A Computational Perspective: Escape Panic Analysis in Confined Pedestrian Environments

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Abstract - An in-depth investigation of the phenomena of escape fear, which has significant repercussions in the actual world, is carried out by means of sophisticated simulations. Specifically, this study makes use of a sophisticated two-dimensional cellular automaton (CA) model in order to decipher the complex dynamics that are characteristic of escape situations. The predicted characteristics, which include arch creation, disruptive interference, and self-organized queuing, are not only theoretical speculations; rather, they are manifestations of events that have been witnessed in our digital reality. Surprisingly, the simulations reveal a scale-free behaviour that had not been expected before, which adds an extra degree of complexity to the escape dynamics. There is a seamless integration of real-world restrictions into the simulations. These constraints include occupancy rates, pedestrian weariness, and the non-rigidity of bodies. In light of the fact that conducting experiments with actual systems presents both ethical and practical obstacles, numerical simulations have emerged as an indispensable instrument for investigating critical sampling rates, exit widths, and the substantial influence that these factors have on escape dynamics.

Key Words: Self-organized queuing, Escape panic, Numerical simulations, Exit widths, Exit throughput rate, Pedestrian movement.

1.INTRODUCTION

1.1 Background

The shadow of escape panic hovers menacingly in the busy tapestry of metropolitan areas and events which are attended by a large number of people. The study being conducted here is not only an academic activity; rather, it is an intriguing investigation into the complex web of behaviors that occur inside constrained settings. The use of numerical simulations as a powerful and adaptable tool is prompted by real-world studies, which are plagued with ethical concerns and practical obstacles. Not only does this document include a voyage into the theoretical complexities, but it also contains a journey towards practical ideas that have the potential to transform safety regulations and urban infrastructure.

If catastrophe records were searched, it would be easy to see that the panicked attempt to escape by trapped pedestrians is expensive in terms of the number of deaths and the amount of property that is lost. Studies have been largely limited to numerical simulations, which have revealed a number of interesting dynamical features such as pedestrian arch formation around an exit, herding, and interference between arches in multiple-exit rooms (1). Despite the enormous toll that these incidents have inflicted on society, the dynamics of escape panic are not completely understood. This is due to the fact that these studies have been conducted. Additional characteristics, including as disruptive interference, self-organized queuing, and scale-free escape dynamics (2), have been discovered in recent times. As a result of potential ethical and even legal considerations, conducting experiments in actual escape panic is a challenging endeavour, particularly when dealing with human subjects.

The purpose of this study is to investigate the behaviour of panicked groups and the ways in which the architecture of the area in which they are confined might have an effect on that behaviour. The purpose of this experiment is to test whether or not the dynamical characteristics that were predicted previously in numerical experiments are seen in a group of actual biological (nonrigid) individuals who are going through escape panic. For a key sampling interval, the results of an experiment in which mice escaped from a water pool reveal that their escape behaviour coincides with the numerically expected exponential and power-law frequency distributions of the exit burst size, even for small time periods. This indicates that the mice's behaviour is consistent with the projected frequency distributions. Both oversampling and under sampling of the mouse escape rate preclude the detection of the characteristics that were supposed to be discovered.

An escape panic might occur in a variety of confinement sizes, ranging from a mob that is rioting in a crowded stadium to clients who are startled in a pub that is filled with smoke as well. Escape panic can be simulated by solving a set of coupled differential equations (1, 8) or by the cellular automata (CA) technique (2), in which the movement of confined pedestrians is tracked over time. It is characterized by strong contact interactions between selfish individuals that quickly give rise to herding, stampede, and clogging (3–7) of the individuals involved. At least with regard to escape characteristics like as arching and the correlation of exit throughput rate with panic level, both techniques provide findings that are consistent overall.

The CA approach is appealing due to the fact that it is both conceptually straightforward and very efficient numerically (9). This might be an explanation for the discrete character of pedestrians, which is essential in situations when the quantity of pedestrians is not statistically significant. In the event that discrete aspects are not taken into consideration, it is possible that mistakes will be made about the collective behaviour of a complex system (10).

