A Multi-agent based Approach to simulate Uncertainty of a Crowd in Panic with Sharable Ontologies

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***Abstract*— Crowd simulation is listed under many practical applications in computer industry; such as safety modeling, pre-planning building architectures, urban modeling and entertainment software. Most of these existing simulations are created by implementing computer algorithms based on extending deterministic models such as particle systems, clustering, cellular automata and fluid motion. However, extending a crowd model to simulate uncertainty of crowd behaviour during panic still remains a key challenge; since a computer algorithm approaches a solution by parameterizing predictable elements within a problem.**

It is evident from literature about the proven success of multi-agent technology behind modeling complex systems; comprising of many distributed entities interacting with each other and operated under lot of uncertainty. Thus it can be postulated that multi-agent technology provides a basis to model the uncertainty raised within a crowd during panic. Our proposed solution simulates this uncertainty by considering evacuation of a crowd from a building during fire. Each individual in the crowd is modeled as an agent associated with a local ontology. The local ontology of an agent is a collection of rules, representing the knowledge known to each individual prior to occurring fire. Rules embedded within local ontologies are shared among individuals as they interact with each other. As a result non-anticipated global behaviours arise within the crowd leading to emerging uncertainty during fire. Output of the system is a visualization of crowd behaviour during fire with recorded statistics. The statistics recorded during each simulation session indicate evacuation related information per each individual; providing a basis for evaluation by comparison with real world observations.

***Keywords*— Emergence, Multi Agent Systems, Sharable Ontology, Crowd Simulation, Crowd Behaviour**

1. Introduction

A crowd can be defined as a large group of individuals residing within some physical environment[1]. Crowd modeling is one of the most interesting research areas in computer simulations; focusing on how to simulate the behavior of each individual, in order to generate a resultant behaviour for the entire crowd. Owing to their different approaches, existing studies on real world crowd behaviour under different contexts[4][6][7] and developing a crowd simulation model based on recorded observations from these studies[1][2][7] are quite distinctive to each other. Yet a difficulty lies behind extending an existing crowd simulation model to support panic; where every individual must quickly adapt with unpredictable surroundings [1][2]. The major reason for this challenge is that; conventional approaches behind developing existing crowd simulation models concentrate on forming a predefined method or an algorithm by observing a predictable pattern in the crowd for a given scenario.

Panic behaviour of a crowd during an emergency is a decentralized process involving lot of uncertainty which can't be predicted beforehand. An example is how people in a building would immediately evacuate during a fire [2]. In most cases a single crowd may cluster into asymmetrically distributed subgroups. This happens due to arbitrary actions done by individuals for survival during fire in which they even aren't aware of. Therefore the real problem arises when attempting to model uncertainty of a crowd in panic by using a deterministic approach such as algorithms.

Multi-agent technology [9] provides a basis for developing solutions for decentralized systems involving a lot of uncertainty. Special characteristics of multi-agents such as communication via message passing combined with emergence could be used as a base to model an unpredictably changing physical environment with uncertain individuals. Therefore, individuals in a crowd can be modeled as agents having certain perception about their vicinity with their own limited knowledge? These individuals can be made to communicate among themselves, share each one's incomplete knowledge and let overall crowd behavior "emerge" due to interaction [9][10].

The rest of this paper is organized as follows. Section 2 reports observations from real world crowd behaviour studies during panic and reviews existing crowd simulation models. Section 3 states relevance of multi-agent technology with crowd simulation. Section 4 describes multi-agent based knowledge sharing approach behind emerging uncertainty in a crowd during panic. Section 5 elaborates design of the multi-agent based crowd simulation model. Section 6 describes about the implementation. Section 7 focuses on evaluation while Section 8 stating final conclusion with further work.

2. Crowd Behaviour, The State of The Art

This Section attempts to, (i) discuss general observations from studies based on real world crowd behavior under panic and (ii) study underlying concepts behind developing a crowd simulation model; hence identifying the limitations behind extending a crowd simulation model to support uncertainty of crowd behavior during a panic.

A. Studying Crowds under Panic: General Observations

Studies by Helbing et. al. [3][4] state that following characteristics can be found within a pedestrian crowd under panic. (1) People try to move considerably faster than normal, (2) Individuals start pushing, and interactions become physical. (3) Moving (especially passing a bottleneck) becomes uncoordinated. (4) Arching and clogging are observed at exits (5) Jams build up (6) Physical interactions in jammed crowds build dangerous pressures able to bend steel barriers or push down brick walls (7) Escape is slowed by fallen or injured people acting as 'obstacles' (8) People show a tendency towards mass behaviour (doing what other's do). (9) Alternative exits are often overlooked or not used in escape situations.

Helbing et. al. [4] further reveals that, the strategy for escape from a smoke-filled room, involves a mixture of (1) individual behaviour and (2) “herding” instinct. Individual behaviour refers to irrational behaviour within individual in panic, especially with scarcity of resources (limited time and limited space for exit). Collective “herding” instinct refers to mass behaviour (i.e. tendency to follow what others do, without thinking is it correct or not). Together, these 2 tendencies cause an un-coordinated motion among individuals during exit, which is the root cause for developing jamming, arching, clogging plus injuries due to crowd interactions.

