Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 108C (2017) 937–947

Procedia Computer Science

International Conference on Computational Science, ICCS 2017, 12-14 June 2017, Zurich, Switzerland

# On the performance and scalability of an HPC enhanced Multi Agent System based evacuation simulator

Leonel Aguilar[1], Maddegedara Lalith[1], Tsuyoshi Ichimura[1], and Muneo Hori[1]

Earthquake Research Institute, The University of Tokyo, Bunkyo, Tokyo 113-0032
leaguilar,lalith,ichimura,hori@eri.u-tokyo.ac.jp

**Abstract**

This paper presents some of the techniques, algorithms and designs used to enable mass evacuation simulations to take advantage of high performance computing infrastructure. A brief overview of a tsunami mass evacuation simulator capable of simulating urban areas of hundreds of $km^2$ in sub-meter detail is provided. Enhancements to the serial algorithms for path finding reducing the path finding time in 94% and a cache friendly visual boundary extraction algorithm cutting the overall simulation time in 50% are presented. Furthermore the hybrid parallel (distributed memory (MPI) + shared memory (OpenMP)) framework is described. A dynamic load balancing technique reducing the idling time from 50% of the execution time to 3% is presented. Finally measures of the thread parallel strong scalability up to 16 threads of 82.69% and distributed process strong scalability up to 2048 processes of 75.93% are presented.


Peer-review under responsibility of the scientific committee of the International Conference on Computational Science

*Keywords:* Evacuation simulation, Multi agent system, High performance computing, Parallel computing

## 1 Introduction

The analysis of mass evacuations provide extensive challenges due to their scale, the uncertainty in human actions and behaviors, the scarcity of these events and the inability to perform real life drills. These challenges have lead to the proliferation of computational models to study evacuations and human mobility in general.

As the computational infrastructure grows in capacity and performance methods and techniques need to be developed to effectively take advantage of them. Reports on the scalability of software used for evacuation simulation are limited to tens of CPU cores [1]. Other pedestrian evacuation simulation software provide scalability reports up to hundreds of CPU cores [2]. Although these programs are state of the art tools, the computational infrastructure has grown rapidly requiring enhancements to achieve better scaling and performance. Modeling complex behavior with millions of agents in detailed environments require further considerations on the performance and scalability of the simulators.

1877-0509 
Peer-review under responsibility of the scientific committee of the International Conference on Computational Science
10.1016/j.procs.2017.05.284

This paper extends the previous work on the HPC enhancements of a mass evacuation simulator[3]. And presents performance and scalability measures along with the techniques and algorithms used to achieve the reported performance.

The contribution of this paper is to provide scalability and performance measures for an evacuation simulation software along with the design considerations and techniques. Additionally it addresses two costly bottlenecks in the simulation: the agents' visual perception of the environment (algorithmic considerations and cache friendliness) and their route planning (graph model reduction).

The rest of the paper is organized as follows. Section 2 provides a brief overview of the evacuation simulator and its multi agent system. Section 3 presents details of the hybrid parallel extension. Section 4 presents the enhancements in the vision and path finding algorithms. Section 5 concludes this paper.

# 2 The evacuation simulator

The evacuation simulator is based on the Multi Agent System (MAS) paradigm. This enables the modeling of heterogeneity in crowds, different modes of evacuation, etc. Autonomous software agents are used to simulate evacuees in an environment. Each agent possesses individual roles, responsibilities, knowledge of the surroundings and characteristics.

In contrast to other evacuation simulators, agents move in a continuous 2D space not restricted to cells or graphs but consider all the traversable space for their movement. An accurate representation of the physical space is critical for the intended use case of tsunami evacuation simulation as the whole tsunami evacuation happens in a few minutes time-frame. The short time-frame amplifies any inaccuracies introduced in the models. Additionally the aim of the evacuation simulator is to handle mass evacuations of urban domains. This requires the use of models of the domain that provide enough information and details about the surroundings but also scales to domains of hundreds of $km^2$. Due to the high computational cost of the simulator a High Performance Computing(HPC) extension has been implemented [3].

## 2.1 Environment

The evacuation simulator is designed to include large urban domains in sub-meter details including indoors spaces. In order to accomplish this a hybrid vector/raster domain is adopted, see Figure 1. This allows to efficiently provide details of the environment without sacrificing higher level features such as path planning.

The dynamically changing details of the environment are provided using a raster model, a grid where each cell represents the state of the region, i.e. unoccupied space, exit, obstacles or designated evacuation/safe areas. Agents rely on their vision to perceive and discover the state and changes in their environment. These changes occur due to debris from collapsed buildings or tsunami inundation [5]. In order to efficiently provide higher level features such as path planning, spatial experience storage and data collection a graph embedded in the traversable spaces is provided. This graph provides a lighter data structure that enables better performance.

## 2.2 Agents

Autonomous agents are used to model evacuees in the simulation. Heterogeneity of characteristics and behaviors in human crowds and different modes of evacuation need to be considered. This is performed by specializing the agents' logic and by providing different instantiations