Performance Analysis of ABM Distributed Simulation for Real Crowd Evacuation Scenarios

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Abstract. Managing crowds is a key problem in a world with a growing population. Being able to predict and manage possible disasters directly affects the safety of crowd events. This kind of problem can be modeled using Agent-Based Model techniques and consequently simulated in order to study evacuation strategies. Our aim from this paper is to prove that this model albeit simple can be expanded and adapted for experts to test various scenarios and validate the outcome of their design. Preliminary experiments are carried out using different initial locations for the agents inside Fira of Barcelona building, whose results are presented, validated and discussed. We shown that crowd evacuation problem has bottlenecks in reality, and the initial location for all agents can increase or decrease the bottlenecks. Finally, we draw some conclusions and point out ways in which this work can be further extended.

Keywords: Crowd Evacuation, Agent-Based Model, Distributed Simulation

1 Introduction

The analysis of building evacuation has recently received increasing attention, as people are keen to assess the safety of occupants. Reports on past huge disasters indicate that human behaviors characterize evacuation during emergencies.

Cases as the Hillsborough Stadium disaster (Sheffield, England in 1989) causing 96 deaths, the Love Parade disaster (Duisburg, Germany in 2010) causing 21 deaths or the Kiss disaster (Santa Maria, Brazil in 2013) causing 239 deaths shows us how bad decisions and planning can lead to human harm. Evacuation management and planning then become a crucial issue. The disasters have occurred in numerous different countries, each of the disasters has a major contribution factor, which is given as either crowd behavior or building design. Most of the disasters have occurred due to building design, a factor that can be controlled by engineers and decision makers.

Exercises such as fire drills allow us to know the evacuation times, but not the conditions, because people have stochastic behavior that determines the variability of evacuation. It is not possible to perform drills to cover all scenarios. In these cases simulations becomes necessary. We will be able to study the evacuation strategies for a specific scenario and with this information take decisions in evacuation cases. This way helps to have knowledge to carry out what is most appropriate evacuation plan, the safest, and fastest evacuation possible. Simulators allow us to have knowledge to take informed decisions that can predict the behavior. Decision Support Systems (DSS) have gained importance in the last years, and the usage of simulators allows predicting the behavior of a system according to a model and helping experts to take decisions.

In crowd evacuations there are random patterns among the public, therefore we need statistically reliable results in order to predict the outcome of each scenario. For that, it is important to use high performance computational solutions and tools. Care HPS [1] is an Agent-Based Model tool that helps to execute experiments in a parallel and distributed architecture. This tool allows us to manage all the components of the model, such as the environment with obstacles, and to execute our simulations efficiently with thousands of agents and thousands of simulation steps.

Therefore, in this paper, we use as a case study Fira of Barcelona model based on the Helbing model [20]. Fira model, implemented in C++, and simulated using Care HPS [2]. We analyzed the behavior of the model in different scenarios and different initial locations for the agents. This gives us more statistically reliable results.

The rest of the paper is organized as follows. We present related works where we show previous previous contribution in this field 2. Then we dedicated section 3 to show the challenges of crowd evacuation simulation and to present our Fira crowd evacuation model, and Care HPS tool that we used to implement and simulate the Fira of Barcelona model. Then, the model experiments are presented and discussed in section 4; and finally, some conclusions are drown in section 5.

2 Related Works

In the last years there has been a growing effort in solving the evacuation safety problem. The research areas interested on the problem vary from engineering, computer science, psychology, architecture or sociology, and each one has been tackling different aspects of it. Inside the evacuation problem lay several sub problems such as: the person model, the psychological components, free navigation through the space, path planning to reach the exit, simulation techniques, and performance issues of the simulator. The aim of all these areas and components have common goals: provide a better understanding of the model and have an advanced way to implement them with simulators. For this common purpose most of the research considers the same starting premise: evacuate a certain number of agents inside a specific space.

An analytic study of crowd dynamics through exits may provide useful information for crowd control purposes. Proper understanding of the evacuation dynamics will allow, for example, improvements of pedestrian facilities designs. In particular, the dynamics of evacuation through a narrow door during an emergency is a complex problem that is not yet well understood. The possible causes for evacuation may include building fires, military or terrorist attacks, natural disasters such as earthquakes, etc. In the light of tightened homeland security, research on evacuation modeling has been gaining impetus and attracting the attention of researchers from various fields.