A study by Nishinari et. al. [7] reveals that the behaviour within group of a ants, reaching a certain destination exhibit similar characteristics to the individual behaviour of humans. Just like each ant used to follow its predecessor ants; humans too tend to follow other humans in a crowd for efficient and safe walking. Ants communicate with each other by dropping a chemical called “pheromone” on the ground as they move forward. The pheromone sticks to the ground long enough (i.e. before getting evaporated) for the other following ants to pick up its smell and follow the trail [8]. In terms of an emergency; humans also tend to follow trails left by predecessor humans for reaching emergency exits or safe places. Similar to pheromone emitted by an ant getting evaporated after some time, trace opened with movement of a predecessor human is closed in quick time due to the rapid movement of individuals and entities in the environment during panic.

Fleya et. al [6] argues that for an individual in a crowd under panic making a decision between adherence to social norms versus going by selfishness; is not only based on scarcity of resources but also pre-known historical context. The study was based on recorded survival statistics during sinking of 2 ships, Titanic and Lucitania. For evacuation from Titanic, social norms took over selfishness. Since it was pre-stated as “Titanic is unsinkable”, passengers anticipated that they will be rescued. During entering life boats; first class passengers, women and children were preferred over others. Abidingby social norms made Titanic sank slowly(on 14th April 1912 for 2hrs and 40mins). Lucitania sank after Titanic (on 7th May 1915 in 18 mins). For Lucitania, scarcity of time along with pre-known historical context on lesser chance for survival, made no emerging in social norms, but selfishness among passengers.

B. Crowd Simulation Models

With the overview from Section 2 Aon real-world crowd behavior during panic; this section focus on existing crowd simulation models and their underlying concepts.

C. Reynolds [11] developed a method for simulating a crowd such as school of fish/flock of birds using particle systems, where each individual in the crowd is treated similar to a single particle within a particle cloud. The major focus of this simulation model is about the motion patterns of the crowd by leading it towards reaching for a specific location as the final target, similar to particles in a cloud flowing along the wind direction. Therefore the motion of a specific individual is always directed towards achieving the final destination.

D. Terzopoulos [12] developed a method to animate crowd behaviour based on modelling each individual in a crowd with capabilities to percept its surrounding environment. The behaviour of each individual is achieved by defining a predefined set of behaviour patterns for a predefined set of sensory inputs. For instance, modelling a school of fish in water; sensory inputs are temperature and vision (to identify surrounding objects). Predefined behaviour patterns are finding food when hungry, avoiding areas with high temperature and avoiding collisions with other fish.

S. R. Musse and D. Thalmann [1] proposed a method to simulate human crowd behavior by identifying inter-group relationships between individuals and mapping these relationships within local and global set of goals formed according to the needs of each individual. This research uses people who visit a museum as its model example. In a museum artifacts belong to certain groups are categorized and separated into areas/rooms. People with same interests gather around these separate rooms/areas forming clusters within the crowd, where each cluster of people has similar interests.

Cherif Foudil [2]argues that the behavior of any crowd is significantly different in terms of a normal situation comparing to a situation in panic. This argument is supported by Helbing's study [3] in terms of simulating pedestrian crowds, where it is clearly identified that crowds demonstrate completely different characteristics in normal and panic situations.Therefore according to Foudil's model, in normal situations a crowd consists of groups of individuals and crowd behavior is distributed to groups followed by individuals. However in terms of panic situations, the concept of a group is lost and all individuals are expected to work for themselves based on their basic instincts and group around exit points.

Further Foudil [2] argues that modeling a crowd as a collection of particles (where each individual is a particle) improves realism in panic situations comparing to fluid-based approach (where crowd movement is considered analog with the fluid flow) followed by some crowd simulation models [3]. The reason is that suppose there are 2 exits in a room, clogging individuals among one of the exits occur due to their unexpected behavior during panic, whereas in a fluid-flow model will divide the loads of the crowd uniformly among the 2 exits; so that this won't reflect the realistic behavior.

Nishinari et. al. [7] extends their study of crowd behavior (described under Section 2 A) and proposes cellular automata based grid model with the concept of "pheromones". The grid represents spread of pheromones within an area. Each cell in the grid either has a pheromone or free of pheromones. Further each cell will have one or more ants. Any ant decides its next direction of movement based on spread of pheromones in its neighboring cells. The argument is that just like temporary traces are created when pheromones fall and disappears when pheromones evaporate, in a similar manner temporary routes towards exits are created and vanished within an evacuating crowd in panic.

C. Multi-Agent based CrowdSimulation Models

With the dawn of multi-agent technology [9] (discussed under Section 3) as a new paradigm to model intelligence in simulations, several attempts have been made to simulate crowd behaviour by modelling individuals within a crowd as agents.

