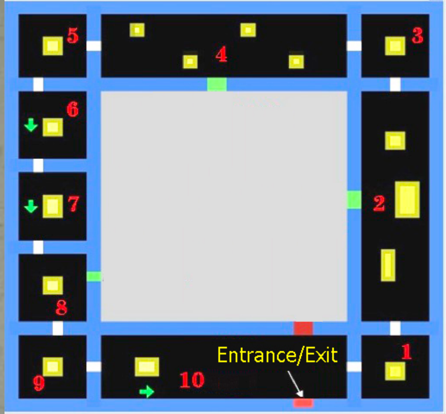
- For each artwork, each agent has a different random interest, i.e. the time he is willing to spend enjoying that artwork, and a different random patience, i.e. the time he is willing to spend waiting for a place in the fruition area around that artwork (dark yellow patches);

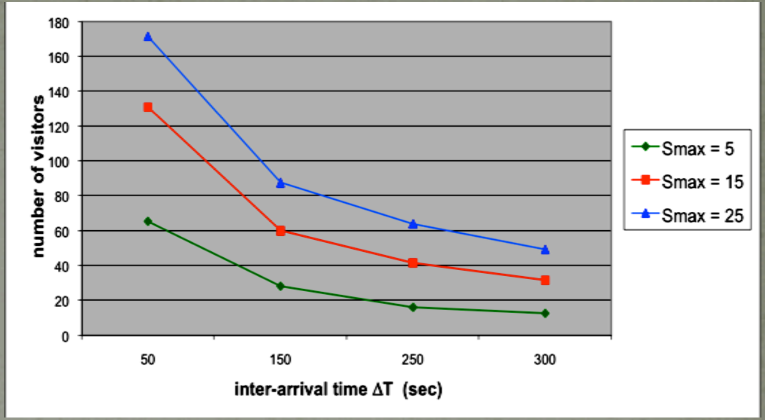
- As a function of the patience, the interest and the time really spent for every artwork, it is possible to calculate the level of satisfaction of each visitor at the end of his tour.

Normal Fruition Dynamics: Simulations Results



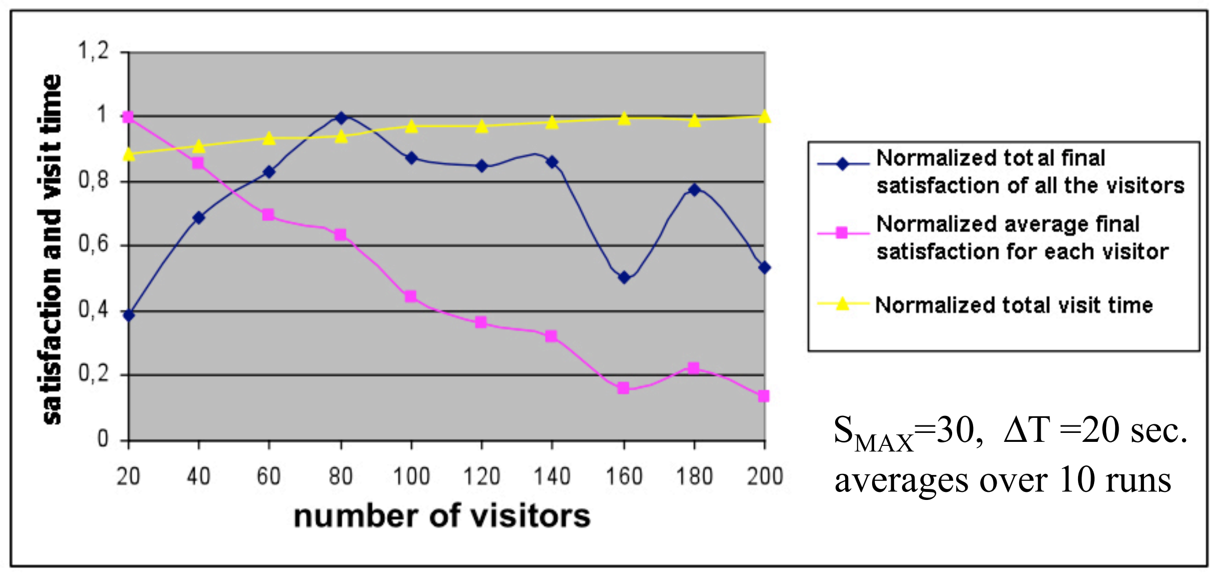
Density of visitors in the various rooms is affected by S_{max}, by the dimension of the room and by the number of artworks (sim.averages over 100 runs)





As expected, the average number of visitors inside the museum increases with decreasing the inter-arrival time and increasing the maximum size of the entering groups (averages over 10 runs).