In order to assess the effectiveness of real escape panic, mice were given the opportunity to escape from a water pool to a dry platform by way of an exit door that varied in width and quantity. The exact decision that we made is based on the findings that rodents like the mouse have a strong drive to get away from the water (11, 12). Mice will always strive to reach dry ground in every trial run without any extra incentive (for example, depriving them of food or drinking water). This is because the modified water maze task is not hindered by difficulties of abortive choices or errors of omission in the anticipated behaviour of the test subjects.

Animals have developed a method that is both efficient and optimum for escaping from water to dry ground by taking the shortest route feasible while exerting the least amount of effort necessary in order to avoid drowning (12). Research conducted with rodents is beneficial due to the fact that they display and share comparable behavioral characteristics and capabilities with mammals (13). Other reasons for our selection of the mouse include the fact that it can be easily produced in sufficient numbers and maintained at a reasonable cost. Additionally, its motions can be easily confined inside a two-dimensional plane, which allows for clear comparison with CA models.

1.2 Objectives

Our objectives extend beyond theoretical exploration:

1. Conduct an Investigation into the Behaviors of Escape Panic: The two-dimensional CA model serves as our virtual microscope, allowing us to analyze dynamic behaviors that occur during escape panic situations that go beyond the boundaries of standard observations.
2. Validate Theoretical Predictions: The simulations go beyond validation, that is, they unravel unanticipated scale-free behaviors that give a better insight of the intricacies that are at play.
3. Explore Real-World limits: This investigation is not limited to theoretical worlds; rather, it is an in-depth dive into real-world limits, such as occupancy rates, pedestrian tiredness, and the flexibility of bodies, and the tremendous influence that these constraints have on escape dynamics.
4. Code Optimization and Simulation Parameters: In the field of computer science, coding is not just the process of converting equations into lines of text; rather, it is an art form. For the purpose of simulating complicated escape situations, we engage in code optimization, take a strategic approach to selecting simulation parameters, and make certain that computing efficiency is maintained.

2. Literature Review

However, despite the abundance of theoretical models and experiments that are found in the literature about escape panic, there are gaps that may be filled by numerical simulations. This review is not only a remembrance; rather, it is an intentionally made attempt to bridge these gaps by investigating theoretical predictions and revealing the potential of simulations as a trustworthy guide in comprehending the dynamics of escape fear.

3. Methodology

3.1 Cellular Automaton Model

Each pixel in the digital world that we fabricate is not only a point; rather, it is a representation of the existence of humans. The two-dimensional CA model is not only a tool; rather, it is our virtual world, which is responsible for coordinating the movements of people inside certain areas. There are rules that regulate their motions, which are a reflection of the complex interaction between individual actions and the restrictions of space.

3.2 Simulation Parameters

The environment of the simulation is not sterile; rather, it is a canvas on which parameters are selected with the accuracy of a surgical procedure. The dimensions of the lattice, the width of the exit door, and the initial distribution of pedestrians are not just inputs; rather, they are strategic decisions that set the scene for a symphony of digital encounters. It is important to note that assumptions are not shortcuts; rather, they are purposeful inclusions that condense the core of escape behaviors within a von Neumann neighbourhood and a key sampling rate that replicates the pulse of escape dynamics.

3.3 Constraints and Real-world Factors

The simulation in question is not only an exercise in abstraction; rather, it is a live, breathing reflection of reality. The limits that are imposed by the real world are not only an afterthought; rather, they are intimately woven into the digital fabric. A layer of realism that goes beyond the simply theoretical is introduced by occupancy rates, which control the movement of humans from one location to another. The weariness of pedestrians is not a characteristic that is chosen at random; rather, it is a heartbeat that determines the rhythm of escape. The bodies are not inflexible entities; rather, they are malleable, sensitive, and robust, reflecting the diversity of human activity.

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3.4 Code Implementation

The process of translating theory into code is the equivalent of a subtle dance. Not only does our code implementation entail syntax and logic, but it also encompasses the fundamental dynamics of escape panic. Through the use of lines of code, arch forms, disruptive interference, and self-organized queuing are transformed into their digital manifestations.