MASSIVE [16] is a commercial software product used for generating crowd related visual effects and autonomous character animation. It has been originally built for a crowd simulation scenario related with "Lord of the Rings" film series and since adopted as well-known crowd simulation software in film industry [16]. From the available information [16] about the internal architecture of MASSIVE, each individual in a crowd is modeled as an agent, and variety of configuration options are available to configure rules for the agents based on conditions related with his/her vicinity. Further within a 3-dimensional virtual space, the user can configure the paths and directions which a certain group of people must follow. Hence the software will simulate the group behavior of individuals based on the motion paths being pre-configured. Therefore the agent implementation of MASSIVE can be concluded as a goal-based agent [17] where the goal is to follow to the destination via the closest defined path.

Ana Luisa et. al. [18] proposes an agent-based model to simulate a pedestrian crowd in a corridor as a tool to observethe behavior of human crowds in, routine and crisis situations. This simulation model combines the ideas from kinetic theory of living systems with ideas from the field of computational agents. Kinetic theory is used to setup global parameters for the crowd simulator such as crowd density, step size and defined paths. In Luisa et. al. [18] model; based on parameters such as pedestrian density and time left to reach the destination, the goal-based intelligent agent [17] (i.e. representing an individual in the crowd) will choose the most appropriate path among several available paths. Based on the perception about the vicinity, the individual (i.e. goal-based agent) might anticipate or give the chance to an action done by another individual, prior to executing his/her selected action.

D. Key Challenge in Extending Crowd Simulations to support Panic Behaviour

For simulating crowd behaviour, different models are proposed based on different concepts with the intension of reproducing the same observations received by studies related to real-world crowd behaviour. Such discussed existing crowd simulation models included; (i) particle systems based crowd models [5][11], (ii) fluid flow based crowd models [2], (iii) cellular automata based crowd models [7] and (iv) clustering a crowd into groups based on similar interests [1]. These models look at a crowd from a macroscopic view (i.e. an overview of the crowd as a whole) and have developed algorithms to simulate crowd behaviours based on the respective approach. Although the above crowd models can simulate observations of crowd behaviour related with normal situations, their capabilities are limited in terms of simulating uncertainty of crowd behaviour during panic. The rationale behind this limitation is that; a computer algorithm always approaches a solution by parameterizing predictability within a problem, whereas crowd behaviour in panic involves a lot of uncertainty.

Existing Multi-agent based crowd models focus on modelling crowd behaviour from individual's perspective (i.e. comparing to macroscopic view/overview of crowd followed by conventional crowd simulation models). The approach is to build intelligence into the agent (i.e. individuals) by means of a pre-defined rule set and make the individual (i.e. agent) more perceptive to the changes of his/her surrounding environment. The individual selects the most appropriate action based on the current status of surroundings and his/her ultimate goal to be reached (i.e. goal-based agent [17]). The goal is predefined and given to the individual by means of proposed path to be travelled towards the destination. Thus goal-based agent approach proposed by existing agent-based crowd models doesn't fit well into the context of simulating uncertainty of a crowd in panic; since during panic, there aren't any predefined goals except survival.

Therefore the key challenge is how is it possible to simulate uncertainty of crowd behaviour during panic?

3. Application of Multi-agent Technology for Crowd Simulation in Panic

Multi-Agent Systems (MAS) [9] proposes a new approach to develop intelligent software comparing with conventional AI approaches (such as neural networks, expert systems and fuzzy logic). A MAS is made up of a large number of agents which interact with each other. Each agent has incomplete information and insufficient capabilities for solving a problem. In MAS there is no system global control (like in neural networks, expert systems) and data is decentralized with asynchronous computation. The key feature of MAS is that although each agent (or most of the agents) possesses incomplete information and insufficient capabilities; it's the interaction between these agents which enables a problem to be solved by each one of them. Due to interaction between agents within MAS, each individual agent receives ability to reason about non-local effects based on its or other agents' local actions, thus forming expectations based on the behaviour of others [9]. This results in emergence, where "emergent intelligence" is defined as ability to arise effective solutions to problems under conditions of uncertainty [10].

For applicability of above MAS concepts to simulate crowd behaviour in panic; consider a sample scenario about individuals evacuating from a building during a fire. There can be different personalities among individuals in the context of escaping from a fire; (1) normal person, (2) fire-warden and (3) security personnel. A normal person is not aware or minimally aware in terms of the quickest steps to be taken in case of a fire. Therefore he/she would have not more than common sense. However a fire-warden appointed for each floor would have a specific training on actions to take during a fire such as operating relevant fire extinguishers. On the other hand security personnel would not have a specific training for fire, but they will have access to information about all individuals in the building in each floor in a given moment, which a fire-warden is not aware of.

All these 3 personalities operate based on incomplete information. In terms of multi-agent technology we can model each individual as an individual agent and each individual will have an "initial local ontology" (i.e. an initial knowledge base) according to his/ her personality (i.e. a normal person, a fire-warden or a security personnel); regarding how to operate during a fire situation. But as time passes these agents will learn from each other (i.e. they will share each other's local ontologies/knowledge) and ultimately manage to solve the problem of evacuating from the building during fire, by emerging the crowd behaviour anticipated during a real fire situation.

4. An Approach with Multi-Agent based Knowledge Sharing for Crowd Simulation

The intention of this section is to discuss our approach behind forming a solution to simulate uncertainty of crowd behaviour during panic by enforcing knowledge sharing with multi-agent technology. The approach is initiated by defining input, process and output for developing our multi-agent based crowd simulator followed by identifying the set of features that can be provided along with the range of end-users who will be benefited from these features.

