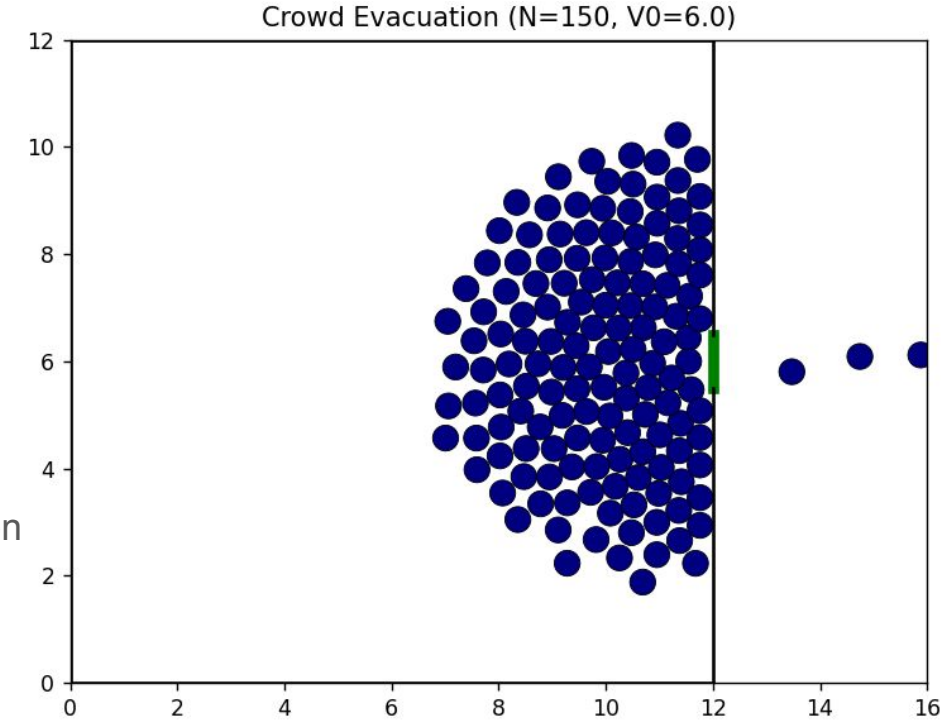
Universiteit van Amsterdam

Complexity and Emergence in Crowd Dynamics

Studying the dynamical behaviour of crowd evacuation



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Why Crowd Dynamics?

The Problem:

- Large crowds under stress exhibit collective dynamics: **pushing, jamming**
- Leads to disasters and the "**faster-is-slower effect**"
- Simulation could discover complex and emergent behaviour of crowds

The Approach:

- Dense crowds resemble **driven granular systems:**
- Individuals interact through physical contact, friction and repulsion: **The Social Force Model**
- Vary model parameters (size of agents, forces between them) to study collective efficiency

The Social Force Model

All particle movement based on this:

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

Four forces
- Desired Movement (A)
- Social repulsion (B)
- Body (C)
- Sliding friction (D)

Both for all individual particles and the walls:

$$\mathbf{f}_{ij} = \underbrace{\{A_i \exp[(r_{ij} - d_{ij})/B_i]}_{\text{(B)}} + \underbrace{kg(r_{ij} - d_{ij})\}}_{\text{(C)}}\mathbf{n}_{ij} + \underbrace{\kappa g(r_{ij} - d_{ij})\Delta v_{ji}^t}_{\text{(D)}}\mathbf{t}_{ij}$$

$$\mathbf{f}_{iW} = \{A_i \exp[(r_i - d_{iW})/B_i] + kg(r_i - d_{iW})\}\mathbf{n}_{iW} - \kappa g(r_i - d_{iW})(\mathbf{v}_i \cdot \mathbf{t}_{iW})\mathbf{t}_{iW}$$

Experiments & Hypotheses

The effect of increasing velocity:

- Higher desired velocity leads to coordination breakdown and jamming.

The effect of random movements using noise:

- Noise (randomness) might paradoxically IMPROVE flow by breaking jams.

The effect of friction:

- Increasing friction stabilizes force chains and increases clogging.

The effect of agent size:

- Larger individual radius leads to coordination breakdown and jamming.
- Higher radius variability leads to coordination breakdown and jamming.

The effect of panic and herding:

- More panic leads to jamming and an increasing difference in door usage.