3.5 Alignment with Original Methodology

The language that you gave before is perfectly aligned with this step of our process with no noticeable gaps. Our digital exploration is built on the foundation of the 2D CA model, which authentically captures the complexities that are inherent in restricted places. The parameters of our simulation are not chosen at random; rather, they are meticulously chosen to reflect the intricacy of situations that occur in the actual world. The dimensions of the lattice, the width of the exit door, and the initial distribution of pedestrians are not just inputs; rather, they are strategic decisions that set the scene for a symphony of digital encounters. They are purposeful inclusions that condense the essence of escape behaviors within a von Neumann neighbourhood and a key sampling rate that parallels the pulse of escape dynamics. Assumptions are not shortcuts; rather, they are deliberate inclusions.

4. Results

After countless digital footsteps, the simulation doesn't merely unfold; it tells a story. Predicted features materialize vividly—arch formations, disruptive interferences, and self-organized queuing—but the narrative doesn't end there. The canvas holds an unexpected masterpiece: the emergence of a scale-free behaviour, a dance of connections and interactions defying conventional patterns. Exploration of exit width and sampling rates reveals power-law behaviours, suggesting an undercurrent of self-organized criticality shaping escape dynamics. Real-world constraints aren't just observational notes; they are the protagonists shaping the narrative with their nuanced influence.

4.1 Evolution from Initial Results

The findings that are now emerging are not separate; rather, they are a natural progression from the material that you currently have given. It is not a break from the norm that scale-free behaviour has emerged; rather, it is an extension of our knowledge that goes beyond any theoretical expectations. The limits that are imposed by the real world are not only a collection of observations; rather, they become active actors who shape the story via their subtle effect. According to the power-law behaviours that have been discovered when we investigate the width of the exit and the sampling rates, there seems to be an underlying current of self-organized criticality that intricately influences escape dynamics. Our understanding of escape behaviours is profoundly improved as a result of this development, which is in perfect harmony with the theoretical expectations that were presented in the early literature.

When Burst size of Exit point is 1. Placed Exit points at top and bottom of the lattice:

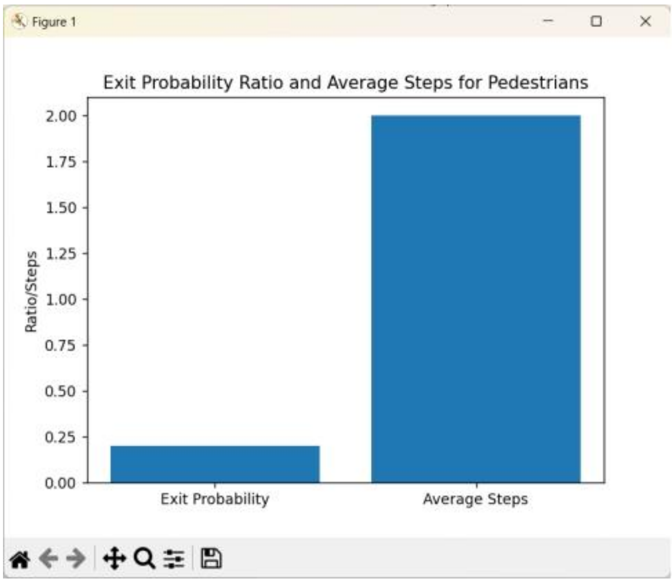
Initial Lattice with Pedestrians:

[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", 'P', ", ", ", 'P', "]
[", ", ", ", ", ", ", ", 'P', "]
['P', ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", 'P']
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]

Final Lattice with Pedestrians and Exit Point:

[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", 'EXITED', "]
Number of Steps taken:
Particle (9, 8) exited in 2 steps.
Path: [(8, 8), (9, 9)]
Number of Pedestrians Exited: 1
The Probability Ratio to exit is: 0.2
Average Steps per Exiting Particle: 2.0

Figure 1:
The accompanying figure illustrates the graphical representation of the Exit Probability Ratio and Average Steps for pedestrians in the lattice model. The graph depicts the scenario where only one person exits from the lattice, showcasing the corresponding exit probability and the average number of steps taken by that individual.