The input for our multi-agent based crowd simulator is the Environment Setup Information, which consists of 3 major input types (i) Fire Related Information, (ii) Exit Point Related Information and (iii) Individual Related Information. Fire Related Information is about the set of fire sources including origin point (i.e. location in the building) of each fire source corresponding to initially starting fire. Exit Point Related Information is about the list of exit locations (either regular doors or emergency exits) within the building.

Individual Related Information is the list of individuals currently residing inside the building. Each individual will consist of (i) his/her location in the building, (ii) individual type (whether he/she is a normal person or a fire warden), (iii) perception bounds value indicating the maximum range which he/she can directly communicate with other individuals and (iv) an assigned initial confidence level.

Upon request of the desired Environment Setup specified by the input, relevant agents will be created for (i) simulating individuals in the crowd and (ii) simulating spread of fire.

Output of the system include (i) rendering a visualization based on changes happening to individuals in the crowd and (ii) recording statistics based on time of exit for each individual from a given exit point of the building.

The main features provided by our crowd simulator include; (i) Configurable Environment, (ii) Statistics collected periodically in terms of individual exit and (iii) Graphical view of Crowd Simulation over time. A configurable environment includes defining; (a) multiple fire sources with their initiating locations within a building, (b) individuals with different personalities (i.e. normal person, fire warden, security guards etc.) within different locations of the building and (c) locations of exit points in the building. The simulator logs the exit of each individual from a given exit point against the time elapsed. This log of individual exits can be later used to (a) compare the validity of the simulation with available data for a real scenario, (b) derive inferences about the consequences in case a real scenario occurs based on the configured environmental setup. Finally the graphical view includes visualization on how individuals would exhibit panic behaviour and ultimately make their exit from the building as the fire spreads.

Our crowd simulator can be used by Building Architects and Security Managers. For instance an architect can be benefited by using the simulator to infer the behaviour of crowds based on the number and position of emergency exits in the system and decide the optimal places to establish the exit points beforehand during building design. A security manager can take decisions such as the numbers and placements of fire wardens, security cameras and security guards for optimal preparation of an existing building infrastructure in a panic situation.

5. Design of Multi-Agent Based Knowledge Sharing Crowd Model

This Section elaborates our approach further as a comprehensive design that can be used as the foundation for implementing a simulation model demonstrating a crowd in panic. Figure 1 provides an overview of the Multi Agent-based design for our proposed Crowd Simulation Model.

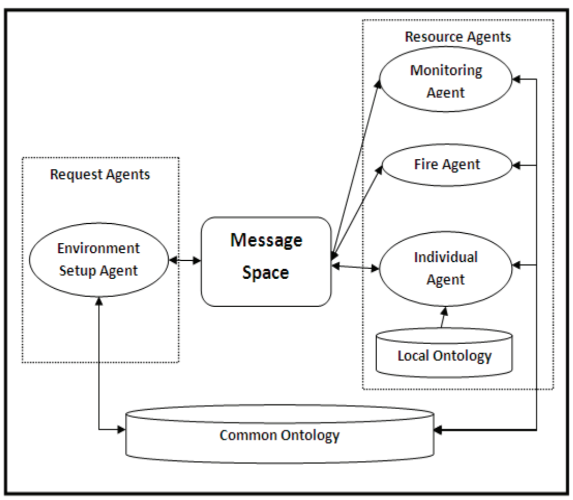

Figure1: Multi-Agent based Design for Proposed Crowd Simulation Model

Note that this design is constructed based on the resource-request-message-ontology architecture [17] proposed for developing multi-agent systems; indicating request agent types, resource agent types, ontologies and message space.

A. *Instantiation of Agents*

In any scenario there will be 1 instance from Environment Setup Agent type and 1 instance from Monitoring Agent type.

The Environment Setup Agent takes the input to the system (i.e. "Environment Setup Information" as described in Section 4) and triggers creation of relevant agent instances for all other agent types based on input.

The Monitoring Agent receives messages from individuals and fire sources within the simulation and records statistics for these messages based on the timestamp.

The number of instances created from Fire Agent type will be equal to the number of fire sources specified under "Environment Setup Information" provided by the input (as described in Section 4). The intention behind a Fire Agent is to simulate spreading of fire and increase in fire severity as time progresses.

Similarly the number of instances created from Individual Agent type will be equal to the number of individuals in the crowd as specified under "Environment Setup Information".

B. *Common Ontology*

The Common Ontology contains 3 types of information; about fire sources, individuals and exit points in the building. In other words, it is a representation of "Environment Setup Information" provided by the input. Note that, this Common Ontology is initialized by the Environment Setup Agent. Later Fire Agents and Individual Agents will update the Common Ontology periodically. Therefore we can conclude about the Common Ontology as a snapshot of the crowd simulator (i.e. individuals and fires) at a given time.

