How do pedestrian crowds react when they are in an emergency situation - models and software

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December 19th 2008, University of Illinois at Urbana-Champaign

Abstract *In my term paper I want to reflect research made for pedestrian behavior in evacuation situations, using different models and software like Exodus. Models used in these calculations consider emergent behavior of pedestrian crowds when panic,close space or a high density of people arise. These simulations play an important role to calculate the time needed to rescue people and help to make new buildings like stadiums or skyscrapers a safer place.*

1 Introduction

Over the last decades,since new technologies made it possible, buildings like skyscrapers, stadiums or theaters got bigger and bigger, more and more people moved into the major cities and therefore the problem of overcrowding became a major issue. Unfortunately these developments also give rise to more accidents caused by the people leaving those buildings in evacuation and panic situations. For example almost 1400 people died in 1990 in Mecca because of a power blackout in a pedestrian tunnel and the following panic.

It became non negligible to pay more attention to safety issues. Hence people started to do research on what exactly changes in the behavior of people and people crowds when they get involved in evacuation situation or in any similar forms of panic and what are the emergent results of these behaviors. Another key point is the question, if computer software is able to simulate these situations so accidents can be avoided by improving safety in advance.

In this paper I want to present the different changes in people interactions while in panic, discovered in recent research projects. These results gave the opportunity to develop different models and even software to simulate the behavior of people in panic. Software like Exodus or PedGo are based on models named "social force model" or cellular automata. Although built for the same purpose those softwares are specifically good in different areas. I want to give a brief overview over the most popular models and compare their advantages and disadvantages.

2 Pedestrian behavior

To understand how people behave we are left with observations, since it is not possible to describe the human behavior with a finite amount of variables. Therefore most of the research groups started their investigations by looking at previous incidents or observation videos. Although human behavior seems to be very complex, in an everyday situation it shows several basic patterns.

2.1 Normal behavior

In their common environment pedestrian tend to show some basic attributes. For starters, pedestrians always try to find the shortest and easiest way to reach their destination. If possible they avoid detours, even if the shortest way is crowded. The basic principle is the "least effort principle", which means everyone tries to reach his goal as fast as possible though spending the least amount of energy and in this example time. In non panic situation, humans prefer not to get to close to the people around them. Everyone has is personal comfort zone, which he tries to protect if possible.[He01]

This results in a usually relatively low crowd density A observable result of the previous statement is an oscillating phenomena appearing at doors or similar narrow passages. If people try to use the same door in different directions., the walking direction through the

door oscillates.
If we assume we have the same density of people on both sides of the door and one side is using the door to pass through it, one of the densities decreases until the other one is high enough to "force" their way through the door and the walking direction changes(Figure 1).[He97]
Another effect of the "repulsing force", humans tend to have, is lane formation. If we consider again pedestrians walking in opposite directions in a narrow hallway, soon we will get a stable state which includes people walking in lanes instead of "boxing" their way through the oncoming people.This allows them to walk at a higher pace and requires less effort to avoid other people. Recent simulation software was able to recreate this state and give explanation for its appearance. Those observations are the most obvious group behaviors. However, for each pedestrian we can assign individual attributes like desired walking speed, which is according to Henderson around $v = 1,3 - 1,5m/s$ and Gaussian distributed in a normal-life situation, depending on sex and age of the person. [He71] [Kl03].Other attributes are more important when it comes to a panic state. Then it becomes really important how individuals behave, if they act as leaders or followers, if they tend to panic or stay calm or if they start to investigate rather than run away.

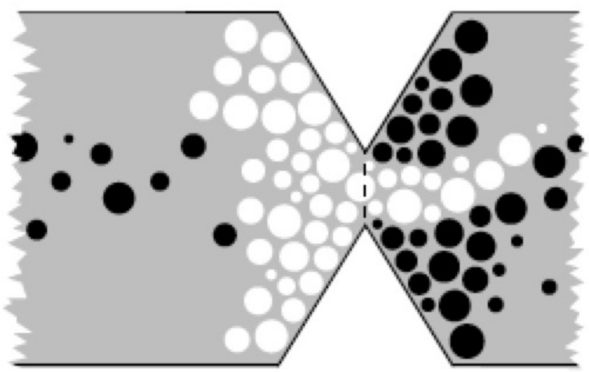

Figure 1: Oscillations of the passing direction at a bottleneck [He01]

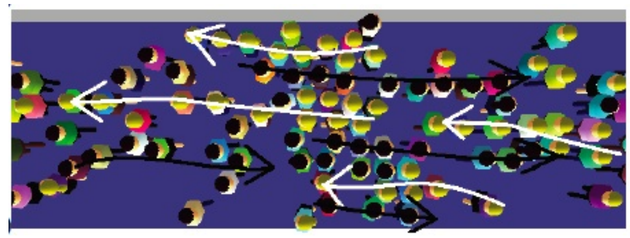

Figure 2: Lane formation as a result of repulsing forces[2Pe07]