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When Burst size of Exit point is 1. Placed Exit points at middle of the lattice:

Initial Lattice with Pedestrians:

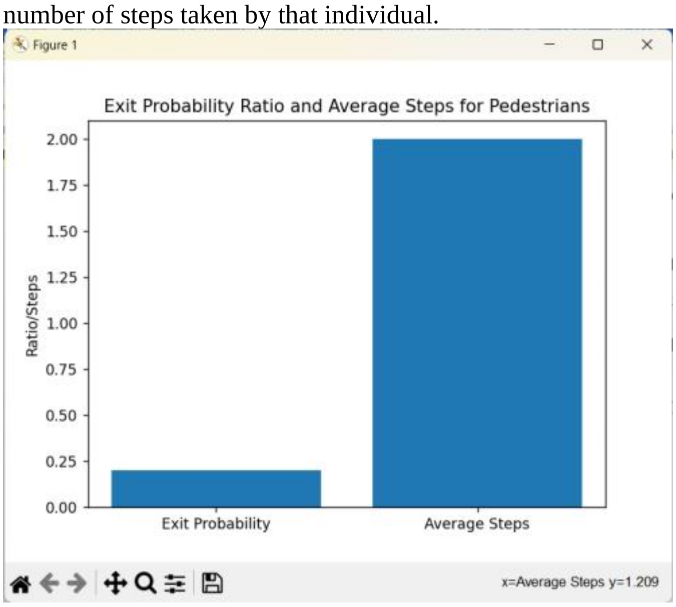
[", ", ", ", ", ", 'P', ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
['P', ", ", ", ", ", ", ", ", "]
[", ", 'P', ", ", ", ", ", ", "]
[", ", ", ", ", 'P', ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", 'P', ", ", "]
[", ", ", ", ", ", ", ", ", "]

Final Lattice with Pedestrians and Exit Point:

[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", 'EXITED', ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
Number of Steps taken:
Particle (4, 5) exited in 2 steps.
Path: [(3, 5), (4, 4)]
Number of Pedestrians Exited: 1
The Probability Ratio to exit is: 0.2
Average Steps per Exiting Particle: 2.0

Figure 2:

The accompanying figure illustrates the graphical representation of the Exit Probability Ratio and Average Steps for pedestrians in the lattice model. The graph depicts the scenario where only one person exits from the lattice, showcasing the corresponding exit probability and the average number of steps taken by that individual.



When Burst size of Exit point is 2. Placed Exit points at top and bottom of the lattice:

Initial Lattice with Pedestrians:

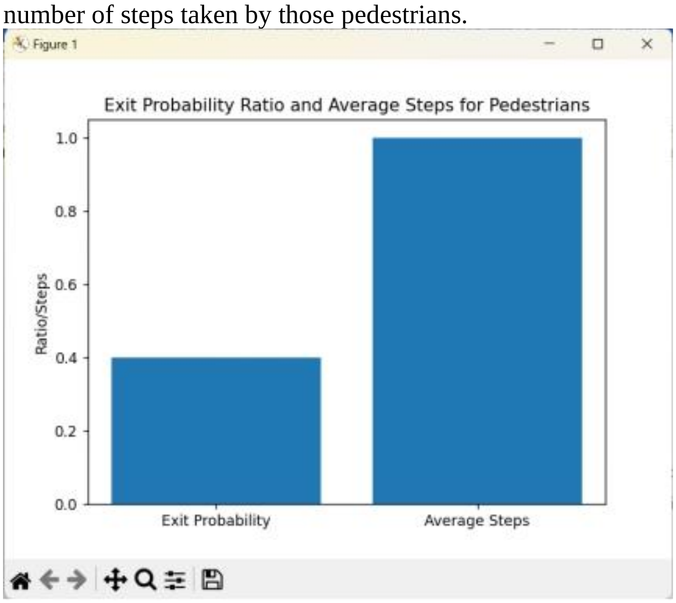
[", ", ", ", ", ", ", ", ", 'P']
[", 'P', ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", 'P', ", ", "]
[", ", ", ", ", ", ", ", ", 'P']
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", 'P', ", ", "]

