Lancaster University

STOR601: Project 2

Modelling Crowd Dynamics During Evacuation Situations Using Simulation

Author:
Hugo Winter

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Abstract

Evacuation of people during emergency situations is a crucial aspect when considering building design. Recently, numerous simulation methods have been constructed to provide insight during building development. The aim of this paper is to understand the causes of crowd disasters and review the simulation methods that are currently in use. Advantages and disadvantages of the different methods will be discussed as well as work that lies at the forefront of current research in this area.

1 Introduction and Motivation

Modelling the movement and behaviour of individuals in a crowd can help engineers to reduce the number of deaths that occur in buildings and public spaces. As the global population continues to grow exponentially, more people attempt to fit into cities that are growing at a slower rate. Public spaces will naturally become busier, which increases the possibility of crowd related disasters. There seems to be no eminent reduction in population densities in the near future which makes modelling in this area especially important.

Table 1 shows a list of the major crowd related disasters in the past two years (where there has been loss of life). The disasters have occurred in numerous different countries, although the rapidly expanding populations of Asia and Africa mainly feature on this list. Each of the disasters also have a major contributing factor which is given as either crowd behaviour or building design. Most of the disasters have occurred due to building design, a factor that can be controlled by engineers and decision makers. Crowd behaviour is not easy to control as many aspects of human behaviour are inbuilt.

Section 2 discusses the two major contributing factors in evacuation situations. In Section 3 a selection of simulation methods are outlined and the advantages and disadvantages of each are discussed. Current and future modelling issues are discussed in Section 4 and finally some conclusions are drawn in Section 5.

2 Evacuation Situations

Two major factors contribute to the ability of people to evacuate a building or public space, crowd behaviour and building design. As discussed in the previous section engineers can change how new buildings are built to reduce associated problems. Many aspects of crowd behaviour are psychological and cannot be changed; people can be educated about what to do, but in panic situations instinct will often take over. As such, when implementing a model to improve evacuation times, attempts are made to model crowd behaviour as accurately as possible whilst varying aspects of building design to obtain the optimal solution.

Year	Location	Deaths	Injuries	Reason
2010	Mali	26	55	**Design**
2010	India	63	44	**Design**
2010	Germany	21	511	**Design**
2010	India	10	12	Behaviour
2010	Kenya	7	70	Behaviour
2010	Cambodia	347	395	**Design**
2011	India	102	44	**Design**
2011	Hungary	3	20	**Design**
2011	Nigeria	11	29	Behaviour
2011	Mali	36	70	**Design**

Table 1: List of major crowd related disasters 2010-2011

All simulation models considered in this report focus on the accurate simulation of crowd behaviour and associated problems. Building design will be discussed briefly in this section to give some context, but is not the primary focus of the report.

2.1 Crowd Behaviour

Before it is possible to construct a simulation that attempts to model crowd behaviour, it is necessary to understand the concepts that can be modelled. Previous work has suggested that there are three levels of crowd behaviour [Pan et al. (2007)]: the individual, interactions among individuals and the group.

2.1.1 The Individual

Every crowd is made up of a collection of individuals. As such the behaviour of separate individuals drives the behaviour of crowds in normal and panic situations. During evacuation situations, it is human nature to follow instinct in an attempt to get out as quickly as possible. Following instinct does not require a conscious thought process which is useful for executing actions quickly. However the different options are not evaluated fully which can lead to a phenomena called 'faster-is-slower', where quick uncoordinated movements by individuals cause the whole crowd to move slower.

Individuals do not simply move around in blind panic during evacuations since this would lead to many more major disasters. Experience of an individual is often heavily relied on during panic situations; this can work as both a positive and negative factor. Individuals who have the experience to keep calm and authority to guide others can ensure all exits of a building are fully utilised. This is the best known way to improve evacuation times outside building design [Pan et al. (2007)]. It has been observed that most individuals will exit buildings along a route that they are most familiar with (such as the main entrance or exit). In this scenario, experience works negatively as many people will ignore alternate exits and clogging could occur at those in use.

In theory the choice of exit from a room is a problem that concerns the individual. In non-evacuation situations a rational choice could be made by evaluating each of the exits and choosing the exit that minimises the exit time. In social theory this is known as bounded rationality since not all options may be known to the individual. In a panic situation the extent to which an individual follows instincts or rationally chooses an exit depends upon time and the level of perceived danger.

2.1.2 Interactions Between Individuals

In an evacuation situation there is a significant change in the way that people interact with one another. Individuals who are panicked act on instincts which do not follow social norms. High levels of perceived danger can lead to more physical interactions between people which gradually slow the crowd down. Individuals pushed to the ground can be trampled underfoot, becoming immovable objects which impede the evacuation routes of other people.

Interactions need not be of a purely physical nature. Individuals who lack experience in evacuation situations are more likely to look to the behaviour of others as a guide on how to act, a phenomenon known as social proof. If several individuals rush towards one exit, a stampede can often ensue as others follow the example. This can work positively as people file through the 'best' exit, but can also be negative as other potential exits are completely ignored.