Methodology:

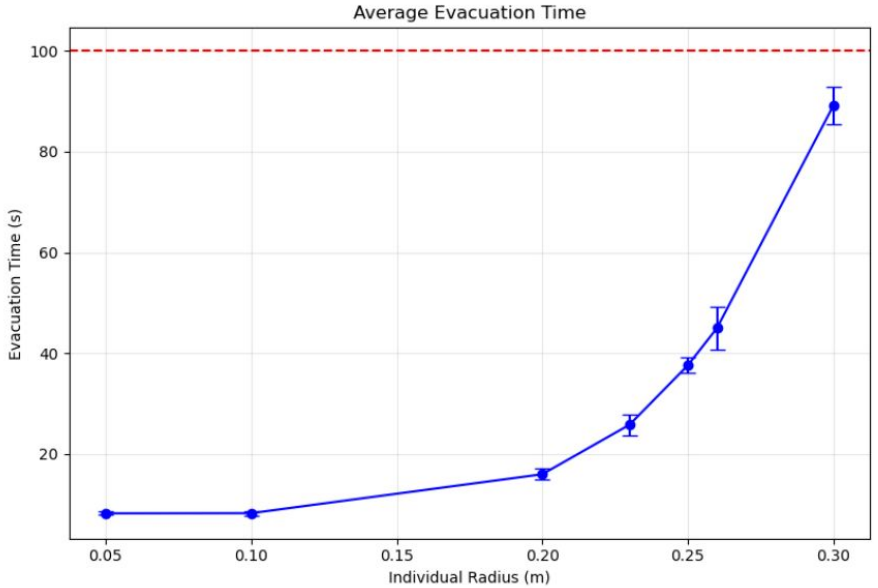
Time integration scheme: $$\vec{F}_i = \vec{F}_i\left(\vec{x}_i, \vec{v}_i\right) \rightarrow \begin{cases} \vec{v}_{i+1} = \vec{v}_i + \dfrac{\vec{F}_{i+1}}{m} dt \\ \vec{x}_{i+1} = \vec{x}_i + \vec{v}_{i+1} dt \end{cases}$$

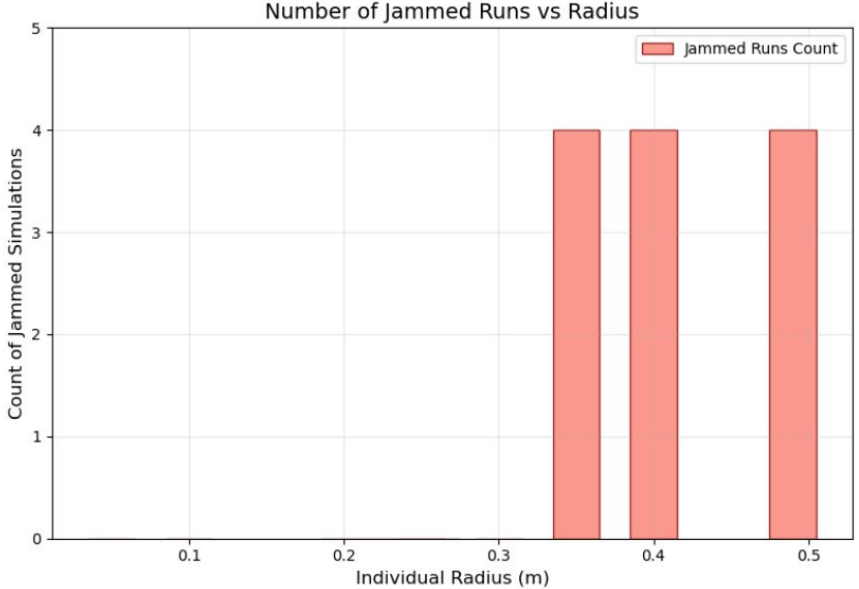
- **Sampling Step:** $dt = 0.001s$ *(Worst case scenario)*
- A state is **Jammed** if the simulation take 100s or if the flow is interrupted for 20s

Experimental Goal:

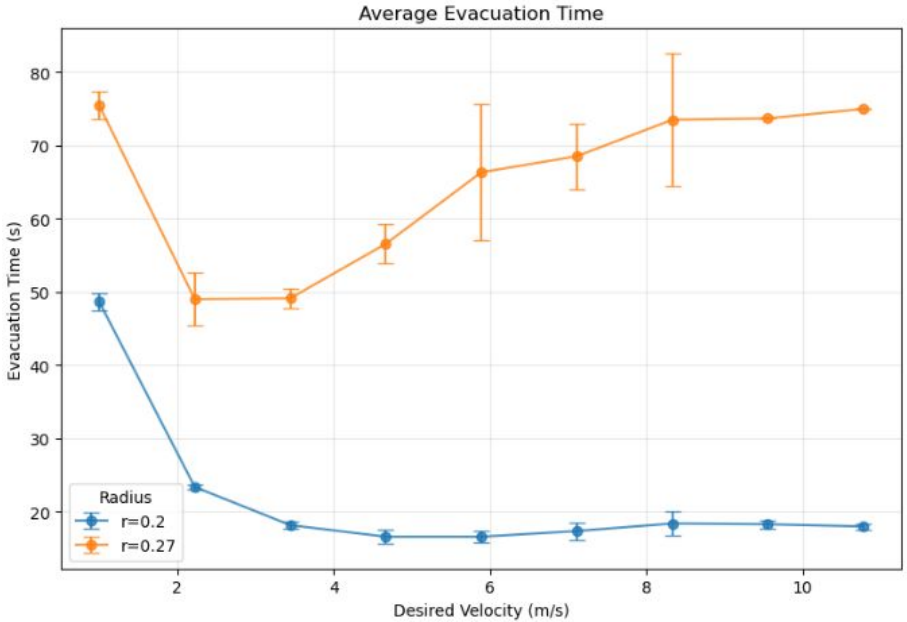
- Study of Phase Transition: **Evacuation Time vs Systems Parameters** (Pedestrian Radius, Desired Velocity, Friction Coefficient, Noise)
- Two different approach: door oriented vs panic parameter

