A Multi-Agent Simulation Framework for Emergency Evacuations Incorporating Personality and Emotions

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Abstract. Software simulations of building evacuation during emergency can provide rich qualitative and quantitative results for safety analysis. However, the majority of them do not take into account current surveys on human behaviors under stressful situations that explain the important role of personality and emotions in crowd behaviors during evacuations. In this paper we propose a framework for designing evacuation simulations that is based on a multi-agent BDI architecture enhanced with the OCEAN model of personality and the OCC model of emotions.

Keywords: Multi-agent Systems, Affective Computing, Simulation Systems

1 Introduction

Evacuation simulation systems [1] have been accepted as very important tools for safety science, since they help examine how people gather, flow and disperse in areas. They are commonly used for estimating factors like evacuation times, possible areas of congestion and distribution amongst exits under various evacuation scenarios. Numerous models for crowd motion and emergency evacuation simulations have been proposed, such as fluid or particle analogies, mathematical equations estimated from real data, cellular automata, and multi-agent autonomous systems. Most recent systems adopt the multi-agent approach, where each individual agent is enriched with various characteristics and their motion is the result of rules or decision making strategies. [2, 3, 4, 5].

Modern surveys indicate that there is number of factors [8, 9] influencing human behavior and social interactions during evacuations. These factors include personality traits, individual knowledge and experience and situation-related conditions like building characteristics or crowd density, among others. Contrary to what is believed, people don't immediately rush towards the exits but take some time before they start evacuating, performing several tasks (i.e. gather information, collect items) and look at the behaviors of others in order to decide whether to start moving or not. Also route and exit choices depend on familiarity with the building. Preexisting relationships among the individuals also play a crucial role upon behavior as members of the same group like friends and members of a family will try to stay together, move with similar speeds, help each other and aim to exit together. Additionally, emergency evacuations involve complex social interactions, where new groups form and grow dynamically as the egress progress. New social relations arise as people exchange information, try to decide between alternatives and select a course of actions. Some members act as leaders, committed to help others, by shouting instructions or leading towards the exits while others follow. [10]

Although individuals involved in evacuations continue to be social actors, and this is why under non-immediate danger, people try to find friends, help others evacuate or even collect belongings, stressful situations can result to behaviors like panic. [11] During an emergency, the nature of the information obtained, time pressure, the assessment of danger, the emotional reaction and observed actions of others are elements that might result to catastrophic events, such as stampedes.

The authors claim that above factors and their resulting actions should be modeled, for realistic behaviors to emerge during an evacuation simulation. The proposed approach takes in consideration recent research not only in evacuation simulation models but also in multi agent system development [7], cognitive science, group dynamics and surveys of real situations. [8] In our approach, decision making is based on emotional appraisal of the environment, combined with personality traits in order to select the most suited behavior according to the agents' psychological state. We introduce an EP – BDI (Emotion Personality Beliefs Desires Intentions) architecture that incorporates computational models of personality (OCEAN) and emotion (OCC). The emotion module participates in the appraisal of information obtained, decision making and action execution. The personality module influences emotional reactions, indicates tendencies to behaviors and help address issues of diversity. Additionally we use a more meaningful mechanism for social organization, where groups form dynamically and roles emerge due to knowledge, personality and emotions. We claim that these additions may provide the necessary mechanisms for simulating realistic human like behavior under evacuation. Although the need for such an approach is widely accepted, to our knowledge no other evacuation simulation framework has been designed incorporating fully integrated computational models of emotion and personality.

2 The Proposed Framework

The proposed agent architecture (Fig.1) is based on the classic BDI (Beliefs-Desires-Intentions) architecture enriched with the incorporation of Personality and Emotions. The agent's operation cycle starts with the *Perception* phase, where the agent acquires information on the current world state through its sensory subsystem. Depending on the agent's emotional state at the time, its perception may be affected and some information may possibly be missed.

The newly acquired information is used to update the agent's *Beliefs*. Based upon its new beliefs, the agent performs an appraisal process, using its personality and its knowledge about the environment in order to update its emotional state. The agent's *Decision making* process follows, where current conditions, personality and agent's own emotional state are synthesized in order to generate a *Desire.* This desire is fulfilled through an appropriate *Intention,* which will be executed as a ground action in the simulation environment.