2.1.3 The Group

The movement of the group (or crowd) as a singular entity is affected by both internal and external factors. The density of a crowd significantly affects the way in which it moves. As the density increases, the comfort level of individuals within the crowd is diminished which increases the risk to the individual. Individuals can be swept along with the flow of people, unable to free themselves from the sheer mass of people. Under these circumstances trampling and injuries are very likely to occur.

Constraints forced by the environment can restrict the movement of the group as a whole. Narrow exits, obstructed corridors and inadequate number of exits (and many more factors) lead to a reduction in the speed of crowd evacuation. Slow evacuation then affects the perceived tension in each of the individuals in the crowd. An increase in the perceived tension in enough individuals will lead to uncoordinated movement which slows down the crowd further.

2.2 Building Design

When engineers design buildings and public places there are numerous factors that can be altered to reduce evacuation times. The three most important factors are the placement and width of exits and the placement of environmental objects [Daoliang et al. (2006), Helbing et al. (2002)]. Intuition suggests that rooms should be built that have as many wide exits as possible with environmental objects kept to a minimum. Design is rarely this simple, hence the need for simulation. For example, a single file exit might create structure for people exiting through a door whereas larger doors may encourage too many people to attempt to escape at the same time. Clogging of the doorway could lead to slower evacuation times [Perez et al. (2002)].

A result that provides evidence for simulation concerns positioning of environmental objects [Helbing et al. (2002)]. It has been discovered that placing a column in front of an exit can increase the outflow from a room by up to 50% in an evacuation situation. This occurs as pressure from behind is relieved by subdividing the crowd into two separate groups. Engineers have been unwilling to implement this measure in buildings due to the social perception of such a decision. Such a counter-intuitive measure could increase the perceived danger of an individual, which could lead to more danger than if there was no column at all. This emphasises that a simulation model must be subject to practical evaluation. Even if a simulation model suggests improvements, implementing them is not always the most sensible course of action.

3 Simulation Methods

Numerous simulation methods have been created in recent years which have roots in different areas of science. Figure 1 gives an overview of the different aspects in simulation modelling. This report focuses on conceptual modelling and issues of model validation. Computer implementation and choice of software is not discussed since there many different software packages available for each method outlined in this review.
Cellular Automata models are the oldest still in usage and originate from work on biological systems. Social force models have grown from studies on the social aspects of crowd behaviour. Fluid dynamics models were found to have several analogies to the movement of pedestrians and agent based models have been used by simulators to understand individual behaviour for many years. The aim of this section is to briefly explain each of the methods as well as outlining different advantages and disadvantages. Models coming from such disparate areas do have significantly different behaviour, but each describe the dynamics behind crowds well.

3.1 Cellular Automata

Cellular Automata (CA) is a method that has been used in different applications for about sixty years. It was first proposed by Von Neumann in an attempt to generalise biological systems

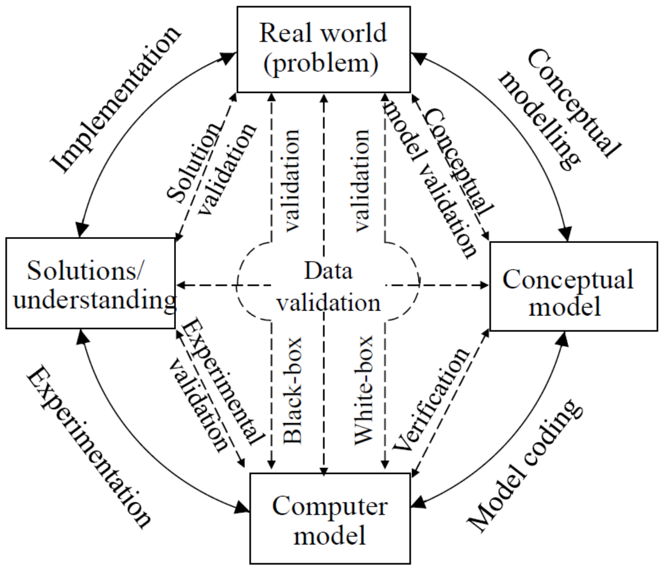

Figure 1: Overview diagram of simulation modelling [Onggo (2012) adapted from Pidd (2004)]

[Von Neumann (1951)]. Dynamical systems are divided into a set of regular grid squares and evolution from one time step to another is determined by the neighbouring squares and a set of local rules.

In recent years CA methodology has been applied to crowd dynamics during evacuations. The environment is divided into a set of cells which can either be empty or occupied. Each pedestrian (P) attempts to leave the room in the quickest time and knows beforehand the position of their nearest exit. If the neighbouring cell in the exit direction is occupied, an attempt is made at random to enter one of the adjacent empty cells.