There are three main reasons for developing computer simulations of crowd behaviors: firstly, to test scientific theories and hypotheses; secondly, to test design strategies; and finally, to recreate the phenomena about which to theorize [3]. Computer models for emergency and evacuation situations have been developed and much research on panics of empirical nature and carried out by researchers from the social science [4], [5], [6], [7], and [8].

A critical review offered selected simulation models of evacuation [9]. Also, authors have identified social science approaches that could improve contemporary simulation models. They argue that social sciences could provide important new directions for simulation models of emergency evacuations. [4], and [5] developed a continuous pedestrian model based on plausible interactions, and pointed out that pedestrian dynamics shows various collective phenomena, such as arching, clogging, and herding [7]. According to their findings, every simulation model should reproduce such behaviors in order to be rather realistic. They believe that the above models can serve as an example linking collective behavior of a mass psychology phenomenon (from the socio-psychological perspective) to the view of an emergent collective pattern of motion (from the perspective of physics). They suggest that the optimal behavior in escape situations is a suitable mixture of individualistic and herding behavior. [10] present a simulation model for emergency planning and crowd management purposes.

Other simulation studies, combined with optimization algorithms, aim at improving the evacuation efficiency. This can be achieved in terms of evacuation times, assessment and analysis of evacuation plans, as well as routes/path optimization. [11] has deeply studied the mathematical and analytically models, comparing and analyzing them on a systematic basis. In [12], the analysis of evacuation processes on-board is taken into consideration. The authors of the study apply Cellular Automata to reproduce crowd motion for the detection of possible bottleneck situations during the evacuation process. [13] address the building evacuation optimization problem. [14] developed a discrete-event computer simulation model for assessing evacuation programs and provide a comprehensive idea of evacuation plans for hospital buildings in the event of a possible bomb threat. Crowd pedestrian behavior was solved in areas of AI and computer graphics rendering. The goal is to introduce in agents a realistic pedestrian behavior, drive them to the goal and render big populations of individuals [15]. 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 rendering. Also crowd turbulence phenomena integrated on GPU cards [16], The implementation is a hybrid model between Verlet integration method and Agent Based Model. MPI was used in city evacuations distributing the space and agents [18]. These tools are normally tested with hundreds of individuals. Many crowd evacuation models using agent based model simulated people behavior by deploying cloud services for high performance simulation [19], the input is just a PNG image and the output are statistical results of the simulation executed on the cloud.

In this literature study, we note the need for further contributions in parallel and distributed solutions to carry out models with thousands of people. Also, tools can easily change the environment characteristics in order to simulate better layouts of space for fastest evacuations.

3 Crowd Evacuation Model

The present work is focused on the crowd evacuation modeling problem, crowd simulators, and their performance. Crowd models aim to understand the behavior for big populations of people in a closed space.

In modeling the problem of representing the reality can be tackled from different perspectives. Each view will have its own pros and cons based in terms such as: complexity, performance, simplifications, and aim. Modeling has allowed the humanity to advance its knowledge and improve its day living. In the particular case of evacuations and crowd dynamics there has been an increasing interest in reproduction of evacuations through several approaches during the last years, such as discrete time or continuous time models. These approaches differ on the focus of how to extract the natural characteristics of the reality and how to implement them. Each approach has pros and cons, and choosing one or another is always a trade-off.

Simulators implement the ideas designed by models, and simulation allows us to interact with the model and generate results without interacting with the real system. Our model and simulator have mainly the purpose of provide knowledge of potential problems, also analyze theories and simulate them. Moreover, one of the main final goals is to provide a decision support system where the complexity of the model and the performance is hidden to the final user by integrating the crowd evacuation model with Care HPS tool. Whereas we work with thousands of agents interacting between each other and with the environment by reproducing different scenarios. The simulation will have high computational needs that has been resolved by integrating Care HPS and improve it to be adapted with this model's needs.

Our present model is a discrete time model able to handle thousands of agents, whereas the model recovers ideas from Cellular Automata to be computationally efficient. This model reproduces crowd phenomena in Sala del Manga, which is the building 2 of Fira de Barcelona. And it can hold almost a hundred thousands of people. This environment has different zones and obstacles, which make the evacuation more complex.

