Combining Conflict-based Search and Agent-based Modeling for Evacuation Problems (Extended Abstract) *

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Abstract

We address the problem of evacuation from the heuristic search perspective combined with agent-based modeling (ABM). The evacuation problem is modeled as a navigation of multiple agents in a known environment. The environment is divided into a danger and a safe zone while the task of agents is to move from the danger zone to the safe zone in a collision-free manner. Unlike previous approaches that model the environment as a discrete graph with agents placed in its vertices, at most one agent per vertex, our approach adopts various continuous aspects such as a grid-based embedding of the environment into 2D space and continuous line of sight of agents. In addition to this, we adopt hierarchical structure of our multi-agent system in which so called *leading* agents are more informed and are capable of performing multi-agent pathfinding (MAPF) via centralized algorithms like conflict-based search (CBS) while so called *following* agents with limited knowledge about other agents are modeled using simple local rules. Our experimental evaluation indicates that suggested hierarchical modeling approach can serve as a tool for studying the progress and the efficiency of evacuation processes in different environments.

Introduction and Background

We address the problem of evacuation (Kurdi et al. 2018) from the perspective of agent-based modeling (ABM) (Wilensky and Rand 2015; Zia and Ferscha 2020) and multi-agent path finding (MAPF) (Silver 2005; Ryan 2007; Surynek 2009; Standley 2010). The evacuation problem is understood as a navigation problem for a set of agents that need to move from a dangerous zone to a safe zone in a known environment, typically modeled as a discrete graph with vertices representing locations. An agent can be located in one vertex at a time and can instantaneously move across an edge to an adjoining vertex. Similar setup is used in MAPF, a problem from which we borrow the centralized algorithmic approach.

In evacuation, we usually do not care about the precise goal locations of agents. An agent can choose any location from the safe zone as its goal. This is an important difference from MAPF where each agent has one specific goal location. Since centralized control of all agents is hardly reachable in practice, we need to assume that agents are controlled locally to a significant extent. Individual agents in evacuation do not share the knowledge of locations of other agents. This precludes direct application of MAPF algorithms in solving evacuation problems at the level of individual agents. On the other hand, fine-grained behaviour of individual agents can be captured using the ABM approach.

Previous works often model the evacuation problem as a network flow (Chalmet, Francis, and Saunders 1982; Even, Pillac, and Hentenryck 2014; Arbib, Muccini, and Moghaddam 2018) in a discrete graph. The disadvantage of these approaches is that they model the problem at a too coarse level where for example collisions between individual agents is omitted. Hence these approaches are rather suitable for evacuation modeling at the scale of cities and road networks (Kamiyama, Katoh, and Takizawa 2006). More detailed modeling of agents is required for evacuation inside buildings where ABM techniques appear to be more suitable (Liu, li Mao, and min Fu 2016; Liu et al. 2018; Zafar et al. 2016). On the other hand, ABM models often the lack centralized aspect which often leads to insufficient performance of the evacuation process (Trivedi and Rao 2018).

Although some aspects important for evacuation such as deadlines (Ma et al. 2018) or volumetric agents (Li et al. 2019) have been considered in MAPF, these studies do not consider the ABM perspective. We combine centralized approach from MAPF and ABM in a novel hierarchical multi-agent system that both keeps the performance and makes modeling of local behavior of agent possible.

Evacuation Model

The evacuation problem (Selvek. and Surynek. 2019) is an anonymized form of multi-agent path finding (MAPF). It takes place in an undirected graph $G = (V, E)$, where each vertex is marked either as safe or endangered, that is $V = S \cup D$, where S are safe vertices and D are endangered vertices. The goal vertex of an agent is not just one vertex, but any vertex from S.

The task is to find a set of non-conflicting paths for a set of agents $A = \{a_1, a_2, ..., a_k\}$ that navigates them from en-

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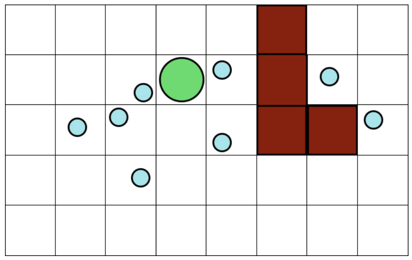

Figure 1: Continuous representation of the environment.

dangered vertices D to safe vertices S. Each agent from A starts in its own vertex, so that no more than one agent is present in a vertex at a given time.