C. *Message Space*

"Message Space" provides the infrastructure for our Multi-Agent based Crowd Simulator to enable asynchronous messages between agents; which is an essential feature of a Multi-Agent System. Any message sent by any agent is dispatched to message space. The Message Space stores any message (sent by the sender agent) until its recipient agent queries and retrieves the message completely.

D. *Individual Agent*

During execution, any Individual Agent will refer to his/her own "Local Ontology" in addition to the Common Ontology. Further an individual agent may also update his/her Local Ontology, which implies learning over time from other individual agents. This local ontology of each individual is "initially" created according to the personality type for each individual. For example in case of our example scenario of evacuation from fire, we may think of 2 different types of personalities; normal person and fire warden. Therefore there are 2 templates to represent the pre-known knowledge of a normal person and a fire warden prior to occurring fire. A template is a collection of rules representing general actions those are possible by an individual having the personality focused by the template.logy maintains knowledge related to agents in the system.

E. *Local Ontology of an Individual Agent*

Each Rule within a local ontology of an agent consists of the components illustrated as in Figure 2.

ID is used as a unique identifier to represent each rule.

ID
Environment Mode
Sharability
Confidence Range
Priority
Action

Figure2: Contents inside a Rule

Environment Mode indicates the specific type of environment, which the individual must consider about applying these rules. The environment mode of the system will vary with time based on the changes of the environment encountered due to various activities happening in the system. For instance, in the case of evacuation from fire during a building, there can be 2 environment modes; Stable Mode (before fire starts) and Fire Mode (after fire has started and during fire).

Sharability indicates about the extent which the action specified by a rule can be shared by other personalities. For instance an action such as running towards an exit point can be done by any person. However an action such as using fire extinguisher can be done only by a person who has undergone some form of fire avoidance program (such as a fire warden).

The individual confidence level of each person will vary with time as the fire progresses. For instance the confidence level of a person is very low, when the fire is severe and the person is very close to fire. On the other hand the confidence level of an individual is high when fire is not severe and the individual is far away from fire. The Confidence Range of a rule indicates the minimum and maximum levels of confidence, which a particular individual will attempt selecting a given rule for execution.

The Action indicates how an individual will behave if he/she selects a rule based on rule selection criteria.

1) Rule Selection Criteria: Each individual agent will periodically select a rule (containing an action), from his/her local ontology. This rule selection will be based on; (i) Environment Mode, (ii) Confidence Range and (iii) Priority. The agent will select a rule which matches the current Environment Mode along with his/her current confidence level. If there is more than 1 rule matching these criteria, the agent will prefer the rule with highest priority.

2) Neighbour's Rule Acceptance Criteria: After executing the action of a particular rule from the ontology by a particular individual, the other individuals in the vicinity will come to know the action taken by this individual. In other words the latest action taken by a particular individual is multi-casted to all individuals in his/her vicinity. Others will try to incorporate the rule, just executed by this individual, if they are interested about the action came out of this rule. This interest of an individual towards a neighbour's action depends on; (i) Neighbour's Confidence Level, (ii) Environment Mode and (iii) Sharability. Obviously for a person to consider about a neighbour's choice, the neighbour must exhibit higher level of confidence, other than the person's own. The Environment Mode assists in finding whether the neighbour is doing something relevant with the current state of the environment. Sharabality indicates whether, what is done by the neighbour; can be done by the individual as well. If all these conditions are met an individual will update his/her own local ontology by adding the rule applied by the neighbour.

3) Emergence with an Evolving Local Ontology: As time passes the exchange of messages between individual agents lead to sharing the "Local Ontology" of each agent among each other, since every agent gets to know the actions done by his/her neighbour. For instance a normal person could learn on what a fire warden does and will update his/her Local Ontology based on what just the fire warden did. This leads to evolving the "Local Ontology" of each individual, leading to learning within each individual. Therefore in a given instance of time, any individual agent exhibits a "better evolved local ontology" adapted towards the panic situation; comparing to his/her "initial local ontology". This evolution of the Local Ontology within each individual agent results emergence of previously not anticipated behaviour patterns when the overall system is observed.

6. Implementation of Multi-Agent based Crowd Model with Sharable Ontologies

This section describes implementation of request/resource agents, message space and ontologies identified during the design; into a prototype that can be used for demonstrating a fire evacuation session for a given input scenario. The overall implementation of the prototype is carried out using JADE (Java Agent DEvelopment) framework [13], which is an open-source platform designed for developing multi-agent applications involving peer-to-peer communication between agents.

A. *Communication between Agents in Message Space*

Communication between agents in "Message Space" is implemented such that any message being sent by a sender agent is stored in the message space provided by the JADE platform until the relevant receiver agent/agents retrieve the same message. As stated by Table 1; 3 custom message types are used to exchange messages between agents.

