WALK: A Modular Testbed for Crowd Evacuation Simulation

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Abstract. When large numbers of people gather in public spaces such as stadiums, railway stations, shopping centers and concert halls there is an increased risk of mass emergence and disasters. Critical situations could possibly be prevented with appropriate tools to anticipate them. WALK is a modular designed crowd evacuation simulation system using a multi-agent approach.

One major goal of WALK is to provide a framework for the simulation and comparison of different socio-psychological theories to gain essential insights about the emergence of crowd behavior. Moreover, the framework is supposed to allow the simulation of many diverse scenarios. In order to achieve these goals, the system has to offer a maximum level of flexibility by following software engineering best practices. In this paper, we will explain the customizable architecture of WALK, which enables scientists from different fields, e.g. psychology and computer science, to use it as a testbed for their studies.

Keywords: Crowd simulation, multi-agent system, pedestrian evacuation

1 Introduction

Latest occurrences like terrorist attacks and accidents at public mass events [e.g. 1] have indicated a demand for efficient evacuation concepts. Due to the fact that field tests of crowd evacuations are not feasible and in most cases plain impossible, evacuation concepts are tested using computer simulation systems. There are many different approaches for simulating crowd behavior: Flow-based and gas-kinetic approaches, social force models and cellular automatons [e.g. 2, 3]. Although these approaches are adequate to show crowd movement, they do not facilitate the simulation of divergent individual behaviors caused by personality traits or emotions. The currently most promising and most commonly used approach is to simulate human beings as agents within a multi-agent system. It allows the simulation of individuals on a microscopic level, whereas crowd behavior is not explicitly defined but emerges from the sum of the agents' individual decisions. This seems to be the most natural way for modeling persons.

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In many simulation systems, there is spent little effort in the system design. As a consequence these systems are inflexible and tightly bound to specific well-defined scenarios. The agents are most often designed to show just one particular aspect of human decision-making in detail. This can produce realistic human-like behavior in a single scenario, but does not work for different ones [4]. There is a lack of a more generic system that can handle diverse scenarios and enables testing of different socio-psychological theories.

The goal of WALK is to fill this gap and to be usable for many areas of application. For that reason, the system is based on a flexible architecture which follows proven software engineering principles. It comprises two levels where flexibility is crucial: First, the overall system should allow the definition and simulation of different scenarios with differing environment complexity and crowd sizes. As we want to simulate small crowds with hundred agents up to large-sized crowds with thousands of agents, the system must be scalable. To achieve this, we will implement a distributed multi-agent simulation system. Second, the agents have to be composed of different components for decision-making, socio-psychological aspects and action. This enables WALK to be applicable in two different ways:

- By its scenario-independent and extensible design, it can serve as a tool for civil protection in governmental institutions. It can be used to prevent or analyze crowd accidents and evacuations in different situations.
- As it is open towards different socio-psychological theories, WALK can serve as a testbed for studies of psychologists, social scientists and computer scientists in fundamental research.

This work shows the WALK architecture on the two levels mentioned above and points out the benefits of our design decisions. In section 2 some essential socio-psychological factors are described. Section 3 explains the architecture on the overall system and the agent level. In section 4 we describe our development methodology, which ensures the system to be as general as possible. In section 5 the current state of the system and open issues for future research are discussed.

2 Psychological Aspects

Crowd behavior occurs in a wide range of situations. Science still tries to understand crowd phenomena und to explain why and how crowd behavior patterns emerge. There is no unified socio-psychological theory about crowd behavior in emergencies. Scientists differ in their opinions regarding typical behavior of individuals, their rationality or emotionality [5], psychosocial vulnerability (e.g. 'selfishness', mass panic) or collective resilience (e.g. help, unity) in critical life-threatening situations [6].

One of the main insights of research in the last years is that crowd behavior is affected and generated by the sum of individual decisions. In other words, each individual responds to and is affected by a situation in his or her own way [6]. On the other hand the role of the social context, the surroundings and dynamics are decisive. Specifically, the motives, goals and behavior of a person are influenced by the physical environment (e.g. stairs or a fence), the social surroundings (strangers, friends or family) and the internal state of the person (cognitive and emotional, e.g. being afraid or curious) [7].

It is hardly possible to study crowd behavior under real circumstances. Systematic studies of human behavior in critical situations and quantitative theories capable of predicting crowd dynamics are rare. Due to the ethical implications of such research, it is not possible to reenact a disaster or mass over-crowding. Thus, the behavior of people panicking under these circumstances is difficult to observe. As a consequence, computer simulations seem to be the most promising approach to validate different theories and to facilitate a confident management of mass evacuations.

Many computer scientists have modeled human factors, e.g. emotions and personality, into their agents. Often they have utilized very mathematical or logical approaches because these fit to our way of thinking. Many systems use the emotion model of Ortony, Clore and Collins [8] due to its clear and structured definition. As it is structured like a tree, it is well-suited for computational models even though it has some drawbacks: It describes what emotions are and under which circumstances they arise but does not explain how behaviors in critical situations emerge from specific emotions, which is crucial for the correct implementation of a crowd simulation.