Fixing $S_{MAX}=30$ and $\Delta T=20$sec., we see that the total visit time increases with the number of visitors, while the total final satisfaction of all the visitors at the end of their tour has a maximum at about 80, number which could be interpreted as the Carrying Capacity of the museum.

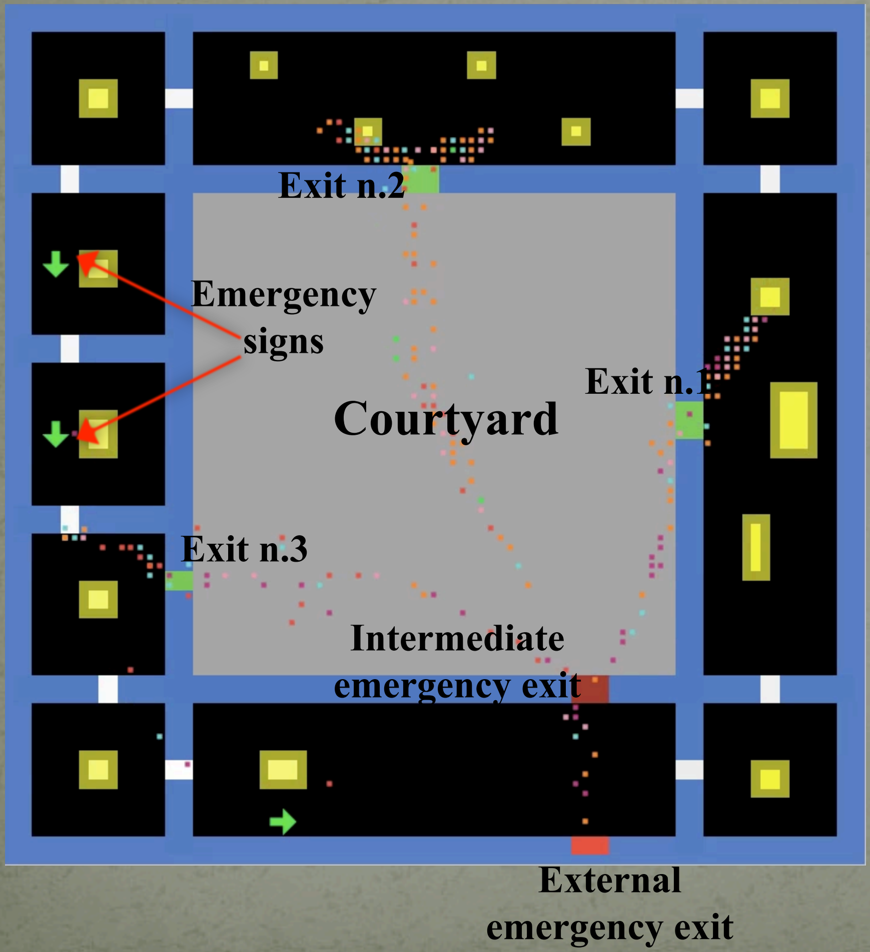


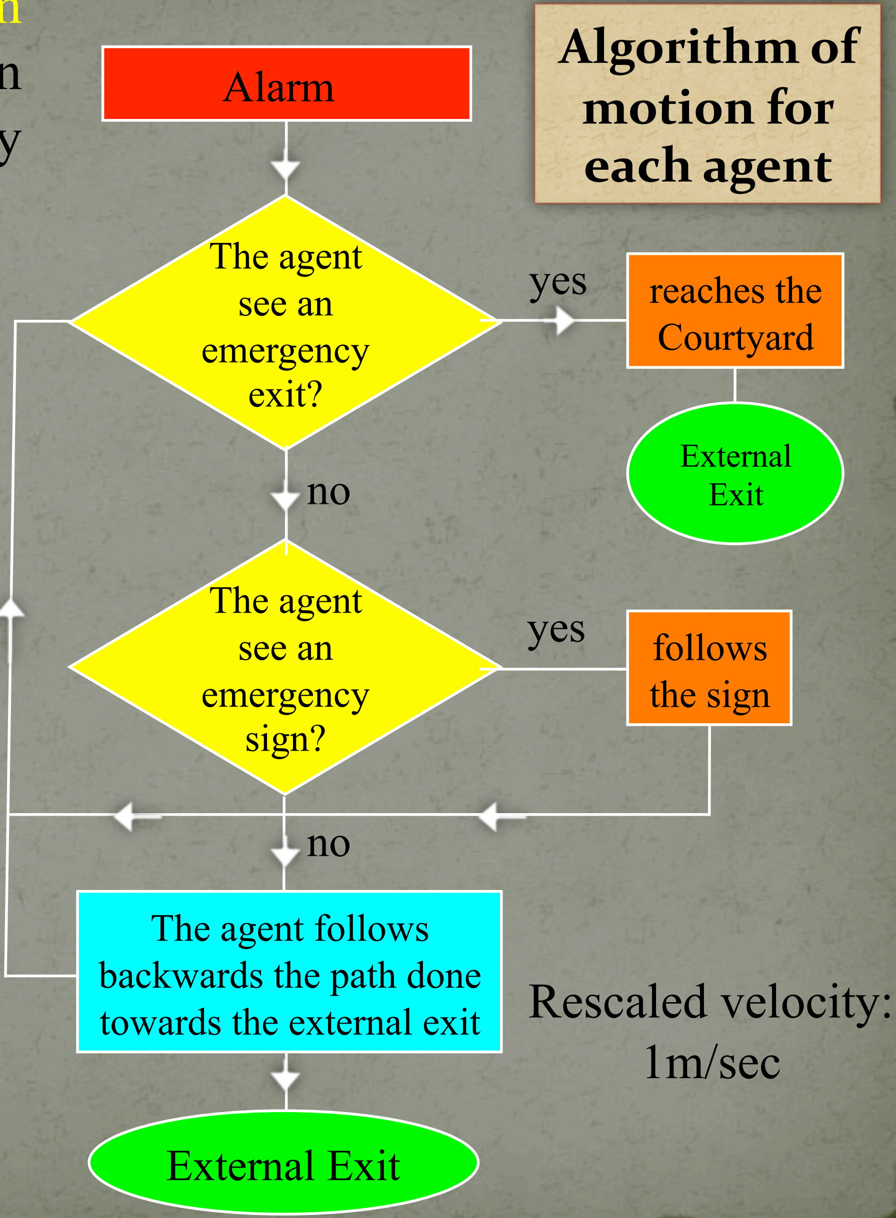
$S_{MAX}=30$, $\Delta T=20$ sec.
averages over 10 runs

Emergency Alarm Dynamics

Emergency Alarm Dynamics

Let us to explore what happens if an alarm goes off at a suitable time, when a given number of visitors are simultaneously present inside the museum:





Algorithm of motion for each agent

Alarm

The agent see an emergency exit?

yes → reaches the Courtyard → External Exit

no ↓

The agent see an emergency sign?

