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Individual-Oriented Model Crowd Evacuations Distributed Simulation

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Abstract

Emergency plan preparation is an important problem in building design to evacuate people as fast as possible. Simulation exercises as fire drills are not a realistic situation to understand people behaviour. In the case of crowd evacuations the complexity and uncertainty of the systems increases. Computer simulation allows us to run crowd dynamics models and extract information from emergency situations. Several models solve the emergency evacuation problem. Individual oriented modelling allows to give behaviour rules to the individual and simulate interactions between them. Due to variation on the emergency situations results have to be statistically reliable. This reliability increases the computing demand. Distributed and parallel paradigms solve the performance problem. In the present work we present a crowd evacuations distributed simulator. We implemented two versions of the model. One using Netlogo and another using C with MPI. We chose a real environment to test the simulator: pavilion 2 of *Fira de Barcelona* building, able to hold thousands of persons. The distributed simulator was tested with 62,820 runs in a distributed environment with 15,000 individuals. In this work we show how the distributed simulator has a linear speedup and scales efficiently.

Keywords: IoM, Distributed Simulations, MPI, Crowd Evacuations

1 Introduction

When a building is designed or when a macro festival is prepared the best configuration for the evacuation of the building has to be known. A bad configuration can be critical. Crowd evacuations represent an abnormal but potential situation where human lives are in risk to suffer any harm or even, to die. Motivations of evacuations can be floods, fires, terrorism, bomb attack, gas leak, biological agents, earthquakes, etc. The aim of a good configuration is to get the faster and more secure evacuation for all the individuals. In the case of moving human crowds through the space the crowd dynamics determine the behaviour of the individuals. Human simulations are not reliable as the human rules used in an emergency evacuation situation are different from a simulation when there is no danger for the individual. Variables as panic, velocities or

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obstacles determine variance. In the specific case of crowd evacuations it becomes more complex because the number of individuals has the order of thousands or more. How do we simulate the behaviour of thousands of individuals in a crowd evacuation situation with statistical significant results? To solve these problems simulation is needed. Simulation will allow us to predict the behaviour of the system and get information without interacting with the real system and be able to learn and take decisions from the output of the simulation. That way the evacuation time is known beforehand and this information can be used to take decisions in case of evacuation. For this we need to create a model with rules extracted from the real system.

The crowd evacuations problem is solved by different approaches. We chose individual-oriented models (IoM). IoM emerged to solve problems involving populations whom behaviour is determined by each individual behaviour. This modelling technique is used in flocks, herds[13], fish schools [15], hospital emergency systems [16], etc. It allows us to introduce rules to the individuals. These rules will determine the behaviour of the whole system, which is unknown at the begging. The individual rules can not give the results of the system in an analytical way without simulation. The advantages of IoM are a more real conceptual situation where the individual is independent and has its own properties. The motion is calculated separately for every individual, in front of analytical models that assume the whole population as a function.

There are simulators oriented to solve evacuations as EXODUS, REGAL's Evacuation Planning Tool, Simulation of Transient Evacuation and Pedestrian Movements or PEDSIM that are able to run sequential simulations in order to analyse how the individuals behaves according to the environment. NetLogo [12] is a common used modelling tool. It is useful to test and validate a model, but when a final tool is needed problems emerge. In the case of crowd evacuations with thousands of individuals and big space to gather this crowd NetLogo can present limitations. Due to this restrictions a crowd evacuations simulator is proposed. High level languages, and message passing libraries allow us to create high performance simulators that speedup the execution time of common simulators.

When a simulation is launched, the results generated are valid if they are statistically reliable. The results of a reduced number of runs will not be reliable if we have a big standard deviation from the mean. In order to check this, the method proposed by Diaz-Emperanza [4] can be used to calculate the runs for normal distribution results. The number of replications of the simulations will impact on the accuracy and reliability of the results. The number of simulations chose in this paper will be calculated with this method.