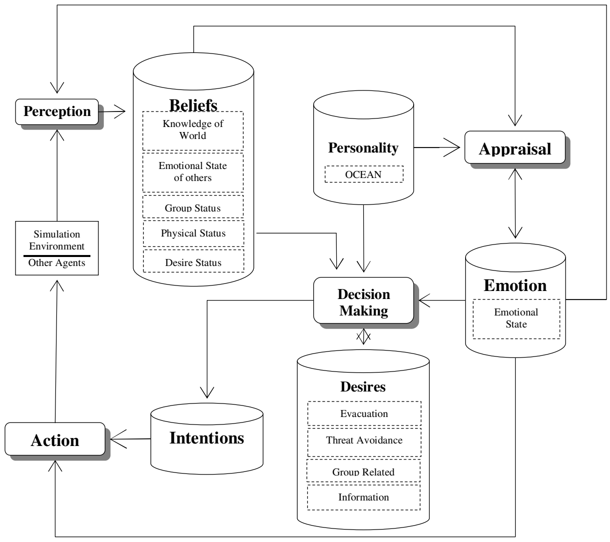

Fig. 1. The proposed agent architecture

The personality model adopted in the proposed framework is the Five Factor Model [12], also known as OCEAN by the initials of the five personality traits it defines: Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism. Every agent considered to possess the above characteristics in varying degrees and is assigned a personality vector, instantiated with values representing their intensity. It has been shown in psychology research that personality and emotion, although distinct concepts, are closely interdependent and there is a link between personality and types [13]. Based on this premise, the proposed architecture follows an original approach in evacuation simulation systems, by closely intertwining the functions of emotion and personality, in practically every step of the operation cycle. The emotion model adopted is based on the OCC model and particularly its revised version, as presented in [14]. In the current approach, we model five positive/negative emotion types, the first of which is an undifferentiated positive/negative emotion, as coupled emotion pairs: Joy/Distress, Hope/Fear, Pride/Shame, Admiration/Reproach and SorryFor/HappyFor. The first three emotions concern the agent itself, while the last two focus on other agents. Each agent is assigned a vector representing its *emotion status* at a specific temporal instance of the simulation.

Agents can perceive objects, events and messages through sensors and update their beliefs accordingly. Their initial beliefs include at least one route to the exit, i.e. the route they followed entering the building, and, besides imminent perception, they may acquire knowledge about other exits or blocked paths due to the exchange of messages. Agents can also perceive the emotional state of others, which may impact their own emotions as well. The agent's own emotional state may influence perception, affecting an agent's ability to notice an exit sign or an obstacle. Relationships between agents like reproach or admiration may cause a communication message to be ignored or accounted as truth respectively.

Perceived events, actions and information from the environment are appraised according to their consequences on the agent's goals, and the well being of itself as well as other agents. All events, negative or positive, affect one or more of the agent's emotions, in a varying degree, according to its personality. The level of influence a particular event may have on the agent's emotional status depends on its evaluation, the agent's personality, and an association matrix that links personality traits to emotions. This drives the agent into an, intermediate emotional state that affects the agent's appraisal of the actions of other agents. Attribution-related emotions (pride/shame, admiration/reproach) are updated by evaluating the current desire's achievement status with respect to an emotional expectation that is associated with each desire. Finally, the agent's emotional state is updated with the calculated impact. This process is repeated for all events newly perceived.

Every agent has a number of competing desires each of which is assigned an importance value. This value is affected by the agent's emotional state, personality and by his beliefs about the state of the environment and of its group. These desires have been determined by surveys on human action during emergency situation [8] and include: a) move towards an exit, b) receive information, c) transmit information d) join a group, e) maintain a group f) expand a group and g) avoid threat. Each of these is assigned a set of activation conditions and they can become active only if these conditions are met. Once the decision process starts, the activation conditions of all desires are checked and the valid desires are determined. The agent, in every cycle, will try to accomplish the desire with the highest importance value. This value is calculated as the weighted sum of two independent values, one calculated from the agent's personality and one from his current emotional status. The first is produced using an association matrix that relates specific OCEAN profiles to personality-based importance values for each desire. The relative distance of the agent's personality value to the profiles in the association matrix determines the personality-based importance value that will be assigned to the active desires. On the other hand, emotion-based importance values are assigned according to agent's current emotional state and the expected emotional outcome, if the desire is fulfilled.