yes → follows the sign

no ↓

The agent follows backwards the path done towards the external exit

External Exit

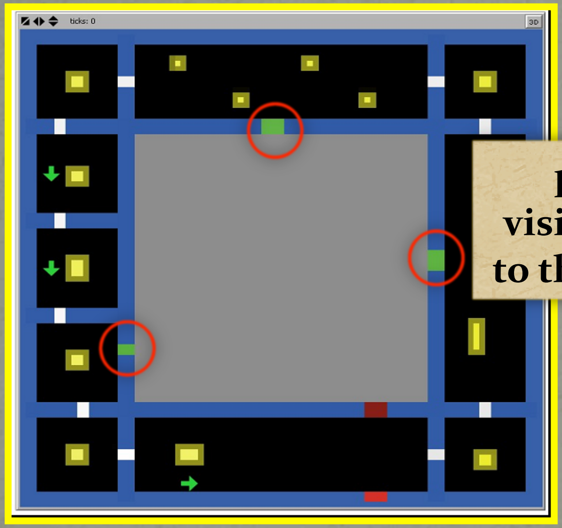
Rescaled velocity: 1m/sec

Emergency Alarm Dynamics in the Existing Configuration

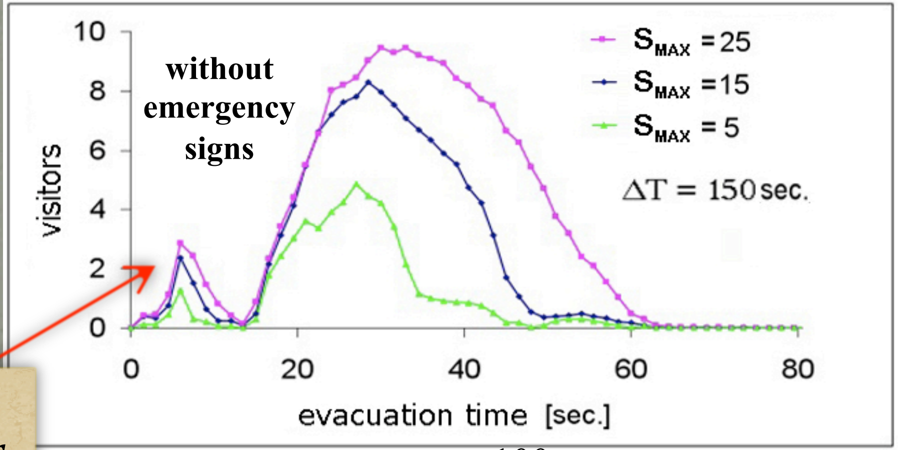
First of all, let us study the distribution of the evacuation time (i.e. the time each visitor takes to reach the last external exit door from the moment when the alarm starts) as function of the group size fixing the inter-arrival time to ΔT=150 sec., in the existing configuration of three internal emergency exits, with and without emergency signs:

Existing Configuration:

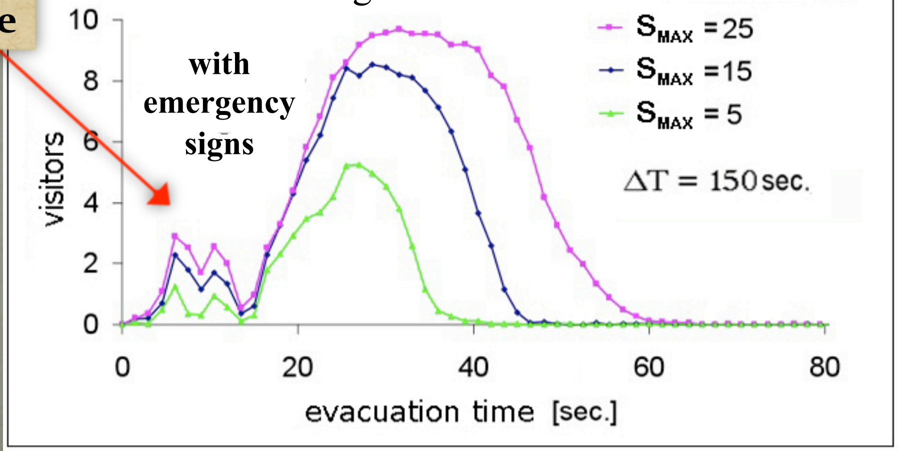
3 Emergency Exits: n.1, n.2 and n.3



peaks of visitors closer to the entrance



averages over 100 runs

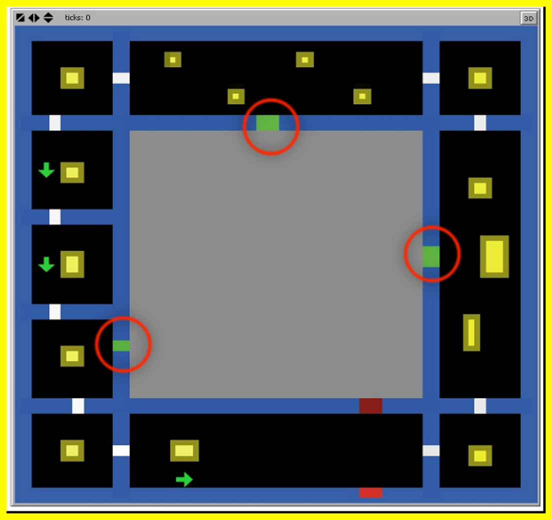


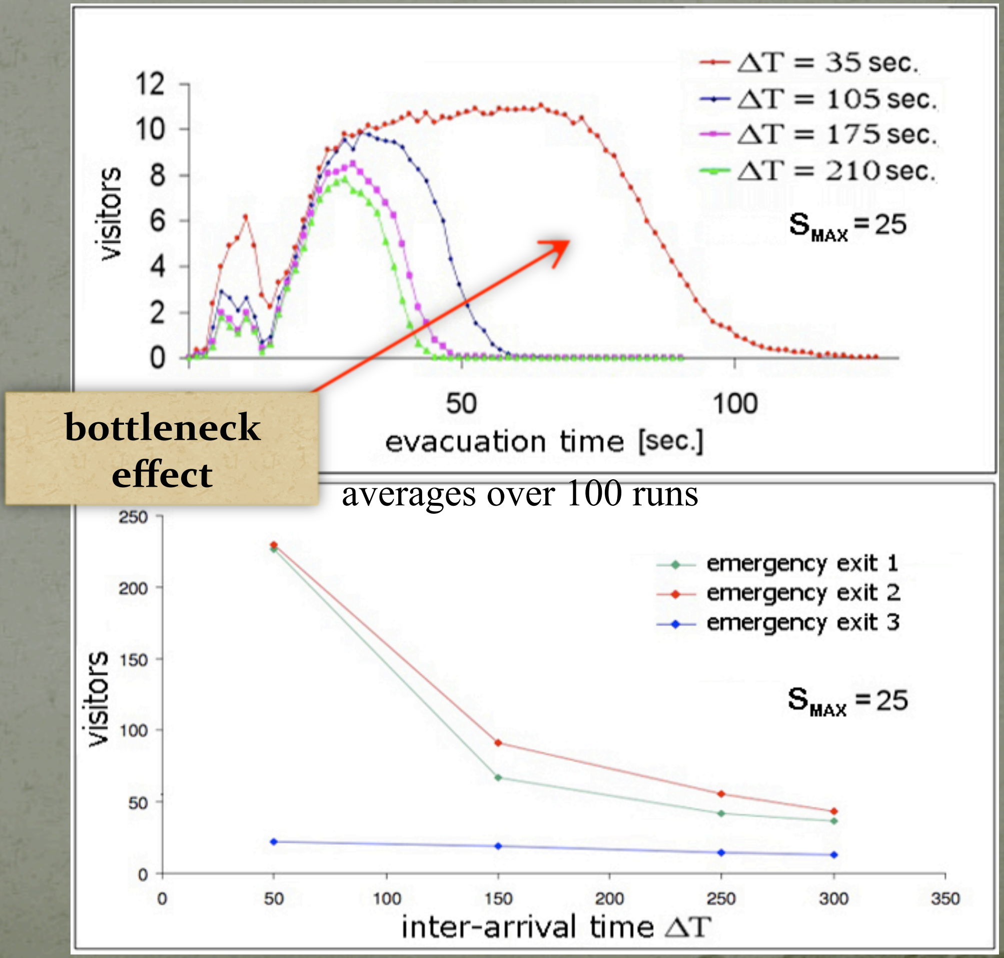
Emergency Alarm Dynamics in the Existing Configuration

We see now how the evacuation time distribution is affected by the inter-arrival time, fixing the group size S_{MAX}=25 and in presence of emergency signs. Again, the centroid visibly shifts towards an higher evacuation time when the inter-arrival time decreases. In particular, for ΔT=35 sec, the distribution becomes