In this work we present a crowd evacuations HPC simulator. This simulator allows to test the evacuation time and run thousands of simulations with thousands of agents. The aim is to provide a HPC tool to run a big number of crowd evacuations simulations to obtain statistically reliable information of interactions in big populations. The expected results are an scalable tool to support the decision taking process.

In section 2 we analysed the related work in crowd evacuations; in section 3 the crowd evacuation models and the building used to test the model are described; in section 4 the number of simulations are calculated and the simulator is explained and in section 5 the experimental results are presented.

2 Related work

Evacuation modelling allows to simulate the behaviour of thousands of individual without the need of testing the real environment. There have been several approaches to solve the evacuations problem. Mathematical models, cellular automata (CA), flow nets, rule based models, experiments based on non-human animals, etc, and these methods have been already compared [19]. In the case of CA there is an extense literature [5] [2] [7] [11], but in the present paper IoM is used instead of CA.

Crowd pedestrian behavior was solved in the areas of AI and computer graphics rendering. The goal is to introduce in the agents a realistic pedestrian behaviour, drive them to the goal and render big populations of individuals [17]. Rendering indexes are important metrics in these researches.

In the area of HPC to solve crowd problems GPUs have been used to implement the crowd dynamics algorithm and the rendering [1]. MPI was used in city evacuations distributing the space and agents[10]. On the other hand there is research solving the evacuations problem to provide knowledge [18]. These tools are normally tested with number of individuals of the order of hundreds.

In the present work we present our simulator based on the Helbing model [8]. The 9 rules extracted from the analysis of scenarios that determine the model will be used and not the *social force* model. This simulator allows us to load an environment and run thousands of agents, and thousands of executions in a MPI cluster. We implement a NetLogo model to test the behaviour of our model and to check what is the performance of this tool simulating crowd systems. This will give us more statistically reliable results.

3 Crowd evacuations model

Models allow to summarise the basic rules that determine the main behaviour of a system. Our model is an abstraction of the model developed by Helbing [8]. Our model is able to avoid obstacles, presents bottlenecks in emergency exits as in real emergency situations, crowd slows down, clogging occurs close to the exits and individuals tend to have a mass behaviour. In the design of the model we selected to discretize the space in a grid. Every individual has an 8 connectivity neighbours. Components of the grid has a size of 40x40cm. The model considers that this is the space needed to hold one individual. This simplification allowed to access directly the neighbours without iterating over all the individuals. Every individual has exclusivity to this space and the movements are between adjacent grid positions. Because of this every individual walks at the same velocity.

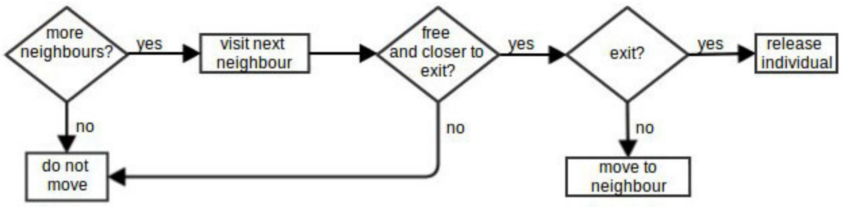

Figure 1: Flowchart of the individual logic for one simulation step

In IoM the rules of the individuals determine the final output of the system. In the Fig. 1 can be seen the logic that determines the behaviour of every agent in our model. In every simulation step every agent checks their 8 neighbours. Neighbours can not be always iterated in the same order or the individuals will move only to one side of the space. The position is checked and tested if it is free (this also means that there is no wall) and if the individual is approaching the exit. When there is an obstacle while going in the exit direction it is avoided until free space is reached. In the case that the individual cannot approach the exit it will not move and will wait. Once the individual reaches the exit it disappears assuming it is safe and released.

The individual has an objective function determined by the selected exit. Because of this the exit determines the movement of the individual that is trying to reach the goal. Every exit will have a cluster of individuals associated. These will be the set of individuals with this exit as objective. The variable that will determine the exit target is the distance. In the Fig. 2 can be seen that each individual holds a position in the grid. The simulation show how the individuals are able to cross doors and overpass walls in order to achieve their objective.