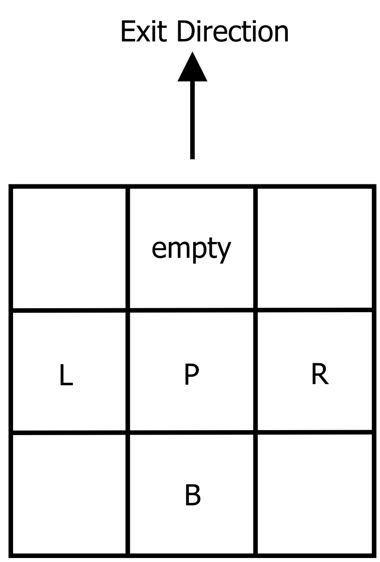

Figure 2: Simplified diagram of CA methodology

Figure 2 gives a visual representation of the simulation method. The pedestrian P will face the neighbouring cell in the exit direction and move if

$$L + R < B + \phi \tag{1}$$

where L,R and B represent the total number of neighbours to the left, right and behind respectively. A measure of anxiety or panic is given by ϕ. A pedestrian escapes from the environment when they occupy the exit and need not be considered after.

CA is a simple model conceptually and is computationally efficient. At each time step it is necessary to evaluate equation 1 for each grid square that is occupied. As pedestrians leave the environment through the exit, fewer calculations need to be made. Simulation results from CA seem accurate when compared to experimental data from previous studies and are easily repeatable [Zheng et al. (2009)]. Certain aspects of crowd behaviour are well explained using CA, such as "faster-is-slower" and arching phenomena [Perez et al. (2002)], whilst others are not. During a panic situation people that are trampled underfoot can become non-moving obstacles, a problem that is completely ignored in current CA models. Distilling all aspects of perception of danger and human anxiety into a single value can also be seen as an oversimplification.

3.2 Social Force Models

An alternative method to CA was proposed by Helbing and Molnar in 1995, called social force. Human behaviour was noted to be complicated and viewed as almost chaotic by numerous parties; the idea behind social force was to find a set of basic rules based upon behavioural aspects. Each pedestrian (α) is affected by four major factors:

- He/she wants to reach a certain destination
- He/she keeps a certain distance from other people
- He/she keeps a certain distance from borders and other obstacles
- He/she can be attracted by other people or objects

The total effect of each of these factors on pedestrian α is given by

$$\begin{aligned} \mathbf{F}_\alpha(t) = \mathbf{F}^0_\alpha(\mathbf{v}_\alpha, v^0_\alpha \mathbf{e}_\alpha) + \sum_\beta \mathbf{F}_{\alpha\beta}(\mathbf{e}_\alpha, \mathbf{r}_\alpha - \mathbf{r}_\beta) \\ + \sum_B \mathbf{F}_{\alpha B}(\mathbf{e}_\alpha, \mathbf{r}_\alpha - \mathbf{r}^\alpha_B) + \sum_i \mathbf{F}_{\alpha i}(\mathbf{e}_\alpha, \mathbf{r}_\alpha - \mathbf{r}_i, t) \end{aligned} \tag{2}$$

The term on the left hand side of the equation gives the total effect of the four factors on pedestrian α. The first term on the right hand side is the effect of the pedestrian's desire to reach their destination. This acceleration term is specified as

$$\mathbf{F}^0_\alpha(\mathbf{v}_\alpha, v^0_\alpha \mathbf{e}_\alpha) = \frac{1}{\tau_\alpha}(v^0_\alpha \mathbf{e}_\alpha - \mathbf{v}_\alpha) \tag{3}$$

where $\mathbf{e}_\alpha(t)$ is the direction the pedestrian wishes to walk in, v^0_α is the desired velocity and $\mathbf{v}_\alpha(t)$ is the actual velocity. A deceleration from the desired velocity will lead to a tendency to approach the desired velocity within the relaxation time τ_α.

The other terms on the left hand side define the repulsion effects of the other pedestrians, borders and the attractive effects of certain other pedestrians. The mathematical details are not expanded on in this review, but extra details are available [Helbing and Molnar (1995)]. The completed social force model is defined as

$$\frac{d\mathbf{w}_\alpha}{dt} = \mathbf{F}_\alpha(t) + \text{fluctuations} \tag{4}$$

This final form adds a fluctuation term which takes into account the random behaviour of pedestrians. Under certain situations the choice of direction around an obstacle may not matter as both have the same utility. Accidental and deliberate deviations from the optimal path may also occur. The fluctuation term covers both of these important behavioural traits.