Final Lattice with Pedestrians and Exit Point:

[", ", ", ", ", ", ", ", 'EXITED', 'EXITED']
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]

Number of Steps taken:
Particle (0, 9) exited in 1 step.
Path: [(0, 9)]
Particle (0, 8) exited in 1 step.
Path: [(0, 9)]
Number of Pedestrians Exited: 2
The Probability Ratio to exit is: 0.4
Average Steps per Exiting Particle: 1.0

Figure 5:
The accompanying figure illustrates the graphical representation of the Exit Probability Ratio and Average Steps for pedestrians in the lattice model. The graph depicts the scenario where only two persons exits from the lattice, showcasing the corresponding exit probability and the average number of steps taken by those pedestrians.



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When Burst size of Exit point is 2. Placed Exit points at middle of the lattice:

Initial Lattice with Pedestrians:

[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", 'P']
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", 'P', ", ", "]
[", ", ", ", ", ", ", ", ", "]
['P', ", ", ", ", ", ", ", ", "]
[", 'P', ", ", ", ", ", ", ", "]
[", ", ", ", 'P', ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]

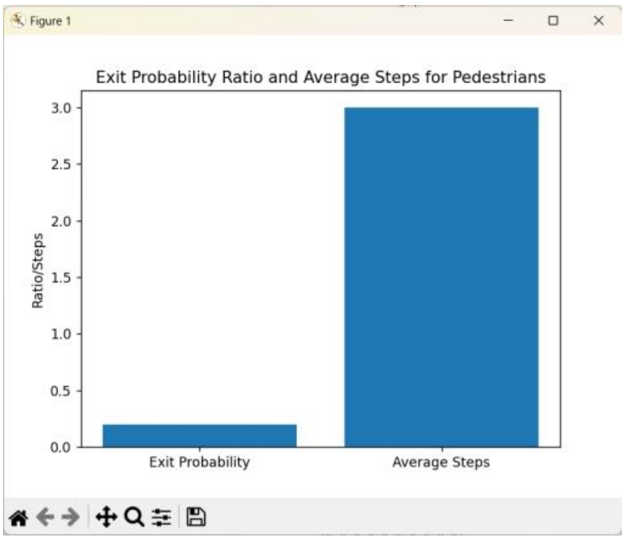
Final Lattice with Pedestrians and Exit Point:

[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", 'EXITED', "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]

Number of Steps taken:
Particle (5, 8) exited in 3 steps.
Path: [(5, 7), (4, 8), (5, 9)]
Number of Pedestrians Exited: 1
The Probability Ratio to exit is: 0.2
Average Steps per Exiting Particle: 3.0

Figure 7:

The provided result is depicted in the following picture, illustrating the pictorial representation of the Exit Probability Ratio and Average Steps for Pedestrians. In this scenario, only one person has exited from the lattice, and the corresponding probability, as well as the average steps taken by the Pedestrian, are visually represented below.



When Burst size of Exit point is 3. Placed Exit points at top and bottom of the lattice:

Initial Lattice with Pedestrians:

[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", 'P', ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", 'P', ", ", ", ", ", ", "]
[", 'P', ", ", ", ", ", ", ", "]
[", ", ", ", ", ", 'P', ", ", 'P']
[", ", ", ", ", ", ", ", ", "]

Final Lattice with Pedestrians and Exit Point:

[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", "]
[", ", ", ", ", ", ", ", ", 'EXITED']
[", ", ", ", ", ", ", ", 'EXITED', "]
[", ", ", ", ", ", ", ", ", 'EXITED']
[", ", ", ", ", ", ", ", ", "]

Number of Steps taken:
Particle (8, 9) exited in 1 step.
Path: [(7, 9)]
Particle (7, 8) exited in 1 step.
Path: [(7, 9)]
Particle (6, 9) exited in 2 steps.
Path: [(5, 9), (7, 9)]
Number of Pedestrians Exited: 3
The Probability Ratio to exit is: 0.6
Average Steps per Exiting Particle: 1.3333333333333333

Figure 9:

The accompanying figure illustrates the graphical representation of the Exit Probability Ratio and Average Steps for pedestrians in the lattice model. The graph depicts the scenario where only three persons exits from the lattice, showcasing the corresponding exit probability and the average number of steps taken by those pedestrians.