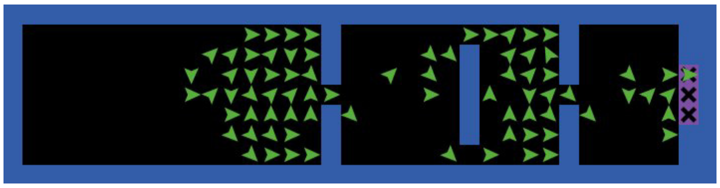

Figure 2: Simulation of the model in NetLogo

The aim of the research is to provide a tool for the real world. A necessary approach for the simulator is to select real buildings. We chose the building 2 of *Fira de Barcelona* [6]. This space receives international conferences and fairs with thousands of attendants. The event *Salo del Manga*[14] is one of these events. It hosted 105.000 visitors in 2013. This attendance has motivated the election of this space with the distribution of the mentioned event. In the Fig. 3 can be seen the original map. We did simplifications in the map digitization involved chairs, platform, importance of exits and the bar exit. The building was chosen for testing purposes, but the simulator is building independent, and other spaces could be loaded to run the simulation.

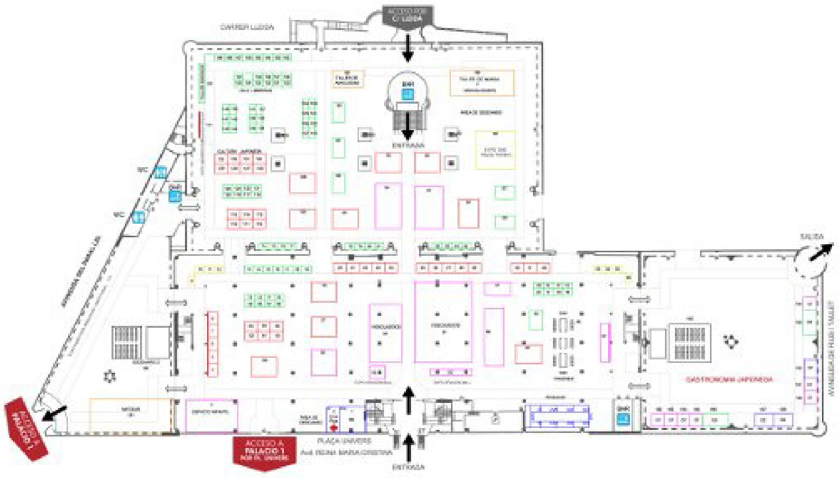

Figure 3: Map of *Fira de Barcelona*

4 Model Implementation

We simulated the space *Fira de Barcelona* with populations of 3,000, 6,000, 12,000 and 15,000 individuals. We have implemented the model in the tool NetLogo and in the simulator able to distribute the simulation with OpenMPI in a MPI cluster.

Studies like [9] [3] are able to solve the calculation of the numbers of runs of a simulator beforehand. In our work we use Diaz-Emperanza study [4] to calculate our number of runs. Before we analysed the simulation execution time for 1,000 independent runs and the results approach a normal distribution testing with chi^2 and Kolmogorov-Smirnov. According to Diaz-Emperanza the number of simulation runs (T) needed are calculated with the Formula 1.

$$T = \frac{t^2_{\frac{\alpha}{2}} p_H (1 - p_H)}{A^2} \tag{1}$$

Where t is a parameter determined from the density of the normal function, H is the interval of probability, p_H is probability in H, $1-\alpha$ is the level of confidence and A is the accuracy. This probability is held in the interval [0.045 0.055]. The number of runs has to be $runs \geq T$. Only $1-\alpha$ values over 0.90 are reliable. In our case we chose 0.95. As the aim of this work is to get a tool for good accurate results the A of 0.0002. Due to the interval that we are working with our p_H is 0.05. Replacing these values in the previous formula we solve and get the number of runs.