Table 1: Message Types Exchanged between Agents

Message Type	Purpose	Message Contents	Sender Agent Type	Receiver Agent Type
FIRE MESSAGE	Simulates sensing a fire by all nearby individuals	(i) Location of fire center, (ii) Current severity of the fire source	Fire Agent (Representing a single fire source)	Individual Agents within the affected vicinity of fire source
INDIVIDUAL ACTION MESSAGE	Simulates an individual getting sense of what his/her neighbor does at a given moment	(i)ID of the current rule being executed, (ii)Current confidence level of the Individual who does the action, (iii)Any useful information for executing the action related to this rule	Individual Agent (i.e. representing a single person) who is doing the selected action from his/her local ontology	All Individuals in the vicinity of the Individual Agent who is doing the action
INDIVIDUAL EXIT MESSAGE	To notify monitoring agent about the exit of an individual from fire with the given timestamp	(i)ID of the Individual Agent, (ii)Timestamp during Exit, (iii)ID of the Exit Location	Individual Agent who just managed to reach the Exit	Monitoring Agent

Table 2: Initial "Local Ontology" of a Fire Warden

Rule No	Environment Mode	Confidence Range	Action	Sharable With Whom (Other Personality Types)	Useful Additional Information to Execute Action	Priority
1	Stable Mode	0% - 100%	Common Sense	With Anyone	-	1
2	Fire Mode	10% - 30%	Run to the nearest safe Exit Point	Normal Person, Security Guard	Locations of all exit points	2

B. Sharing Local Ontologies of Individual Agents

Table 2 describes the example rule set used in the initial "Local Ontology" of a fire warden according to the rule structure discussed in Section 5. Table 3 shows initial "Local Ontology" of a normal person.

Table 3. Initial "Local Ontology" of a Normal Person

Rule No	Environment Mode	Confidence Range	Action	Sharable With Whom (Other Personality Types)	Useful Additional Information to Execute Action	Priority
1	Stable Mode	0% - 100%	Common Sense	With Anyone	-	1

The sample "Local Ontology" configurations (in Table 2 and Table 3) are used in the prototype to demonstrate the concept of sharing ontologies between individual agents, which leads to emerging non-anticipated complex behavior patterns during a simulation session.

A normal person can get to know about the exit points in the building during a fire via a fire warden who exists within his/her neighbourhood. This is made possible since the knowledge (i.e. the 2nd rule in fire warden's initial "Local ontology" about exit points) of fire warden is shared among all individuals in his/her vicinity. Thus this will lead to updating the initial "Local Ontology" of the normal person with fire exit related information. Therefore a normal person will learn from a fire warden in its vicinity leading to emerging a previously non-anticipated behavior in the crowd.

The decision taken by a normal person on whether to update his/her "Local Ontology" will be based on "Neighbour's Rule Acceptance Criteria" (see Section 5). Upon updating his/her "Local Ontology", an individual agent will pick up the most appropriate rule to execute his/her next action, by selecting this most appropriate rule based on "Rule Selection Criteria" (see Section V) from his/her updated "Local Ontology".

C. Implementation of Individual Agent

Each Individual Agent has his/her own "Local Ontology", initialized during the creation of the Agent. In addition to the initialized "Local Ontology", each Individual Agent will have an initial confidence level, as specified by the input fire scenario followed by a perception bounds value and the Environment Mode.

In terms of assigning confidence levels; the initial confidence level for an individual is assigned based on his/her personality type. In general, fire wardens are more confident for facing an emergency fire situation. Therefore a fire warden will exhibit a higher initial confidence level comparing to a normal person. As the fire progresses the confidence level of each individual agent will be updated based on the severity and location of his/her surrounding fire sources. If the severity of surrounding fire sources is high and fire sources are located nearby; then the confidence level of any individual agent will decrease. In contrast, if the severity of surrounding fire sources is low and fire sources are located far, then the confidence level of any individual agent will increase.

The "Perception Bounds" value indicates the range of other individuals visible to a particular individual. Note that during implementing our prototype we have considered a circle with individual agent's current location being the center and perception bounds value being the radius, as the perceiving area for a person.

The "Environment Mode" indicates how an individual has understood the current status of his/her surrounding physical environment. An individual will behave in different ways when the environment is stable and environment is under fire. Initially the environment mode for an individual agent is set as "Stable Mode", since a fire has not been started. But as an individual agent receives a fire message (in other words when a person senses a fire in his/her surrounding environment) from a surrounding fire source, the environment mode of the individual agent is set to "Fire Mode".

Finally the pseudocode on next page describes how the behaviour of an Individual Agent is implemented according to our "Multi-Agent based Knowledge Sharing Approach" discussed under Section 4.

```
WHILE "Confidence Level > 0 (i.e. I'm alive)"
DO
    Search for pending incoming messages
    IF there are any pending messages THEN
        message =: getNextPendingMessage()
        IF (message is a FIRE_MESSAGE) THEN
            Set "Environment Mode" as FIRE_MODE
            Re-calculate my "Confidence Level" based on
severity and location of fire source
        ELSE IF (message is a
INDIVIDUAL_ACTION_MESSAGE) THEN
            IF confidence level of the other person is higher
THEN
                Update my "Local Ontology" based on
          "Neighbour's Rule Acceptance Criteria" (Refer Section
          V)
            END IF
        END IF
    END IF

Get the most appropriate Rule from "Local Ontology" based on
"Rule Selection Criteria" (Refer Section V)
 Execute the "Action" related to the most appropriate Rule
Find all individual agents in my vicinity (based on my
"Perception Bounds")
     FOR EACH individual agent IN my vicinity
          Send the Rule associated with my current "Action" as
an INDIVIDUAL_ACTION_MESSAGE (along with any useful
information helpful for executing the action)
     END FOR EACH

     IF there's a change in my Location after the latest action
THEN
          Update my location in the "Common Ontology"
```