Environment

Discrete and continuous aspects are combined to model the evacuation environment. The environment is represented by a discrete grid map embedded in 2D space. Agents are expressed as circles with a fixed radius chosen on the basis of preliminary experiments. To make the distribution of agents in the environment more realistic, each agent is placed randomly within its square cell. Agent positions are determined by the cell and by the coordinates within the cell (Figure 1).

The continuous aspect of the environment is used for determining the visibility of agents. If the line given by the centers of circles defining agents intersects another agent or an obstacle, the agents do not see each other which is important for making local decisions.

Agents

Our hierarchical multi-agent system has two types of agents. The motivation of this design is evacuation in the school environment. The two types of agents are called *followers*, representing students, and *leaders*, representing teachers. *Leaders* can communicate and can perform MAPF solving in a centralized way. *Followers* are locally controlled agents that form swarms around *leaders* and follow them.

Follower A *follower* is a purely *reflex agent* (Russell and Norvig 2010) that uses local rules. It can observe a *leader* in its immediate neighborhood if no obstacle prevents it from doing so. If there are more *leaders*, it is able to decide which one is closer, as it has a basic understanding of distance. It follows either the nearest *leader* or an assigned *leader*. If the *follower* sees the *leader* in its proximity, it moves closer towards the *leader*. Otherwise the *follower* moves randomly.

Leader The goal of *leaders* is to find the shortest paths out of the dangerous zone while keeping a certain distance between themselves so that their swarms of *followers* do not mix. *Leaders* know about positions of followers in their proximity if no obstacle prevents them from observing the followers. The *leader* is designed as an agent with a goal and an environment model (Russell and Norvig 2010) and hence is capable of centralized search. Specifically, *leaders* are performing conflict-based search (CBS) (Sharon et al.

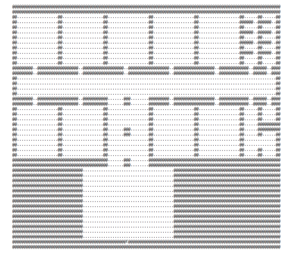

Figure 2: Environment representing a floor-plan of a building.

2015) where conflicts are defined as potential collisions between respective *follower* swarms and each *leader* has entire safe zone as its goal. Leaders are not represented by single coordinate, but as a set of all possible coordinates that would present swarms to become close to each other.

Experimental Evaluation

The most important experiments we carried out studied the impact of various parameters of agents' behavior on the numbers of evacuees. We used various maps modeling real-life evacuation scenarios such a map representing floor-plan of a building (Figure 2), a plane, or a hospital.

Figure 3 shows the impact of the obedience parameter on the progress of evacuation – the probability that a *follower* will decide to follow its *leader* at a given time step and will not try to move away from the *leader*.

As obedience decreases, the makespan of evacuation, that is the time until all agents are in a safe zone, increases significantly. We observed that disobedient followers are not only losing their leaders but are also interfering with other swarm hindering their evacuation which causes congestions and slows down the evacuation even more.

Conclusion

Our hierarchical multi-agent system combining conflict-based search and local behavior of agents provides a tool for studying the evacuation process. The system can identify the impact of various parameters such as the obedience of locally controlled agents or the quality of search performed by centrally controlled agents on the success of evacuation.

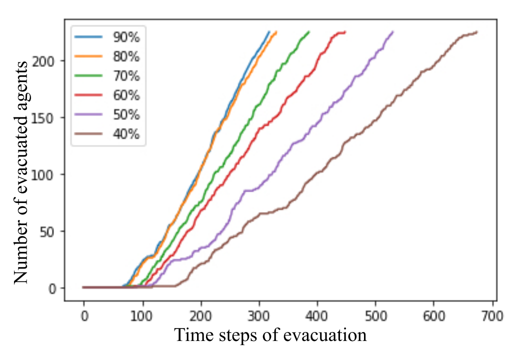

Figure 3: The impact of the obedience parameter

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