The current proposed social force model does not take into account aspects that occur under panic situations. Helbing extended the social force model to create a model that could exhibit numerous different phenomena [Helbing et al. (2000)]. The model is defined as

$$m_i \frac{\mathrm{d}\mathbf{v}_i}{\mathrm{d}t} = m_i \frac{v^0_i(t)\mathbf{e}^0_i(t) - \mathbf{v}_i(t)}{\tau_i} + \sum_{j \neq i} \mathbf{f}_{ij} + \sum_W \mathbf{f}_{iW} \tag{5}$$

where m_i is the mass of pedestrian i, v^0_i is the desired speed, $\mathbf{e}^0_i$ is the desired direction of movement and $\mathbf{v}_i$ is the current velocity with characteristic time τ_i. Interaction forces $\mathbf{f}_{ij}$ and $\mathbf{f}_{iW}$ model the attempts of each pedestrian to keep a velocity-dependent distance away from each other and the borders.

Social force models can reproduce certain phenomena such as ‘faster-is-slower’ and clogging at exits. However, criticism has suggested that the underlying assumptions oversimplify how pedestrians behave. Pedestrians in the model tend to adjust their speed of motion inversely proportional to the distance from borders and other pedestrians. In reality, pedestrians may formulate better escape strategies (for example moving between two other pedestrians to find a quieter route) which are not taken into account by this set of models.

3.3 Fluid Dynamic Models

It has been conjectured previously that crowds move in a similar manner as fluid flows. Thus early work in this area suggested that the Navier-Stokes equations could be applied to pedestrian flows [Bradley (1993)]. Modern methodology no longer implements the Navier-Stokes equations in their entirety, rather the concepts of fluid dynamics are combined with consultation from behavioural scientists. This overview focuses on the model based on the continuum hypothesis [Hughes (2002)].

The continuum hypothesis holds for pedestrian flows when the crowd density is high since at lower densities the hypothesis becomes questionable. The governing equations require three hypotheses to hold along with regular continuity equations:

1. The speed of pedestrian movement is determined by the crowd density only
2. Pedestrians have common sense of the task
3. Pedestrians seek to minimise estimated travel time while avoiding areas of extreme crowd densities

An example of hypothesis 2 relates to the fact that if two pedestrians occupy squares of the same utility, they will not swap since there is no benefit. Previous work has suggested that hypotheses 1 and 2 hold for pedestrian flows whereas hypothesis 3 depends on the motivation of the pedestrians. Pedestrians need to be goal-orientated for hypothesis 3 to hold which is indeed the case for pedestrians attempting to evacuate in an emergency situation. The governing equations for the flow of a single pedestrian type are [Hughes (2002)]

$$-\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}\left(\rho g(\rho) f^2(\rho)\frac{\partial \phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(\rho g(\rho) f^2(\rho)\frac{\partial \phi}{\partial y}\right) = 0 \tag{6}$$

and

$$g(\rho)f(\rho) = \left[\left(\frac{\partial \phi}{\partial x}\right)^2 + \left(\frac{\partial \phi}{\partial y}\right)^2\right]^{-1/2} \tag{7}$$

where ϕ is the remaining travel time, ρ is the density of the crowd, $f(\rho)$ is the speed of the pedestrians and $g(\rho)$ is a discomfort factor. Measurements are taken throughout time t in the Euclidean (x, y) plane. Appropriate choices of the speed and discomfort functions make the governing equations simpler, despite their time-dependence and non-linearity.

The main advantage of this method is that a set of governing equations provide an analytical tractability that allows general results to be derived more easily [Hughes (2003)]. At very high pedestrian densities fluid dynamic approximations are more accurate than other numerical tools, yet break down at extreme levels. Further studies have introduced 'thinking fluids' which model some aspects of crowd behaviour such as clogging of doorways and tiring of pedestrians.

Practical application of fluid dynamics methods is still difficult as the governing equations are non-linear and based upon three hypotheses [Zheng et al. (2009)]. For example, hypothesis 2 holds when pedestrians are visually informed, but this is not always the case in evacuation situations. It also becomes difficult to build confidence in a model where it is hard to get an intuitive grasp on what is happening. Decision makers prefer to have a model which they can validate themselves under a set of different scenarios. The equations provide little knowledge about the behaviour of individuals and the interactions between individuals, only about the total movement of the crowd. This is a serious drawback when compared with social-force and agent-based models which provide information about individuals and the group.

3.4 Agent-based Simulation

The origins of agent-based simulation (ABS) trace back to research in complex adaptive systems and artificial intelligence. Complex adaptive systems consist of a set of interacting, autonomous components that have the ability to adapt as individuals or groups. ABS began as a set of ideas and techniques that were used to implement models of complex adaptive systems [Macal and North (2010)].