IF I've reached any of the exit points THEN
Send INDIVIDUAL_EXIT_MESSAGE for the Monitoring Agent
Terminate myself
END IF
END IF
END WHILE

7. Evaluation

In this Section we present the evaluation of the proposed multi-agent based crowd simulation model. Note that, the prototype developed (as described in Section 6)has been used as the major tool for evaluation. Evaluation was carried out by executing a sample set of pre-designed input scenarios on this prototype and comparing the observed results from simulation sessions with general observations found in similar real world crowd evacuation scenarios.

Statistics recorded from different types of real world fire escape scenarios [14] reveal that, the following general observations are found within a crowd running away from fire; (i) asymmetrical distribution of individuals among exit points, (ii) arching/clogging near exit points and (iii) difference in statistics in case the same scenario is repeated with same environment setup (due to uncertainty in crowd behaviour during panic).

During evaluation as the first step, a sample fire evacuation scenario involving a small number of individuals was modeled using the prototype. The scenario represented a floor in a building with 2 exit points (i.e. emergency exits). Fire was represented as a single fire source, where the fire center is located near to the middle of the floor. There were 10 individuals at the time of starting the fire. Out of these 10 individuals 2 were fire wardens whom aware of the emergency exit points to be used during a fire and the other 8 were ordinary people. This scenario was executed twice (i.e. 2 simulation sessions) by using the prototype. The recorded statistics (i.e. recorded separately for both simulation sessions) were compared with the general observations from real world scenarios.

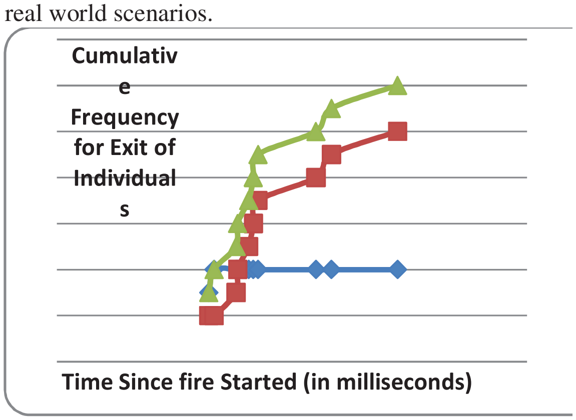

Figure3: Variation of cumulative individual count with time. Scenario 1 (10 individuals), simulation session 1.

Figure 3 is a graphical representation of results from the 1st simulation session with 10 individuals. It is evident that out of the 10 individuals 8 individuals have managed to exit from the 2nd Exit Point. Thus the distribution of the individuals among the exit points has been asymmetrical. Further after elapsing around 60 seconds since the fire has started (i.e. around 60000 milliseconds) several individuals have tried to escape from Exit 2 at the same time. This is an indication of arching/clogging around an exit point during a panic situation, since individuals reach exit points in groups at the same time due to circumstances ruled by uncertainty occurred during panic.

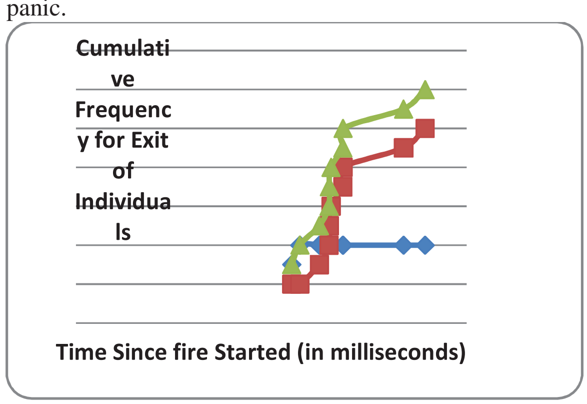

Figure4: Variation of cumulative individual count with time. Scenario 1 (10 individuals), simulation session 2.

Figure 4 shows results for the 2nd simulation session with 10 individuals and also indicates similar patterns like in Fig. 3, such as asymmetrical distribution of individuals among exit points, arching/clogging. However in terms of the arching/clogging effect it is evident that during 2nd simulation session (i.e. Fig. 4) 6 individuals have been subjected to clogging near 60 seconds (i.e. around 60000 milliseconds), whereas during 1st simulation session (i.e. Fig. 3) it was only 4 individuals who were subjected to clogging near 60 seconds mark. This means that although it is the same experimental setup which is executed twice, the statistics have varied slightly between the 2 executions. This is an indication of uncertainty of crowd behaviour during panic via our simulator. Further when comparing Figure 3 and Figure 4 together, it is evident that in both cases the cumulative individual count at Exit 2 is not a gradual increase with time, showing that Exit Points are not fully utilized among individuals which happens due to uncoordinated behaviour occurred during panic.

The experimental setup for Scenario 2 was also similar comparing with Scenario 1 (i.e. single floor of a building with 2 exit points and single fire source), except that the number of individuals used during the experiment was increased up to 30 individuals.