$$T = \frac{2.3^2 0.05(1 - 0.05)}{0.002^2} = 62,818.75$$

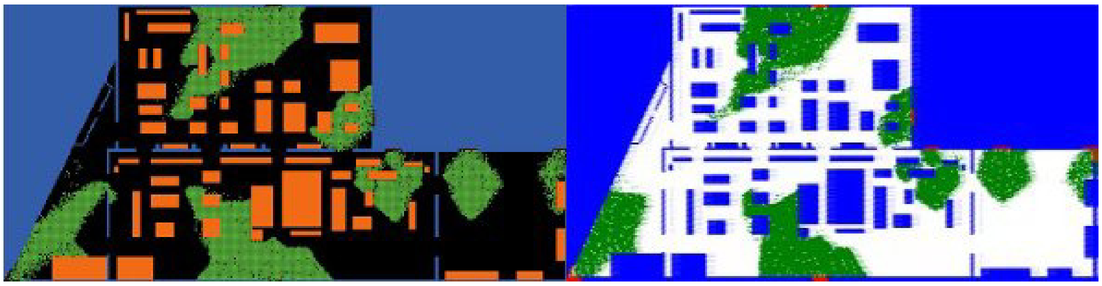

Figure 4: (a) NetLogo visualisation; (b) MPI visualisation

We developed the model described in section 3 using NetLogo, a widely applied modeling tool. We wanted to study the behaviour of the model and also analyse the response time of the simulator. In NetLogo implementation the space is represented by a matrix. In its nomenclature all positions of the matrix is a patch and the individuals are agents. Each agent has a unique associated position or patch. There cannot be two agents in the same patch. As the agent move around the map, the position is updated to the current patch. To load the map we created a bidimensional matrix that contains the information about the patch -where each patch can be identified as coordinates using the rows and columns of the matrix. A patch can be:

- *wall*: that define the boundaries of the map.
- *free space*: where the agent can move freely.
- *exit*: the aiming point for an agent in order to leave the map.

- *obstacle*: specific patches where the agent cannot pass through.

The initial position of the people is generated using random coordinates inside a free space. Every agent knows in advanced which exit should try to direct to. This information determines the agents movement. In the Fig. 4 (a) can be seen an execution of 15,000 agents using NetLogo visualisation as they are heading to the emergency exits. The same scenario is repeated in Fig. (b) but using MPI visualisation.

The initial state is always generated randomly and is the variance that determines the difference simulation time. The space is not altered. The number of agents chose for the MPI simulation is related to the NetLogo simulation individuals chose. We developed a simulator using C to declare the rules and OpenMPI to distribute simulation between nodes. In the Fig. 4 (b) can be seen an execution of 15,000 agents in our C-MPI simulator. The movement is similar to the showed in the Netlogo simulation in Fig. 4 (a).

5 Experimental results

In the NetLogo model we run the simulation with 3,000 to 15,000 individuals. The simulation times includes the random distribution of the individuals among the space and the crowd dynamics simulation. In the Fig. 5 can be seen the response time that increase linearly with the increment of number of individuals. The model was developed using C with the full optimisation parameter (O3) and MPI. The simulator was executed in the cluster described in Table 1.

Table 1: Cluster characteristics.

Cluster	Characteristics
32 IBM x3550 Nodes	2 x Dual-Core Intel(R) Xeon(R) CPU 5160 @ 3GHz 4MB L2 (2x2)
	12 GB Fully Buffered DIMM 667 MHz
	Hot-swap SAS Controller 160GB SATA Disk
	Integrated dual Gigabit Ethernet
	gcc 4.4.7
	OpenMPI 1.6.4