The basic definition of ABS is a modelling approach that models a system as a set of individual, autonomous and interacting agents. Beyond this basic definition there is no universal agreement on the precise definition of an agent. Some consider any type of independent component to be an agent, whereas others suggest that a component must be adaptive to be defined as an agent. Figure 3 gives a conceptual idea of the processes behind ABS. In general agents are considered to have four essential properties:

- An agent is self-contained
- An agent is autonomous
- An agent has a state that can vary over time
- An agent is social and interacts with other agents

The self-contained property implies that each agent has a boundary, making it easy to determine what is part of an agent. Attributes attached to the agents allow agents to be distinguished from and recognised by other agents. Autonomy is the property that allows each agent to function independently of its environment and of other agents. The behaviour of an agent is a function that links the information that the agent senses to the actions that it takes. The state of an agent consists of a set or subset of its attributes [Macal and North (2011)] and is the only information required

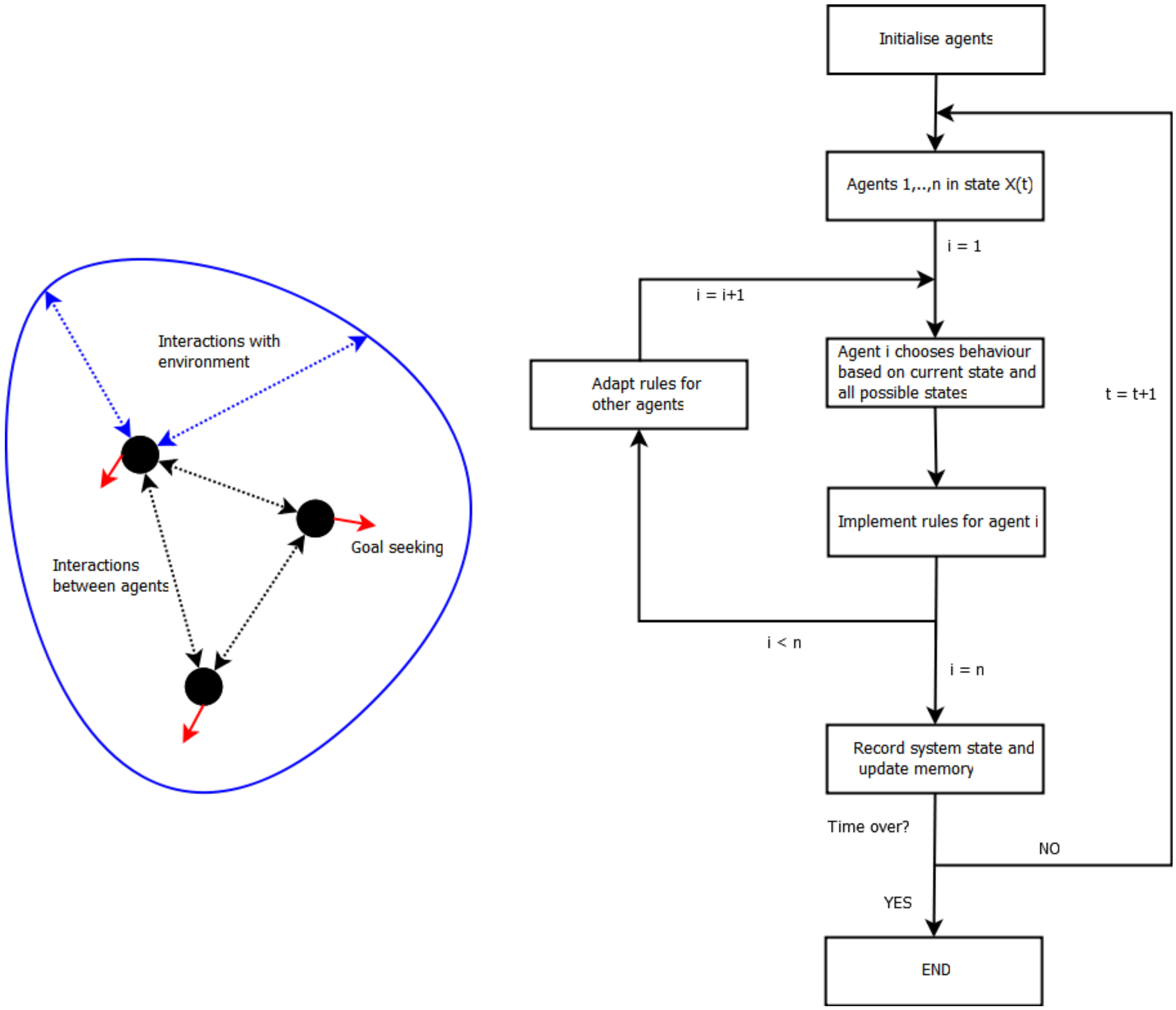

Figure 3: Conceptual diagram and flow chart for ABS

to step forward to the next point in time. An agent with a larger set of possible states will have a larger set of possible behaviours. The social nature of agents refers to their interactions with other agents. In crowd dynamics the most common examples of social behaviour are collision avoidance and contention for space.

There are three other characteristics that agents can exhibit:

- An agent may be adaptive
- An agent may be goal-directed
- An agent may be heterogeneous

An agent that is adaptive has an ability to learn from experience and adapt future strategies to improve their outcome. For this property each agent must be constructed with some form of memory.