Some modification made on the map for simplification purpose, while it includes chairs, important exits and the bar exit. All agents in this model has a behavior and rules to control its movements. We used an algorithm that allows agents to navigate freely avoiding obstacles and walls. The model is divided into two sub-models, agent and environmental intelligence. The agent move between cells approaching to the exit, while there can be only one agent per cell, and when agents achieve the exit, they are released.

The model is described by a set of attributes, which are (A1: Stopped, A2: Moving, A3: Evacuated, N: Approaching the exit, E: Exit reached, F: Free patch), and transitions between states are determined by the attributes of the model. The algorithm used for the environment sub-model is the potential field algorithm, which provides the shortest path and support obstacle avoidance feature. This algorithm is a recursive algorithm that visits the cells in breadth search giving higher values every time.

Figure 1 shows our environment's map with obstacles and exits. This image shows color representation of the potential field. Ignoring the dark blue color, which are ob-

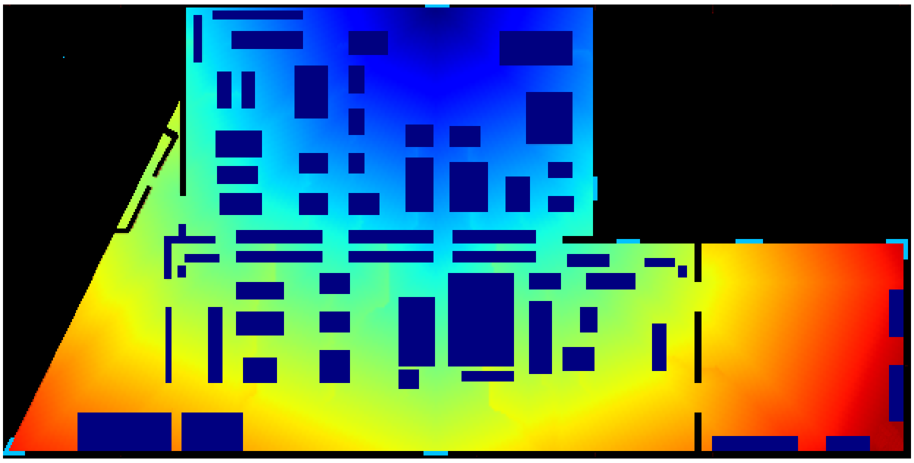

Fig. 1. Potential Field Algorithm applied on Fira de Barcelona map.

stacles. The light blue color indicates that the exit is getting closer and the red color indicates that the exit is the farthest. Notice that the obstacles and walls have the darkest blue and black because the agents will avoid these spaces as these are not approaching the exit. While the potential field is dependent on the exit, there are as many potential fields as exits. Every agent needs to have one exit assigned, therefore, one potential field. In this map we considered that the target exit for the agent is the top middle exit in the map, for this reason the blue color shown around this concern exit.

The data structure is a list of matrices where every matrix are the potential field values that are precalculated at the begging and stored in main memory.

There are several potential field algorithms and we chose a mix of the Manhattan and Chessboard potential field calculation [17]. Every individual will have knowledge of the potential field of their exit and will use it to take decisions between steps.

The (algorithm 1) implements the potential field algorithm. While the implementation is recursive, using the implicit stack of recursion to explore the nodes in breadth way. There is a global structure accessed by all the function's calls that tracks the visited nodes and the values are updated. This happen with the current value which is updated for every level of the recursion until it fills all the structure. Variables x and y are temporal variables referring to positions in the map which are being visited.

We also improved and adapted Care HPS to fit our models needs, where a statistical significant amount of simulations are executed to evacuate all agents through the available exits. The model and Care HPS tool implemented in C++ programming language. In order to test the model with Care HPS, we distributed the simulations using MPI, while the simulator were executed for several configurations with 2,8,32 and 64 OpenMP threads. Therefor we show the efficiency of these configurations in each scenario.

Algorithm 1 Potential field algorithm

```
procedure POTENTIALFIELD
    TotalUnvisited ← 1
    UnvisitedPush(exit)
    while TotalUnvisited ≠0 do
        for all x ∈ neighbours(r) do
            if x ∉ unvisited then
                UnvisitedPush(x)
                TotalUnvisited ← TotalUnvisited + 1
            end if
        end for
        if y ∈ unvisited then
            calculateFlood(y)
        end if
    end while
end procedure
```

4 Experiments

In this section, we will present the experiments conducted over Fira of Barcelona model. Fira is a public space in Barcelona city (Spain) which helds many events that receive a considerable number of people. We will simulate 30000 of agents with the environment using same objects' position found on real space.