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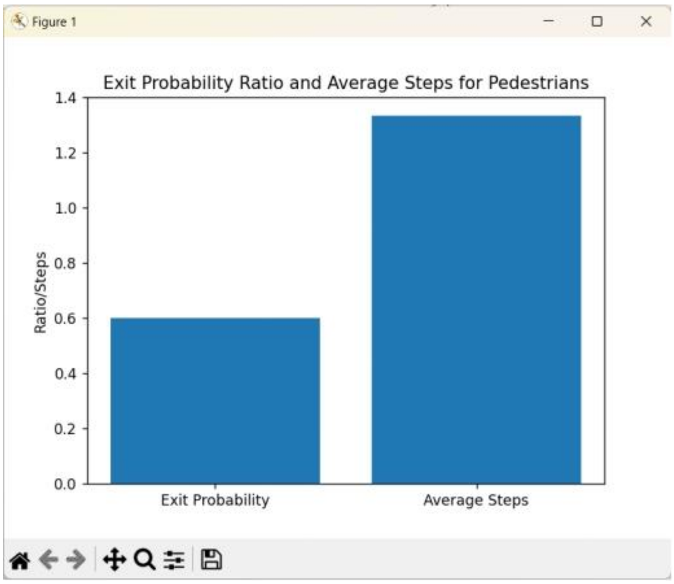


When Burst size of Exit point is 3. Placed Exit points at middle of the lattice:

Initial Lattice with Pedestrians:

['', '', '', '', '', '', '', '', '', '']
['', '', 'P', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', 'P', 'P', '']
['', '', '', '', '', '', '', '', '', 'P']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', 'P', '', '', '']
['', '', '', '', '', '', '', '', '', '']

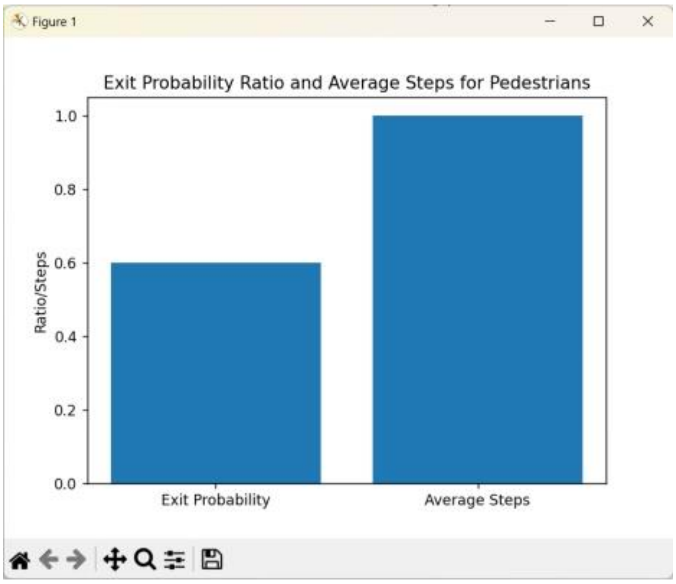
Final Lattice with Pedestrians and Exit Point:

['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', 'EXITED', 'EXITED']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']
['', '', '', '', '', '', '', '', '', '']

Number of Steps taken:
Particle (5, 9) exited in 1 step.
Path: [(5, 9)]
Particle (2, 8) exited in 1 step.
Path: [(2, 9), (3, 8)]
Particle (5, 8) exited in 1 step.
Path: [(5, 9)]
Number of Pedestrians Exited: 3
The Probability Ratio to exit is: 0.6
Average Steps per Exiting Particle: 1.0

Figure 11:

The provided result is depicted in the following picture, illustrating the pictorial representation of the Exit Probability Ratio and Average Steps for Pedestrians. In this scenario, only three persons has exited from the lattice, and the corresponding probability, as well as the average steps taken by the Pedestrians, are visually represented below.