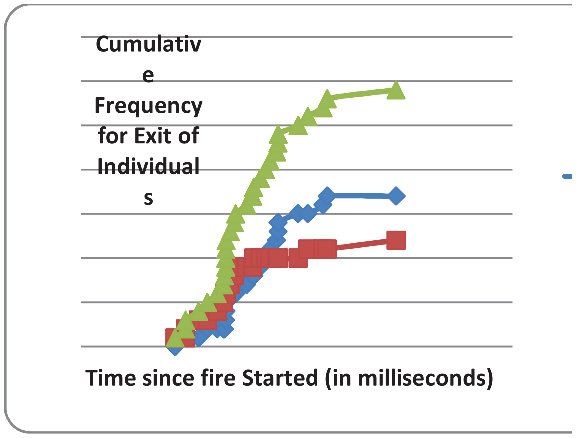

Figure5: Variation of cumulative individual count with time. Scenario 2 (30 individuals), simulation session 1.

During the 1st simulation session for Scenario 2 (Figure 5); 17 individuals have managed to get out from Exit 1, and 12 individuals from Exit 2. This again demonstrates the asymmetrical distribution of individuals among exit points. Clogging/arching effects are observed at both exit points between 60 to 70 seconds (i.e. 60000 to 80000 milliseconds).

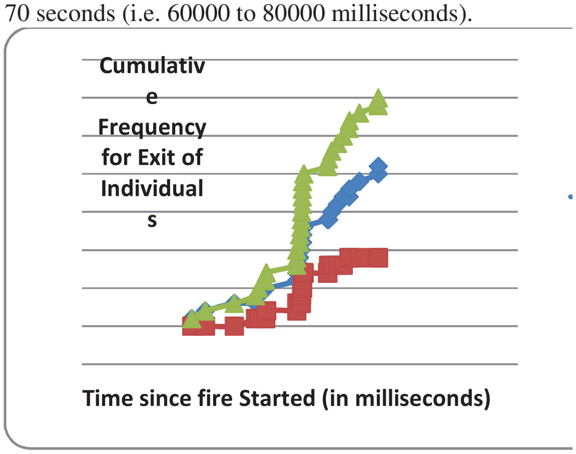

Figure6: Variation of cumulative individual count with time. Scenario 2 (30 individuals), simulation session 2.

Figure 6 shows results for the 2nd simulation session with 30 individuals. During the 2nd execution 21 people have managed to get out from Exit 1 and 9 people Exit 2, demonstrating asymmetry as well as clogging between 70 to 80 seconds (as illustrated in Figure 6). Comparison of results from Figure 5 and Figure 6 reveals that there is a significant difference between the results although they are 2 different simulation sessions related to Scenario 2. However while this difference being evident, still the common observation patterns of crowd behaviour such as asymmetrical distribution of individuals among exits and arching/clogging are preserved.

All the 4 sessions in both Scenario 1 and Scenario 2 (i.e. Figure 3, Figure 4, Figure 5 and Figure 6) reveal that the difference between the 2 graphs in Scenario 2 (i.e. Figure 5 and Figure 6) is considerably greater than the difference evident between the 2 graphs in Scenario 1 (i.e. Figure 3 and Figure 4). This reveals that while our multi-agent based crowd model simulates uncertainty in crowd behaviour during panic; this uncertainty is more evident when the total number of individuals in a Scenario is increased from 10 to 30.

8. Conclusion

The experimental results obtained during evaluation of the prototype indicate the ability of the proposed multi-agent approach to simulate uncertainty of a crowd in a panic. Hence the important aspect learned from multi-agent based approach is its ability to emerge this uncertainty as a result of unplanned knowledge sharing between the individuals.

Unlike the conventional approaches behind developing crowd simulations (such as particle-based approach, fluid-based approach and cellular automata) the agent-based knowledge sharing approach doesn't require developing a global algorithm to simulate the crowd behaviour in groups. Instead with multi-agent based approach assigning a rule-set for each individual with relevant actions for each rule (as discussed during design in Section 5) is adequate.

The initial knowledge of an individual is embedded as a collection of these rules and need not to be complete. Any individual in the simulation can learn something which was previously unknown due to unplanned knowledge sharing with other individuals via communication. Based on this information received through communication (i.e. by message passing) an individual will always update his local ontology (according to Neighbour's Rule Acceptance Criteria in Section 5). Therefore as a result, as time passes each individual will have a better "evolved local ontology" within him/her to decide about the best action(based on Rule Selection Criteria described in Section 5).

Our research work focused about assessing crowd behaviour via developing a computer simulation software and observing a scenario as a simulation. However, another approach is to collect statistical information recorded for a large number of similar scenarios on a given environment setup throughout history. Statistical frameworks [15] can be developed to estimate quantitative metrics such as total number of individuals being escaped in a given time, escape time per individual and percentage of individuals escaped from an exit point. Our crowd simulator can be further calibrated based on these derived statistical metrics by adjusting its configurations. Hence a more reliable level of realism can be guaranteed when results from statistical inference coincide with results from computer simulation.

Acknowledgement

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