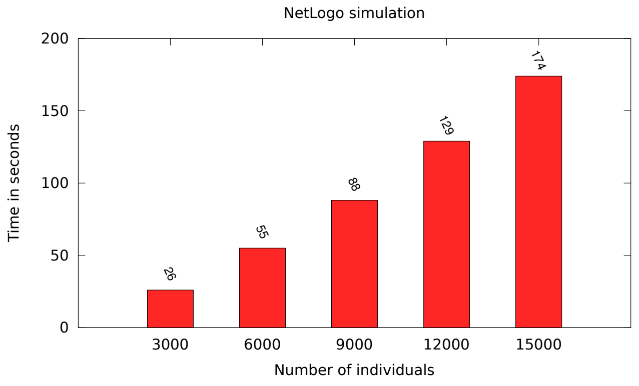

Figure 5: NetLogo execution times(s)

We run the NetLogo simulator in a Intel Core i5-2400 CPU 3.10GHz 6MB L2 (2x2). In the Fig. 5 can be seen the execution times of the NetLogo model. These are the means of 100 runs, where the mean execution time did not have significant variance. The execution time includes several steps of the simulation. First the random distribution of the agents and is executed until the moment when all the individuals have reached the exit and are safe. It can be seen how the times increase as the number of agents increase linearly as the number of agents increase linearly. This shows how the the simulation time increases as the number of individuals increase in NetLogo.

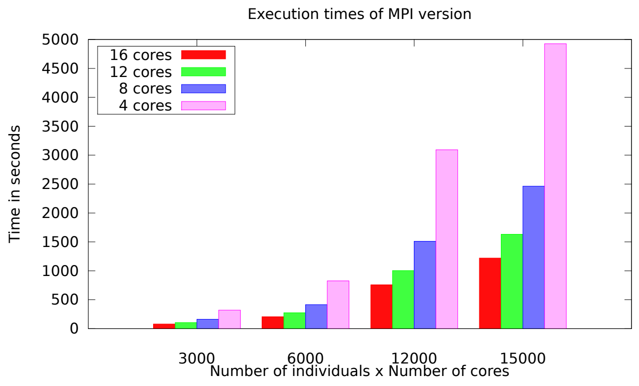

Figure 6: Distributed simulator execution times

In the Fig. 6 can be seen the execution times of this simulator for 4, 8, 12 and 16 MPI process for 62,820 runs, which is a greater number than the simulations run that were calculated. It can be seen how the times decrease significantly due to the increase of nodes thanks to the MPI distribution of the executions.

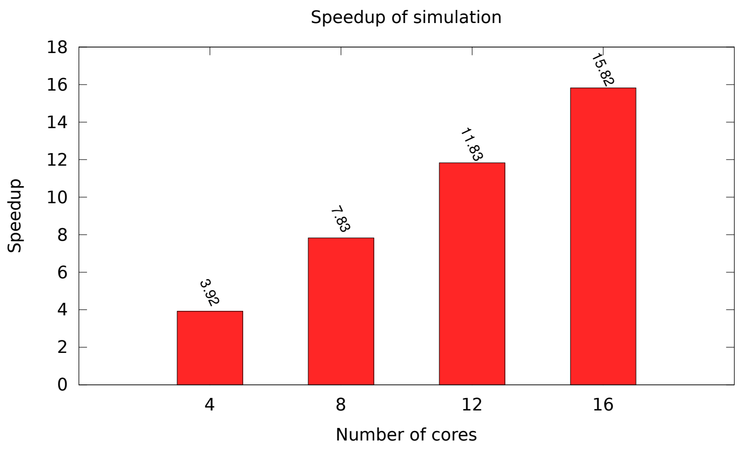

Figure 7: Speedup

We executed the serial version for 62,820 simulations and compared the result time with the parallel versions. In the graphics seen in the Fig. 7 the speedup showed becomes linear. As the efficiency is close to 1 it can be said that the algorithm scales and is efficient. The differences in the scalability (Fig. 8) remains in the variances of the simulations with a stochastic component.