If an agent can compare each available outcome to its goals and adapt future responses then it is goal-directed. This property is important in evacuation situations since each agent is attempting to minimise their evacuation time from the building. Heterogeneity is a property that defines that agents have diversity across a population. Other approaches (fluid-dynamics) consider components as homogeneous particles, an assumption that is not particularly valid when considering a human population.

When programming an agent, all knowledge about the agent can be split into agent attributes and agent methods. Attributes can change throughout the simulation (dynamic) or be fixed (static). The name assigned to an agent is a static attribute whereas the memory of an agent is a dynamic attribute. Agent methods mainly relate to behaviours and any function that links the current state to a set of actions.

ABS is not only concerned with how to model the agents separately. Interactions of different agents are important to evaluate the behaviour of the group as a whole. ABS is built up from the autonomous agents, thus each agent only has information in their local neighbourhood. There are no governing equations that provide global information to each of the agents. Interaction with agents in the neighbourhood provide each agent with more information about their surroundings. The neighbourhood of an agent need not only be defined in a spatial sense. For example, a social network is a set of agents that are in the social neighbourhood of an agent.

Having defined the basic concepts behind ABS, it is important to understand what benefits this type of simulation provides. There are three major benefits to ABS over other simulation methods [Bonabeau (2002)]:

- ABS captures emergent phenomena
- ABS provides a natural description of the system
- ABS is flexible

The overall behaviour of a system can be different from the behaviour of the separate agents, a result known as emergent phenomena. Emergent behaviour provides strong evidence to the benefits of using simulation. In ABS each agent is given a set of rules and a small change in these rules can lead to a large change in the overall behaviour in a system. The emergent behaviour may also seem counter-intuitive which highlights that intuition can often be misleading when analysing outcomes of complex systems. An example of emergent behaviour in evacuation scenarios is herding behaviour.

Emergent behaviour can be visualised in a simple game [Bonabeau (2002)]. Taking a group of around 30 people, each person selects two people at random (who shall be referred to as person A and B). Each person is told to keep person A between themselves and person B. The people will wander around the room in a seemingly random pattern from the start to the end of the experiment. However, if the rule is changed such that each person must keep themselves between person A and B, everybody will converge in a tight knot in the centre of the room straight away. This game is very volatile to the choice of interaction rule.

ABS can be viewed as the most natural way of simulating a system with many different components. It is an oversimplification to view the whole crowd as one flow, rather than as a collection of individuals. Despite this, the non-linear partial differential equation required to model the flow and densities are more difficult to understand than the set of rules attached to an agent. The relative simplicity of ABS is beneficial when building confidence in a model. Decision makers can validate and calibrate an ABS model by comparing the model set-up to their perception of the problem.

When running a simulation model, it may be necessary to change certain conditions, for example the number of individuals in the study. In ABS it is easy to add or remove agents to a simulation. The complexity of the rules governing each agent and their interactions can be tailored to the situation. A minimalist model might be based upon a set of idealised assumptions to capture only important details, whereas decision support models may need to include real world data and pass more stringent validation. If the level of required complexity is not known ahead of time, adjustments could be made in real-time.

The major drawback of ABS is the amount of computing power required. Modelling the evacuation of a sports stadium may require over $100,000$ agents, each with their own set of rules regarding their interactions. The computing power required for CA is significantly lower, but the simulation obtained from ABS is more useful. The ever increasing processing power of computers make this less of an issue than it once was.

4 Current and Future Research

Current and future work in the field of crowd dynamics is focusing on three main areas. The simulation methods described in Section 3 have been extended in an attempt to model different aspects of human behaviour. Other research has focused on using the wide range of real-time data available for validating, calibrating and adding complexity to current models. New approaches to modelling the problem have been suggested, one of interest is the use of game theory for competitive and cooperative behaviour.

4.1 Expansion of Current Models

There has been recent work on extending CA, social force and ABS methodology by introducing new aspects of human behaviour. CA is often preferred in many situations since it is computationally inexpensive and gives consistent repeatable results. The concept of a floor field can be added to CA where the pedestrians modify the probabilities of transitioning to an adjacent square [Burstedde et al. (2001)]. The floor field can be seen as a second level of grid cells which are split between static and dynamic. The static floor field does not evolve in time and specifies certain more attractive regions (for example emergency exits). Each pedestrian leaves a trace of where they have been before, modelled in the dynamic floor field and subject to diffusion and decay. More recently the floor field concept has been extended to take human anticipation into account [Suma et al. (2011)]. In this model each pedestrian can recognise areas that are expected to be filled by other pedestrians in the future and then speed up or slow down to avoid any future collisions. Other extensions on the floor field concept have added collisions among pedestrians, effects of walls, positioning of exits and density around an exit.

Extensions to social force and ABS models have focused on similar areas. A property that has often been ignored is the tendency for people to walk in groups. In one test it has been suggested that up to 70% of pedestrians in a commercial street walk in groups [Moussaïd et al. (2010)]. At a spatial level it has been shown that depending on the speed that the group is moving, a v-like walking pattern is often adopted. Currently the impact of these structures on current models is unknown, but future research should provide more information. It has been commented that future work for social force will also address the problems of perception, anticipation and communication [Helbing et al. (2009)]. Papers on leadership and communication have been written but not yet applied to computational models [Dyer et al. (2009)].