broader and broader due to a bottleneck effect in the more crowded rooms, usually rooms 2 and 4:

Existing Configuration:

3 Emergency Exits: n.1, n.2 and n.3





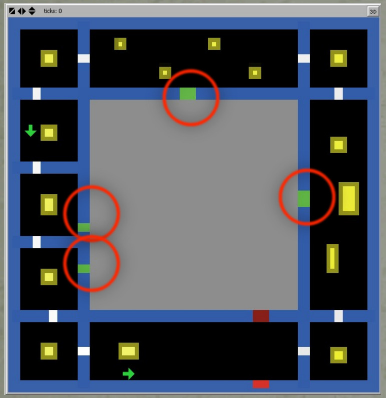
bottleneck effect

averages over 100 runs

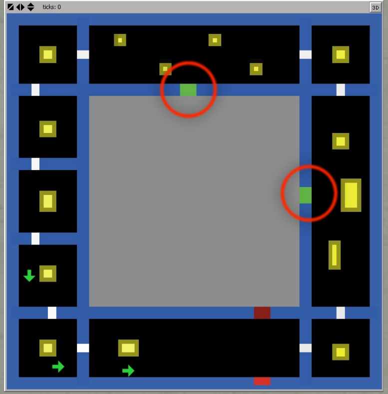
Emergency Alarm Dynamics in Alternative Configurations

Let us to explore now what happens if we take into account emergency configurations alternative to the existing one, being the opportunity to compare to each other different possible evacuation plans one of the most useful application of the agent-based simulations:

4 Exits



2 Exits: n.1 and n.2



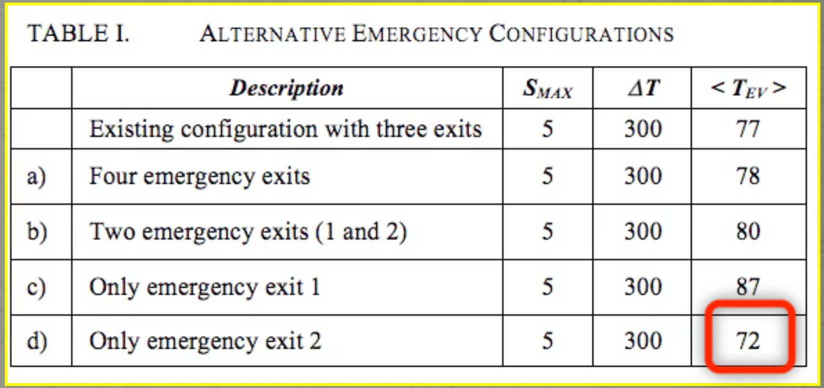
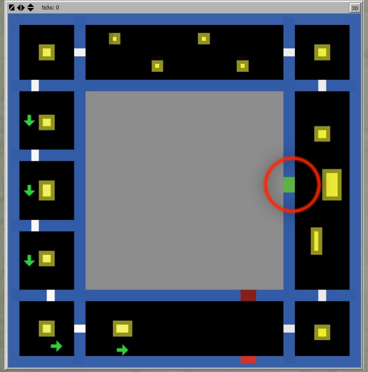


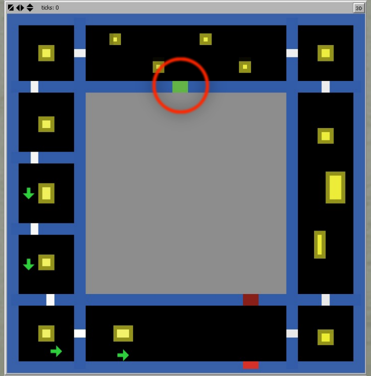
TABLE I. ALTERNATIVE EMERGENCY CONFIGURATIONS

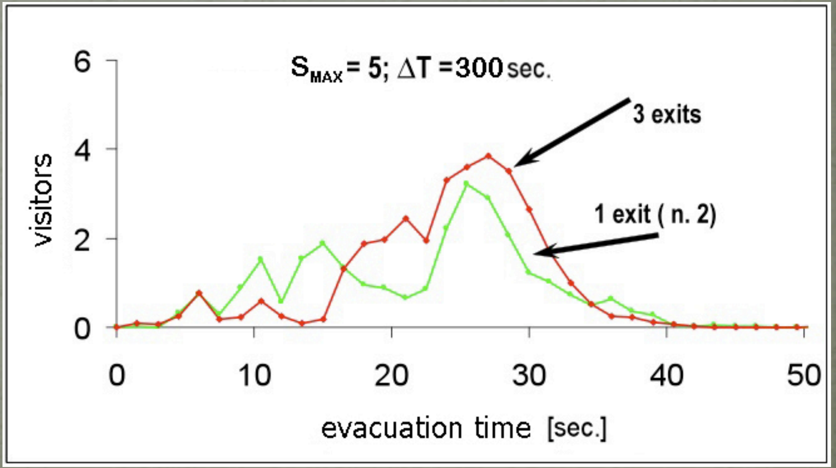
	Description	S_{MAX}	ΔT	$< T_{EV} >$
	Existing configuration with three exits	5	300	77
a)	Four emergency exits	5	300	78
b)	Two emergency exits (1 and 2)	5	300	80
c)	Only emergency exit 1	5	300	87
d)	Only emergency exit 2	5	300	72