We made three variant scenarios (figure 2), each scenario represents different initial location for all agents, the first scenario spreads all agents randomly inside the whole environment, while the second scenario locates all agents in the middle of the environment, and the last scenario locates agents in all the corners of the environment.

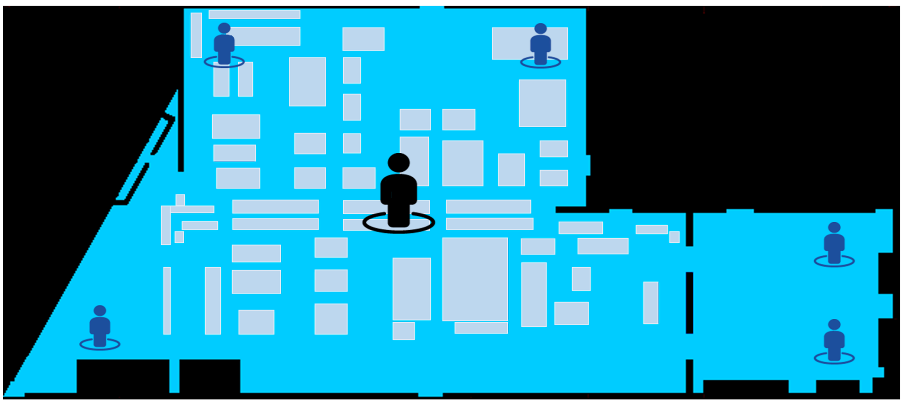

Fig. 2. Agents locations for middle and corners scenarios

(Figure 2) shows the main initial location in the second and the third scenarios.

All scenarios were carried out for 30000 agents, and the agents location changed based on the scenario. These experiments were executed using one MPI process and *n* threads were created. We used the hybrid strip partitioning, this partitioning is one of the features available in Care HPS, where we use MPI and OpenMP threads to simulate agents behaviors. For these experiments, the partitioning was configured using one partition in MPI process and create *n* constant number of threads where the experiments were executed. The best execution time found in the first scenario (Figure 3) was with eight threads, and in the second scenario was with eight threads as well, but in the third scenario was with 32 threads.

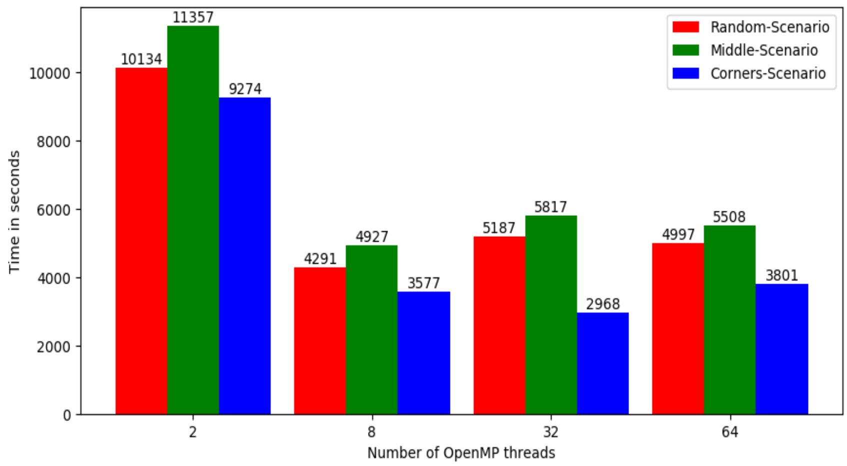

Fig. 3. Compare the scalability for all scenarios with 30000 agents.

As we note in (figure 3), the total execution time increased in the first and the second scenario while it decreased in the third scenario, and the reason behind this is that the model has a limited number of exits and all agents look up and arrive to these exits at the same time, which will create a bottleneck, Therefore, increasing the number of threads does not decrease the execution time, because of the access to exits is sequential and computing of the stopped agents is not too high. But in the third scenario as all agents were located in different corners, and each corner has an exit nearby, then the possibility to have more load on one exit is less, and this will let agents to use all exits efficiently and leave the environment smoothly through those exits.

After analyzing the data of these experiments, we show the speedup in (figure 4) to compare all scenarios from the speedup perspective. In the first scenario we obtained the best speedup with 8 threads, and in the second scenario was with 8 threads as well, but the best speedup we obtained in the third scenario was with 8 and 32 threads.