4.2 Using Real-time Data

There is a large amount of data available in real-time, from video footage and sensor measurements. A recent research area is attempting to use this richness in data to validate and discover other behaviour that could be added to current models. Video tracking of pedestrians has been used to create plots of trajectories on a two-dimensional plane [Johansson et al. (2008)]. Figure 4 shows an example of tracking pedestrian movements over time. These video recordings can then be used to calibrate the parameters of models such as social force and ABS. Processes such as lane formation become easier to understand when the process can be viewed in video footage.

Evacuation situations cannot be set up in a controlled environment and monitored as easily as watching people cross the street. Disasters are rare, difficult to forecast and for ethical reasons it is not feasible to create an experiment where lives are endangered. Major empirical studies in this area have tended to focus on mimic exercises in a simulated situation. Dynamic pictures often

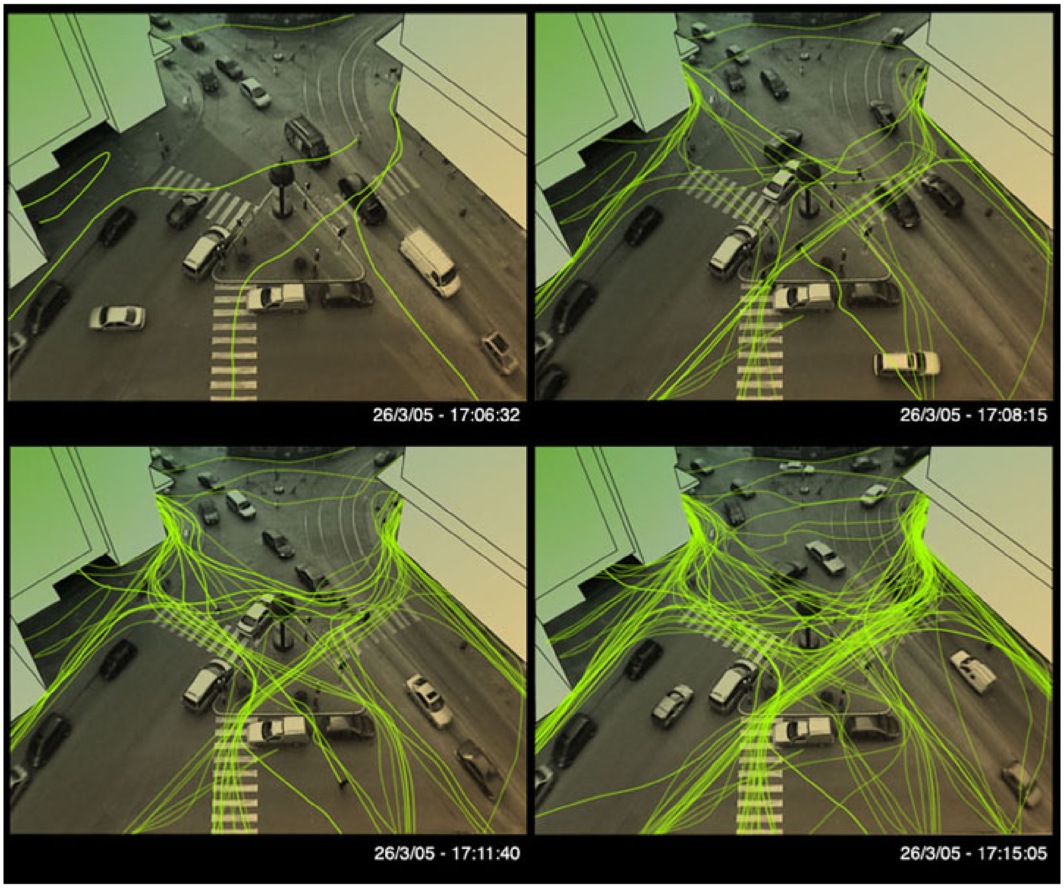

Figure 4: Analysis of pedestrian path movement reworked with computer software [Humphreys (2009)]

suffer since resolution is low and camera positioning is poor. One study has taken advantage of higher quality video recordings to analyse the Wenchuan earthquake on May 12, 2008 [Yang et al. (2011)]. When compared against mimic exercises it was found that there were major differences in the relationship between the time and order of arrivals.

Analysis of video footage from a stampede at the Loveparade music festival in Duisburg, Germany has been used to construct a model for crowd behaviour [Krausz and Bauckhage (2011)]. The idea was to build an automatic vision system that could detect congestion and motion patterns that characterise crowd behaviour prior to stampedes. Since this would run in real-time, action could then be taken to alleviate the potential causes of a stampede. Future work could look into extending this model to account for other observed phenomena and validate using data from other disasters.