3 System Design

For enabling WALK to simulate a wide range of different scenarios and for testing and comparing different socio-psychological theories, a carefully considered and flexible system design is required. In this section the WALK architecture is described on the overall system and the agent level.

3.1 Overall System

In order to provide a customizable and scalable simulation system, we designed a distributed message-oriented architecture. One requirement to WALK is to allow the simulation of large-sized crowds with low communication and management overhead for the agents. Another important requirement is the ability of developing new components for the simulation system in a team in parallel and integrating them into the existing system.

To reach these goals, we propose a service-oriented architecture with independent components communicating over a high speed message bus, the *WALK Communication System*. It distributes all messages among the components of the simulation. By applying this design, a tight coupling between the components is avoided and single modules can be replaced easily without affecting the remaining system. New components can be added without much effort. In addition, the system can be distributed to many physical computers, which results in scalability and enables the simulation of thousands of agents simultaneously. We are currently researching the potentialities of an efficient collocated partitioning. Figure 1 shows the overall system design with the *WALK Communication System* as its central component.

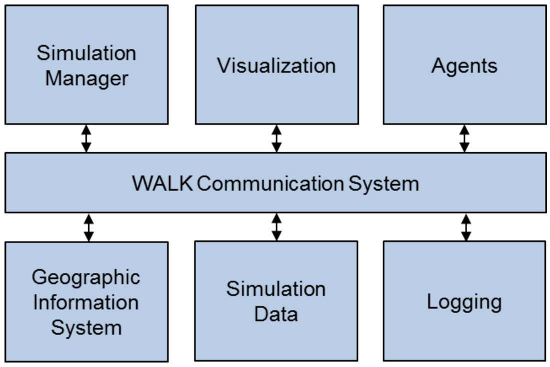

Fig. 1. WALK overall architecture.

Each module in WALK is responsible for just a single task, whereas complex tasks are accomplished by components communicating with each other. By this design, we reach a high degree of cohesion and ensure a simple maintenance and extension of our system. This aspect is crucial as WALK is still under development and refined permanently.

All simulation data will be stored in a database in a common data format. This will allow the replay and visualization of once computed simulation runs on different devices, e.g. desktop PCs, tablet computers and smartphones. Moreover, stopping and restarting the simulation at an arbitrary point in time will be possible. This will enable users of the system to take a particular situation from a recorded simulation run, alter agent parameters and the environment, start a new simulation run with these settings and observe the impact on the simulated course of events.

As mentioned before WALK is able to simulate different scenarios that differ in environment complexity, events and agent groups. To ensure this, no scenario-dependent information is stored directly in the system. The simulation is configured by a scenario definition, which includes a complete specification of the environment, occurring events and agent groups or single agents. Moreover, the environment is stored as geographical data in a *Geographical Information System*, which will use data from Google Maps or NASA Maps in the future. It is capable of storing indoor and outdoor areas. Events can be defined to occur once at a specified instant of time in the simulation or repeatedly within a specified time frame. Examples for such events are the start of a fire at a specified position in the environment or a fire alarm. At last, agent groups or single agents together with their positions and basic parameters, e.g. age distribution and personality types, can be added to the scenario definition.

All these factors enforce a maximum of flexibility and scenario-independence on the overall system level. By this, we reach the first goal of WALK to be able to simulate various scenarios and to be applicable as a tool for the prevention and analysis of crowd emergencies in civil protection.

3.2 Agents

While many simulation systems use an agent-based approach, there are few noteworthy approaches for a general agent architecture that follows proven software engineering principles and enables the modeling of human factors [4]. WALK agents are equipped with a simple, component-based design. By considering socio-psychological factors, e.g. emotion, personality traits and social behavior, our agents are supposed to show realistic human-like behavior. The aim is to create a universal agent architecture, which allows the realization and test of different socio-psychological theories in an easy and experimental way. This testbed will be used together with an incremental development method in cooperation with scientists from different research areas, e.g. psychologists and social scientists, to gain insights about the emergence of crowd behavior and its simulation.

Discoveries in behavioral research have shown that every person in an emergency situation runs through a cycle of perception, interpretation, decision-making and action [9]. This cycle is implemented in the WALK agents. In each phase there are different components involved, which contribute to the process of the agents' decision-making. The agent design is also inspired by cognitive agent architectures like ACT-R [10] and C4 [11] and adapts some of their concepts.

All components interact via a memory which stores all currently important information for the agent's reasoning cycle. It also includes a declarative memory for long-term knowledge, e.g. the building structure, and a procedural memory for knowledge about actions, e.g. how to open a door. Due to the fact that all modules within the agent communicate via the memory, we enforce a loose coupling between them. This structure is similar to the one of the overall system and allows us to develop WALK in an experimental way: As any component can be replaced easily, we are able to implement different socio-psychological theories and compare them with each other. As a consequence, WALK can be used in the second application area mentioned above: As a testbed for fundamental research in the area of psychology, social and computer science. A blueprint of the current agent design is shown in figure 2.