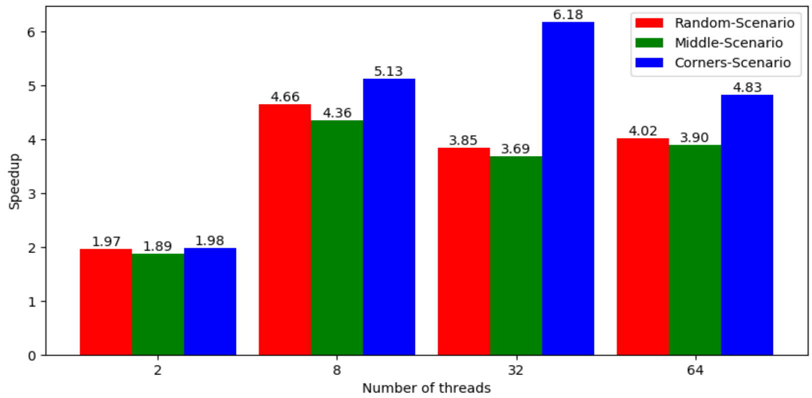

Fig. 4. Speedup comparison for all scenarios.

As we can see from the speedup diagram, the model could not take the advantage of increasing the number of threads because of the reason noted before.

In (figure 5) we show and compare the efficiency of all scenarios. It was clear that the best efficiency recorded in the third scenario where we located all agents in five corners and those corners has equal number of agents, (total number of agents divided by number of corners in the environment).

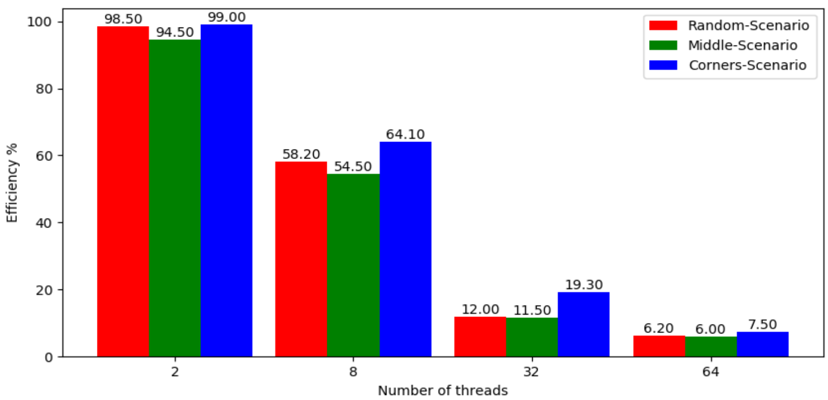

Fig. 5. Efficiency comparison for all scenarios.

From these experiments, we figured out a problem of memory contention due of the concurrency when we increase the threads number. This is a consequence of the bottleneck phenomena. However, from the HPC perspective, we can see that there are very good speedup and efficiency values for the configuration and scenarios we analyzed, for example when 8 threads used.

5 Conclusions

In this paper we described several experiments using different scenarios to evaluate their performance. The parallelism and performance were evaluated on different architectures and discussed. The discrete model was implemented and distributed in a cluster, dividing the total number of simulations. We also tested the model with different scenarios, whereas each scenario initiate the agents in variant locations, by locating all of them in the center of the environment, spread them randomly or spread them only on the corners. We demonstrated how the initial location for agents can affect the evacuation time and increase or decrease the crowd evacuation efficiency.

Actually this kind of scenarios can help decision makers to decide according to the time required to evacuate a certain number of people by reconfiguring the environment and change the position of obstacles and exits in the reality.

Through the experimentation, we found the best scenario is to divide all agents and locate them in the corners, in order to decrease the load on a specific exit. Also, we figured out that crowd evacuation problem has bottlenecks in the reality that will not be resolved by only increasing the number of threads, but also it needs a load balance on each exit. as we found the best case is to have them located in different areas and each area has an exit around. It occurs because of agents dispute the few exits, same way that occurs in the reality.

Acknowledgments. This publication is based upon work supported under contract TIN2014-53172-P, funded by the MINECO Spain. We thank Albert Gutierrez-Milla for his contribution in this work. All trademarks, material, images and information used in this work are propriety of their owners and here is used with academic purposes.

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