Once an agent is committed to pursuit a desire, a list of possible intention for its fulfillment becomes available. For example "evacuate" desire can be translated to either "move to known exit" or "search for exit" and "follow exit sign". The selection of the most appropriate intention depends on current knowledge of the world. Choosing an intention translates to basic actions like walk, run or wait, which are affected by the emotional state. For example, agents in a state of panic will be less careful in terms of keeping their personal space and they will not decrease their speed significantly when approaching other agents, leading to inappropriate and dangerous behaviors, such as pushing.

Social interactions are modeled through group dynamics. There are two types of groups; static groups representing families and friends that don't change during the simulation and emergent groups. The latter are formed during the simulation based on agent's personality, evacuation experience, message exchange, and relationships established between agents. This relationship once is established is evaluated by terms of achieving a goal, keeping safe and maintaining personal spaces. The size of the groups is also an important factor influencing the merging of nearby groups.

3 Simulation Environment

The authors have set up a simulation environment of fire evacuation as an implementation of the proposed framework. The environment is a continuous 2D space in which all static elements are represented as polygonal obstacles and the fire is modeled as a set of expanding regions. The initial agent population, the demographic and personality distribution and the position and spread parameters of fire are user-defined. Agents have individual visual and aural perception abilities and can detect the alarm sound, other agents, the fire, exit signs and exits. They are equipped with a short term memory, which they use to remember the last observed position people and elements that are no longer in their field of view. The visual and aural perception abilities of each agent can be temporarily reduced due to its current emotional state and crowd density. The agents can demonstrate a variety of goal-oriented behaviors. They can *explore the environment* in search of the exit, a specific group or a specific person; they can *move individually*, such as following an exit sign or moving to a known exit, or they can perform *coordinated motion behaviors*, such as following a group or waiting for slower group members to follow. These behaviors are selected according to an agent's desire with the highest priority and the associated intentions it is committed to. Agents may get injured or die during the simulation if they are found in areas of great congestion or if they find themselves very close to the fire.

The authors ran of a series of scenarios under a variety of initial conditions to test the simulation results and to evaluate the proposed framework. The initial tests showed a number of promising results. Emergent groups were formed during evacuation time, due to agents taking the role of a leader and inviting other agents to follow. Some members abandoned the groups because of an increase in anger towards the leader, e.g. due to a series of observed negative events, such as injury of group members or close proximity to the fire. The sight of fire and the time pressure caused an increase in negative emotions, such as fear and distress, and some agents demonstrated non-adaptive pushing behavior. This behavior was appraised negatively by other observer agents, causing distress to spread through the crowd population and leading to an increased number of injuries. Furthermore, the perception of the alarm sound caused agents to seek information about the emergency and to exchange messages with each other about exit routes and fire location. Missing members of preexisting groups caused other group members to search for them, often ignoring bypassing groups and moving to opposite directions.

4 Conclusions and Future Work

We presented a simulation framework for crowd evacuation that incorporates computational models of emotion and personality in order to generate realistic behaviors in emergency scenarios. The proposed approach is based on research results about the actual crowd responses observed during real emergency situations or drills. The initial implementation results demonstrated the ability of the simulation platform to generate a variety of behaviors, consistent with real life evacuations. These include emergent group formation, bi-directional motion, altruistic behaviors and emotion propagation.

Future work includes further research in emotion models and appraisal theories to formalize the decision making mechanism under evacuation scenarios. Further study of the complex social processes, characterizing group dynamics is also needed. Furthermore, we are planning to run a series of case studies using various age and personality distributions and to compare the results with published data from real emergency evacuations in order to evaluate the validity of the proposed framework.

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