Only 1 exit: n.1



Only 1 exit: n.2

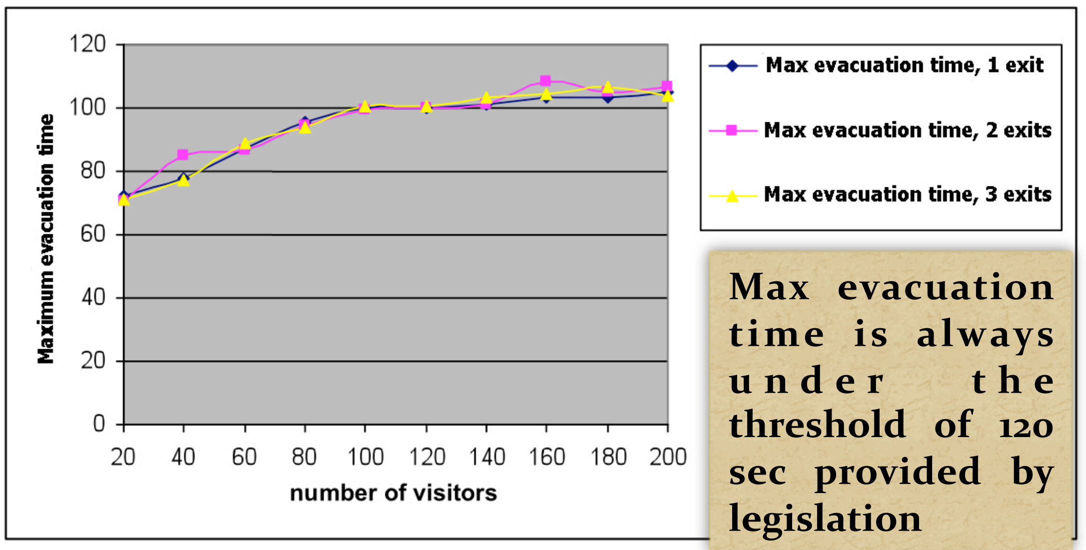




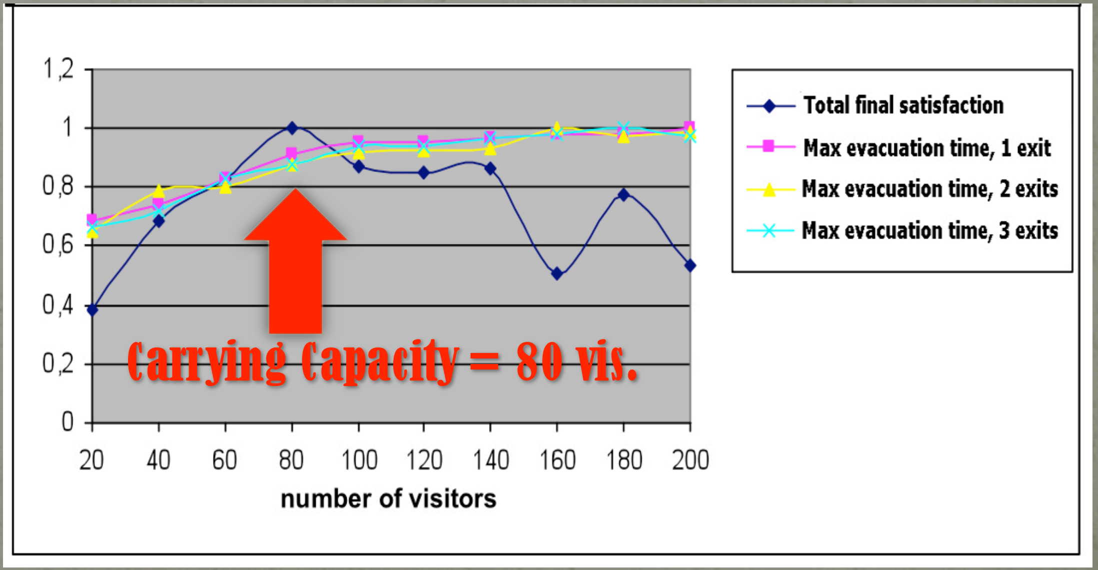
Carrying Capacity and Safety Conditions

Finally, let we look to the behavior of the maximum evacuation time, i.e. to the total time needed for all the visitors leaving the museum, as function of the total number of visitors.

Rescaling times to their maximum value and comparing with the satisfaction curve found in the fruition regime, we see that the global maximum in the satisfaction (carrying capacity) is compatible with a good level of safety, i.e. with a reasonable evacuation time, for all the configuration adopted.



Max evacuation time is always under the threshold of 120 sec provided by legislation



Carrying Capacity = 80 vis.