2.2 Panic behavior

Most of the observed behavior I described earlier vanishes when pedestrians face an emergency situation (it does not always have to be an emergency situation, similar effects can be observed for example in crowds trying to get the best seats at a concert or consumer running for the best sale). The observations made for pedestrian crowds in an emergency situations feature typically the following patterns.
Obviously people try to leave the building as fast as possible, therefore the desired velocity increases which gives rise to some really in-

teresting emergent formations I will describe later on.
The more nervous people get, the less they care about their comfort zone and about finding the most convenient and shortest way. It is observable, that for example, if people have to leave a building in an emergency situation and they don't know the structure of the building well enough, they would run for the exit they used as an entrance, even if other exits might be easier to reach or even safer.[He01] They also might loose the ability to orient themselves in their surrounding and thus show herding or flocking behavior [1Pe07]. Not just that they loose certain abilities,they also start to exhibit new characteristics like pushing or other physical interactions. Those are often responsible for major injuries or great amounts of injured or even dead due to the forces generated by people crowds , which can reach up to 4500 Newtons per meter, "enough to tear down a brick wall" [He01].
Furthermore people who stumble or fall down create new obstacles for following people, which can again slow down the evacuation.

3 Emergent phenomena and symmetry breaking

Now we can ask what emergent behavior and patterns can be found and what variables are controlling them or which symmetries are getting broken?
In this section I want to focus on two emergent phenomena, one is "arching" an emergent phenomena breaking the oscillating symmetry at doors, the other I mentioned before is usually called "herding" or "flocking".

3.1 Arching

Assume the desired velocity to be a parameter to describe crowd actions. In an emergency situation, this velocity is significantly higher than it is usually. This has a huge effect on patterns formed by walking crowds. Observations have shown a phenomena called arching, which appears when a big crowd with a high desired velocity tries to pass through a door. Instead of passing through

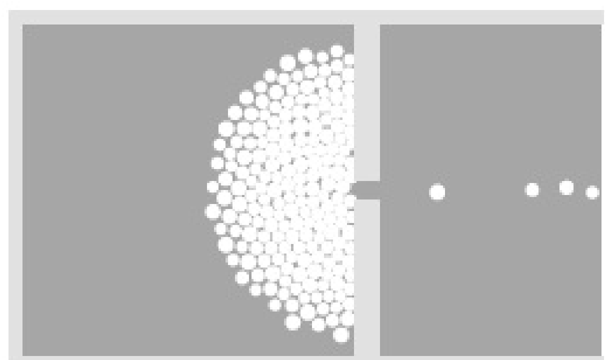

Figure 3: arching simulation [He01]

the door in less time, or giving the oncoming pedestrians a chance to pass through the door, the door gets clogged and the crowd gets arch-shaped . Above a certain desired velocity, the time dependent symmetry of the oscillating walking directions vanishes and instead we get a non symmetric, stable state.

Models have tried to explain this emergent state. It happens most likely due to static friction and higher pressure among the "agents" (pedestrians in a simulation) The door gets blocked because to many people try walking through it at the same time. This effect gets reinforced by the arch-symmetry, none of the pedestrian can use the pushing force for his advantage to get through the door. This often produces long escape times and more injured. Simulations have shown, that this problem can be reduced by "artificial" obstacles, for example a pillar in front of the door. It breaks the arch-symmetry and results in a higher flow through the door.

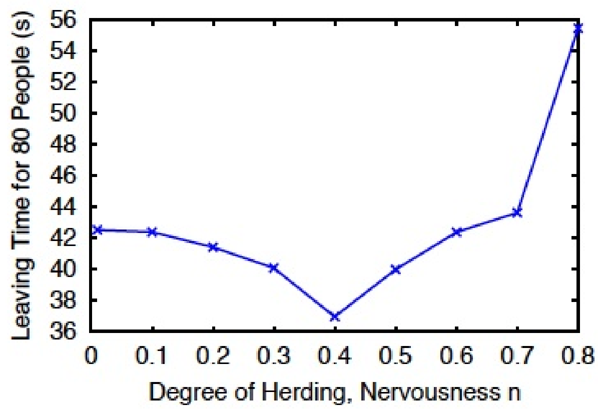

Figure 4: flocking simulation [He01]

3.2 Herding or Flocking

Herding tries to describe a human group dynamic visible in disaster situations. When people get nervous and feel panic, they lose the ability to act logically and to decide on their own. As a result of this lack of independence, people tend to follow others in the assumption they could get them out of the dangerous area. On one side this could actually help people to escape faster, but if for example smoke is reducing the visibility or the person leading the group does not know the structure of the building well enough, it could also reduce the change to find an exit. So instead of people wandering around on their on we get with increasing "nervousness" more and more flocks of people. As simulations have shown, neither walking around on their own nor people only walking in flocks results in optimal evacuation time.[He01] In order to find a explanation for this effect, we have to make the assumption of an emergent attractive force which increases with the nervousness. It is most likely, that this force,despite the nervousness depends a lot on outside influences, for example if the visibility is high or if there is smoke. It might also depend for each human individually on the age and the condition. [Lu08]