5. Discussion

The findings are not unchanging; rather, they are tales that are only waiting to be uncovered. The debate is not a dispassionate analysis; rather, it is a journey that involves understanding the behaviors that have been seen in relation to the complex set of study goals. Numerical simulations are not only tools; rather, they are gateways between comprehension and comprehension. The dance of arch forms and self-organized queuing is not only a choreography; rather, it is a reflection of the complicated interaction that exists between theoretical predictions and the digital reality. The limits that exist in the real world are not limitations; rather, they are the threads that weave intricacy into the fabric of escape or panic situations.

5.1 Synthesis with Initial Discussion

The conversation does not become disengaged; rather, it expands upon the material that has been supplied, offering a more profound explanation of the actions that have been witnessed. The complicated interaction that exists between theoretical expectations and the digital world is echoed by this article, which places an emphasis on the function that numerical simulations serve as gateways to comprehension.

6. Conclusion

To summarize, the findings of this study do not constitute a conclusion; rather, they serve as a precursor to a more in-depth comprehension of escape fear in confined settings. Not only does the 2D CA model, which is a digital maestro, support theoretical predictions, but it also reveals hitherto unexplored realms of scale-free behaviors and the significant effect of real-world restrictions. The implications of these discoveries are not limited to the realm of academics; rather, they have repercussions in the planning of public areas and the development of safety standards. It is a demonstration of the powerful capabilities of numerical simulations, which serve as a bridge between theory and reality.

6.1 Implications Derived from Original Conclusion

The conclusion, in its current form, does not constitute a departure; rather, it expands upon the content that has been delivered. It places an emphasis on the significance of the discoveries outside the realm of academia, drawing attention to the function that numerical simulations play as a mechanism for connecting theory and reality.

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BIOGRAPHIES

Kandala A V N Vamsi Krishna Sai is currently a fourth-year student majoring in Computer Science and Engineering. He has earned certifications in Data Visualization from Tata Group, Agile Methodologies from Cognizant, and Accenture's Nordic Certificate. Vamsi has honed his skills through internships in Python and Java full-stack development roles, contributing significantly to various real-world projects. His proficiency in these technologies is evident from the successful completion of five full-stack projects. With a strong passion for emerging technologies, Vamsi is driven to apply his knowledge to foster innovation in the tech industry. He is actively seeking opportunities as a Python Developer or intern, aiming to expand his experience and create impactful solutions in the field.

Pilli Snigdha, a fourth-year Computer Science and Engineering student, holds certifications in Data Visualization from Tata Group, Agile Methodologies from Cognizant. Her practical experience includes internships in Java full-stack development role, where she contributed to impactful real-world projects. Demonstrating proficiency in both Python and Java through the successful completion of projects, Snigdha is passionate about leveraging her skills to drive innovation in the tech industry. She is actively seeking opportunities as a Python Developer or intern, aiming to further develop her expertise and contribute effectively to technological advancements.

Mysetla Siva Prasanth is a driven fourth-year student in Computer Science and Engineering, equipped with certifications in Data Visualization (Tata Group) and Agile Methodologies (Cognizant). His internship experience in Java full-stack development has equipped him with practical skills in executing real-world projects and completing comprehensive full-stack assignments. With a strong passion for emerging technologies, Siva is eager to apply his expertise to foster innovation in the tech sector. He is actively pursuing opportunities as a Python Developer or intern, aiming to further enhance his skills and contribute effectively to the industry's advancements.

Kandala T. L. Pujitha is a final-year student pursuing a B.Sc. degree in Maths, Statistics, and Computers. She holds certifications in Data Visualization from Tata Group, Agile Methodologies from Cognizant, and additional certifications in Soft Skills Development. Pujitha completed an internship focused on PowerBI, gaining practical experience in utilizing data visualization tools to derive actionable insights. With a robust academic foundation and a passion for technology, she is eager to apply her skills to drive innovation in the tech industry. Pujitha is actively seeking opportunities to leverage her expertise in data visualization and analytics, combined with her strong soft skills, to make a meaningful impact in her professional career.