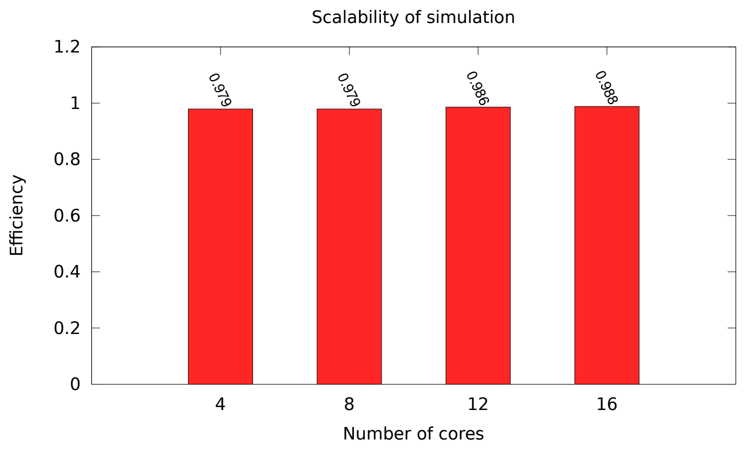

Figure 8: Scalability

Crowd evacuations simulators aim to provide knowledge about the mass behaviour. In the Fig 9 the results showed how about the 80 ticks clogging occurs and the people slows down. In the tick 200 the amount of people evacuated per time unit decreases and the evacuation becomes worst.

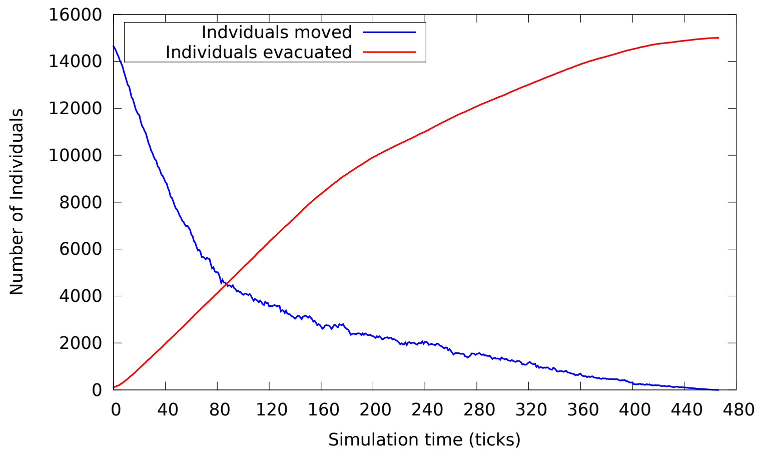

Figure 9: Evacuated individuals and individuals moved per time

6 Conclusions and future work

6.1 Conclusions

Emergency evacuations are important situations were human lives are in risk. The behaviour of the individuals is unknown and it can vary widely. This gives us a lot of combinations and the need of get knowledge for every building and event. Because this we proposed a model and a simulator. We have worked with IoM. We digitised the building Fira de Barcelona as a real scenario for the simulation. It showed big computational times for a single execution. Because the computational needs we developed a C model that was distributed using MPI with 3,000 - 15,000 and showed how all the individuals reached the emergency exit. The main conclusions from the work are:

- A crowd evacuations model based on was presented, based on Helbing's evacuation model.
- Netlogo has been used to implement the model. The simulations has been tested with 3,000, 6,000, 12,000, 9,000 and 15,000 individuals. For 15,000 individuals the executions time was 174 seconds for one simulation.
- We used Diaz-Emperanza method to calculate the number of simulations to have statistically significant results for crowd evacuations.
- The model implemented in the Netlogo platform was implemented in C distributing the simulations with MPI. Both models had the same behaviour.
- The simulator scales efficiently approaching a linear efficiency.

6.2 Future work

The main goals for our future work are:

- Explore new models and individuals characteristics, their behaviour, implement them and compare them with the current work.
- Digitalize new real spaces able to hold crowd events and test the simulator with bigger number of agents.
- Explore new validaton methods for our simulation and their viability.
- Check the impact of the presented work in the decision taking process.

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