4.3 Game Theoretic Models

It has been suggested that certain aspects of evacuation behaviour could be modelled using game theory. Game theory is a branch of mathematics that concerns the strategy that rational players

	Polite	Normal	Vying
Polite	$0, 0$	$0, b$	$0, b$
Normal	$b, 0$	$b/2, b/2$	$0, b$
Vying	$b, 0$	$b, 0$	$-c, -c$

Table 2: Pay-off table for two player game [Zheng and Cheng (2011a)]

should take to maximise their gains. Each player in the game will not have knowledge of the strategy of any other players, which makes it applicable to evacuation situations. Non-cooperative game theory has been used to model the choice of exit from a room affected by fire [Lo et al. (2006)]. At each decision point each pedestrian estimates the evacuation cost and expected movement of the other pedestrians. For example, if there is congestion at a certain exit people will try to find an alternate exit, which could lead to a blockage at that exit. The one problem with the model is a potential lack of generality. It is assumed (based on previous work) that the behaviour of the people is rational as people in a fire are not in a panic situation. This assumption is questionable in itself and makes it difficult to apply to other evacuation scenarios where crowd densities are higher.

Another interesting attempt has been made to combine game theory and CA into a unified approach [Zheng and Cheng (2011a), Zheng and Cheng (2011b)]. A floor field CA model is used for movement except at points where jamming or bottlenecks occur (for example at a narrow exit). Only one person can fit though the exit and each person can take one of three different strategies, 'polite', 'vying' and 'normal'. 'Polite' people will not move and as such obtain a pay-off of 0. Adopting a 'vying' strategy obtains the pay-off b if the exit position is obtained and a cost c if the exit position is no obtained. A person adopting a 'normal' strategy will escape in order if meeting a person using the same strategy (with pay-off $b/2$). The pay-off table can be seen in Table 2.

A Nash equilibrium is obtained when people alternate their strategies, for example ('polite','vying') followed by ('vying', 'polite'). A mixed-strategy Nash equilibrium can be found at $(0, 2c/(2c + b), b/(2c + b))$, which is a vector of probabilities of adopting the different strategies. If the cost c is low then the equilibrium tends to $(0, 0, 1)$ and 'vying' becomes the best strategy. If the cost of not escaping is sufficiently large then the Nash equilibrium tends to $(0, 1, 0)$ and the 'normal' strategy is the best. This contrasts with psychological experiments that suggest people exhibit more 'vying' behaviour under greater duress, a non-optimal strategy according to game theory. In the CA mechanism, the introduction of a rationality factor reflects an individuals ability to choose that best strategy and attempts to circumnavigate the assumption that all people must behave rationally. Herding coefficients are also included to model a person's tendency to emulate the strategies of others.

5 Conclusion

The aim of this paper was to understand the processes behind crowd behaviour in evacuation situations, overview the different simulation models currently in use and highlight future areas of research in the field. To investigate the first aim it is necessary to realise that there are two major contributing factors to crowd related disasters, crowd behaviour and building design. Crowd behaviour cannot be changed as psychological aspects are inbuilt into human nature, whereas building design can be adjusted by engineers. As such, simulation models attempt to model behaviour as accurately as possible whilst leaving building design available to be changed by the user. This report has focused upon simulation methods and modelling crowd behaviour.

Diverse literature is available on different simulation models used to model crowds. These break down broadly into four types: Cellular Automata, social force, fluid dynamics and agent-based simulation. Cellular Automata is the oldest of the methods, yet still used today for its relative computational cheapness and accurate results. It does struggle to cope with some phenomena that have been observed in empirical studies. Social force models are based upon four rules relating to social interactions between people and their environment. This method has been taken forward to encompass many aspects of human behaviour that other models cannot, but has been criticised as an oversimplification of the problem. The differential equations that govern fluid flows have been shown to be mappable to flows of pedestrians, especially at high pedestrian densities. However, the complicated nature of the equations means that they have had little practical application. The newest method is agent-based modelling which looks to model the system from the individual agents upwards. The major benefit of this methodology is the ability to cope with emergent behaviour, although this comes at a computational cost.

Current and future literature seem to focus on extending these four models. The addition of floor fields to Cellular Automata has made the methodology much more flexible, while advances in social force and agent-based modelling have focused on group behaviour, anticipation and communication. With an increase in the amount of real-time data available, behaviour can be better understood and models can be more easily validated. Video data will continue to be used to compare mimic exercises to real life scenarios and hopefully create more warning systems that seek to alleviate the possible causes of crowd disasters. Adding game-theory to models is an interesting idea that can be expanded on in the future, yet the assumption of rationality will always be a major problem.

It is hoped that this report has highlighted that numerous methods can be combined to study crowd dynamics and evacuation situations. Increased study in this area, computing power and availability of real-time data from videos and sensors could hopefully lead to major breakthroughs in the area and reduce the amount and severity of crowd related disasters in the future.

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