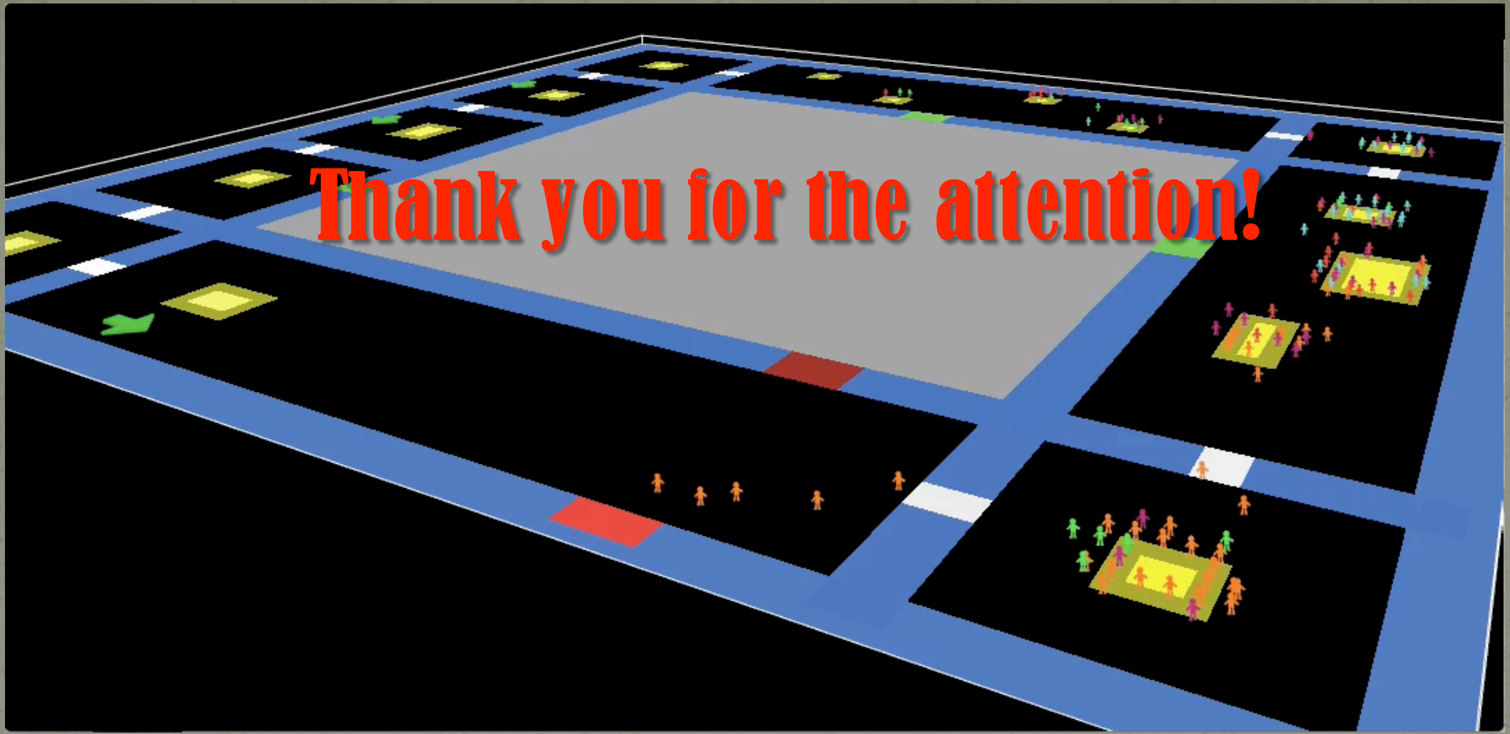
Summary and Conclusions

•Agent-based simulations show their potential in many context of transport management in presence of unusual demand.

•We illustrated these ideas with an example based on the simulation of people visiting and evacuating a museum, which offers an excellent test environment for simulating a collective behavior emerging from local movements in a closed space.

•In the normal fruition regime we found the optimal number of visitors ensuring a maximum in the global satisfaction (carrying capacity of the museum) while in the alarm regime we tested the existing emergency plan for different demand patterns and we compared it with alternative evacuation strategies finding the optimal one.

•Our unexpected and a-priori unpredictable results confirm the usefulness and the effectiveness of the agent-based simulations in the design and analysis of complex social systems, fully supporting more traditional strategies already available to the engineers for building and management of real structures.



Thank you for the attention!

Main References

- *F.Camillen, S.Caprì, C.Garofalo, M.Ignaccolo, G.Inturri, A.Pluchino, A.Rapisarda, S.Tudisco, "Multi agent simulation of pedestrian behavior in closed spatial environments", IEEE - TIC-STH 2009*
- *G.La Ferla, "Simulazione ad agenti per l'analisi della Capacità di Carico e della gestione dell'Emergenza in un ambiente confinato", Degree Thesis in Civil Engineering, Catania (2009)*
- *F.M.Camillen, "Analisi del Piano di Evacuazione dal Museo Civico Castello Ursino di catania per mezzo di un modello di Simulazione ad Agenti", Degree Thesis in Civil Engineering, Catania (2008)*
- *C.Garofalo,"La Carrying Capacity - Saggio di Sociologia Matematica e Computazionale", Simonelli Editore, 2007*