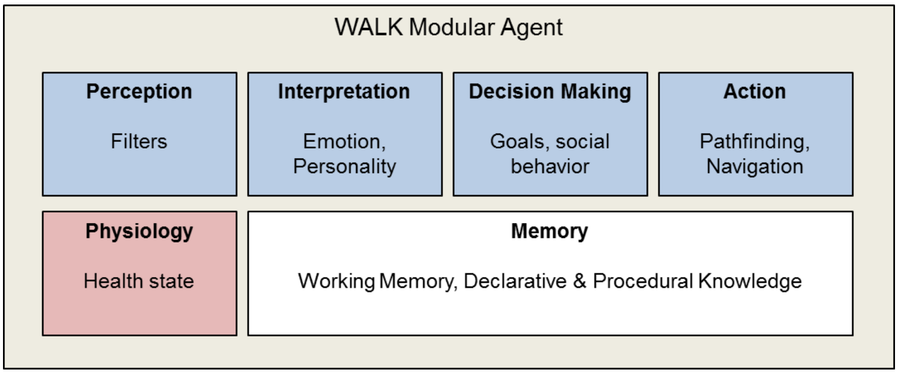

Fig. 2. WALK Agent Architecture

This design enables us to evaluate the impact of different human factors on the emergence of typical crowd behavior in the simulation. For instance, we are able to replace the *Interpretation* component or one of its subcomponents and thus change the way a situation is appraised and an emotion arises in the agent. Due to the fact that there is no unified socio-psychological theory about crowd behavior, we are able to approximate realistic agent behavior in an experimental way by trying different theories.

There are few approaches to simulate social factors, like the theory of social comparison [12]. As social factors are vital for the realism of a crowd simulation, there is demand for further research. We will respect these factors in WALK just as emotions and personality to gain insights about their impact on the simulation results.

4 Development Methodology

The development of a generalizable and scenario-independent simulation system is a great challenge and requires a special approach. We propose a development methodology including steady validation and improvement. This will help us to address the most common problems in crowd behavior modeling: Tight coupling to a specific scenario and insufficient validation techniques [4].

In cooperation with the supervisory school authority in Hamburg, Germany, we collect data from real evacuation drills in schools. By defining the exact school geometry in WALK, we are able to simulate the school evacuation in the system and compare the results to the collected data from the real drill. Data is collected by filming critical areas of the building, e.g. main exits, during the drill and analyzing the video material to identify movement patterns and trajectories of single agents. In addition, anonymized surveys and location systems based on RFID and WLAN are used to track single individuals.

Our development cycle contains prototyping, permanent validation with data from real evacuation drills and gradually improvement. First, psychologists and social scientists form hypotheses about individual and social behavior in a given situation. They serve as "domain experts" and explain relevant theories to computer scientists, who translate these theories into computational models. After that, real evacuation drills are performed and all relevant data is collected. It is then compared to the simulation results. As a consequence, we can use the insights for our next development cycle and refine the system. As there is no "right" way to design the agents and to equip them with socio-psychological factors, this approach ensures a steady reconsideration of our system design, which leads to more generality.

By the application of this analysis-implementation-validation-cycle in cooperation with psychologists and social scientists false assumptions get obvious in an early stage of development and can be corrected immediately. It will help to create a simulation system that is not bound to a particular scenario and approximates realistic human-like behavior gradually.

5 Discussion

The Commission on Civil Protection of the German Federal Ministry of Interior has recently published its latest report on current threats to the public [13]. The report covers a broad spectrum of threats starting from CBRN (chemical, biological, radiological, and nuclear) over to terroristic attacks and the impacts of global change. It does not only reflect the scientific opinion of the commission, but also outlines main results of a synopsis of similar reports from an international point of view.

From that it becomes very obvious that high-quality software tools to support all phases of civil protection and homeland security are urgently needed. But it should be noted that every phase requires specific priorities. For instance, in prevention and training scenarios the sensitivity, variability, and the context of state variables are important, whereas in disaster management performance issues come to the fore.

The WALK system was developed and is under development in tight cooperation with the commission and with other stakeholders of disaster management in Germany. Beside interdisciplinary research issues the applicability and scalability of the generic framework is one of the key goals.

The basic simulation framework is realized and provided with simple agents. Socio-psychological factors are not implemented yet. We are currently preparing the first real evacuation drills in schools. Due to the fact that we are performing the first development cycle at the moment, we have to deal with many questions concerning suitable tracking technologies and data privacy issues. With each cycle performed our system will evolve and also the methodology will get more mature and effective.

Open research issues are the up-scaling of the simulation and an efficient distribution of the system to a cluster of computers. As we want to simulate evacuation scenarios for cities with hundreds of thousands of inhabitants, a partitioning of the system and a dynamic adaption to the necessary level of detail in a simulated scenario will be required. These issues will be considered in detail in further research.

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