4 Models and Software

Since computer became able to simulate big amounts of "particles" a great amount of different models were developed to simulate the behavior of people in a catastrophe situation. The most well-known softwares are using Cellular Automata or a social force model, they either discretize space or treat it as a continuos. [Pe08]

4.1 CA

Using cellular automata as a model means, that buildings are plotted on a 2-dim array and walls and all objects are discretized in space and projected on the 2-dim grid.Every human usually takes up one grid point and moves with his desired velocity as long as one of the neighboring spaces in its preferred direction (exit or next door) is not occupied. The validity of simulations using cellular automata depends a lot on the grid size used by the software, because it is the limiting variable. It limits for example how many people could walk through a door at the same time or cuts actual free space, because of overlap between objects and grid size.[Pe08]
Therefore the overall flow gets limited, which is crucial for emergency time calculations.
Most of the time this model works together with a rule based model which adds the assumption that most of the crowd behavior emerges from a view simple rules, which can be easily adjusted. Unfortunately the assumption, that human behavior is rather homogeneously fails most of the time. Although it often works for animals, human behavior is more likely to be heterogenous. [Sh08] CA based software has its excellence in being easy adaptable to different buildings and being frugal on cpu power and thus can handle greater amounts of pedestrians.
Software using CA is for example EXODUS[Exo]

4.2 social force model

The social force model uses Newton's equation including all kinds of interactions to calculate a microscopic model for human behavior.
Basically the approach looks like :

$$\frac{d\vec{v}_\alpha}{dt} = \vec{f}_\alpha(t) + fluctuations$$

where $\vec{f}_\alpha(t)$ stands for the social forces, necessary to describe human interactions.[He98]
The approach used by Helbing in his paper [He01] includes for normal pedestrian behavior an acceleration and friction term to describe the human intention to reach a desired velocity.Furthermore a repulsive social force term is used to indicate that humans have the tendency to keep a certain distance to their surroundings.
Finally an attraction term is added, which can be used to simulate how people react on outside influences.
To specify the behavior of people in panic, Helbing adds another term, including a Heavyside-function, which starts to contribute as soon as the forces or the density get to high.[He01] Although it may look like particle flow most of the time, social forces models have a lot of advantages since they

do not limit the density or the space because they use the assumption of continuous space. With this model it is possible to explain for example lane formation. When people are walking in opposite directions, they have a higher relative velocity and therefore stronger interactions. These interactions bring people to avoid oncoming pedestrians and a stable state consisting of lanes of people only walking in one direction gets formed.
Helbing was also able to simulate a phenomena he called " freezing by heating". He could show that, if the "fluctuation" in this context the nervousness of the agents rises, people jam occurs. Which means, instead of walking faster through a narrow hallway by forming lanes, oncoming pedestrian groups block each other and some sort of solid gets formed.[2He00]

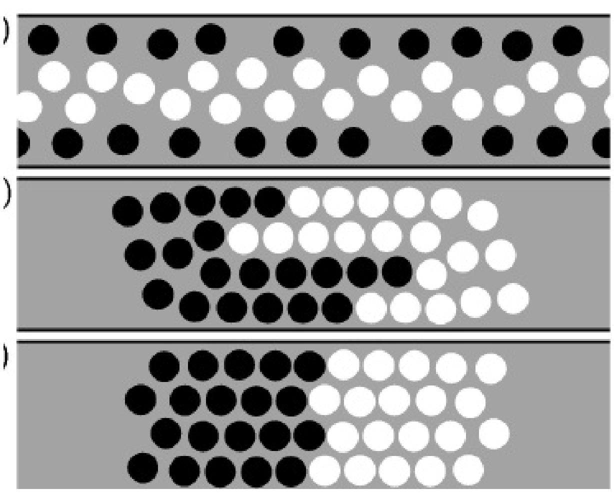

Figure 5: simulation of oncoming pedestrian groups with increasing fluctuations [2He00]

5 Results and Conclusion

A lot of research has been done to improve pedestrian facilities. Some results are rather easy to implement, so for instance, to support lane formation and to prevent its breakdown due to high fluctuations, it would be sufficient to use trees or pillars in the middle of a long walkway to separate the one walking direction from the other one.
To prevent doors from clogging, an easy solution is a convex shaped surrounding of the door, which simulations have shown to be the optimal shape for a fast exit. [He01]
One of the most recent strategies was presented by Lue a view months ago . It exists of three modules "namely crowd behavior module, individual behavior module, and physical behavior module."[Lu08], the model does not only use physical interaction, it also gives the individuals different objectives, e.g leadership, follower etc. and it allows the people to communicate among each other about hidden exits or new obstacles.

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