Radius Results: bigger particles block the flow





Velocity Results: The “Faster-is-Slower” Effect



Small Radius: fluid behaviour.

Bigger Radius: presenting phase transition from laminar flows to crowded states.

Hypothesis confirmed!

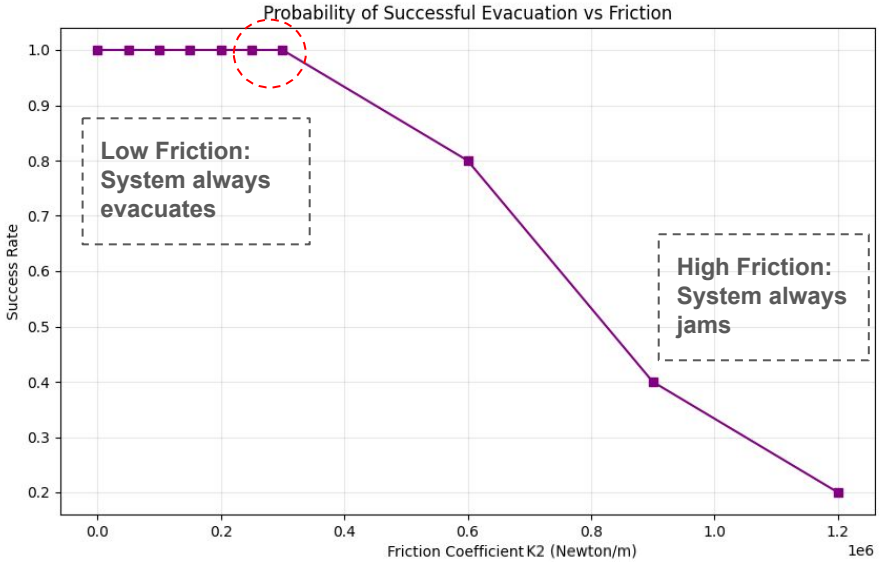
Friction Analysis:

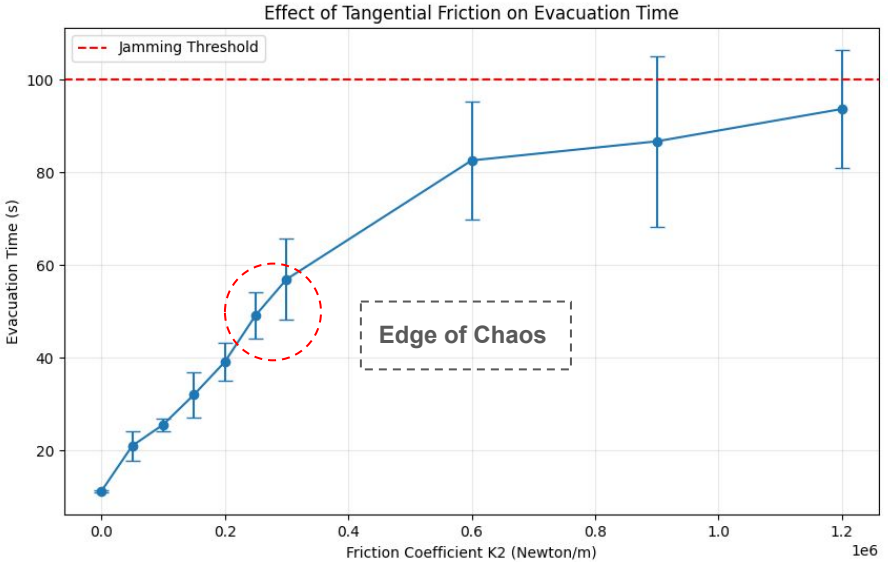
Increasing friction stabilizes force chains and increases clogging

- def FrictionExperiment(K2_values, runs):
  - run simulation (100 individuals, 5 runs) for K2_values
  - measure evacuation times
  - if system jams: assign a penalty time of 100seconds
  - count amount of jammed and evacuated simulations

Results: Friction Experiment

Studying the Friction Coefficient (K2) and the impact on crowd flow





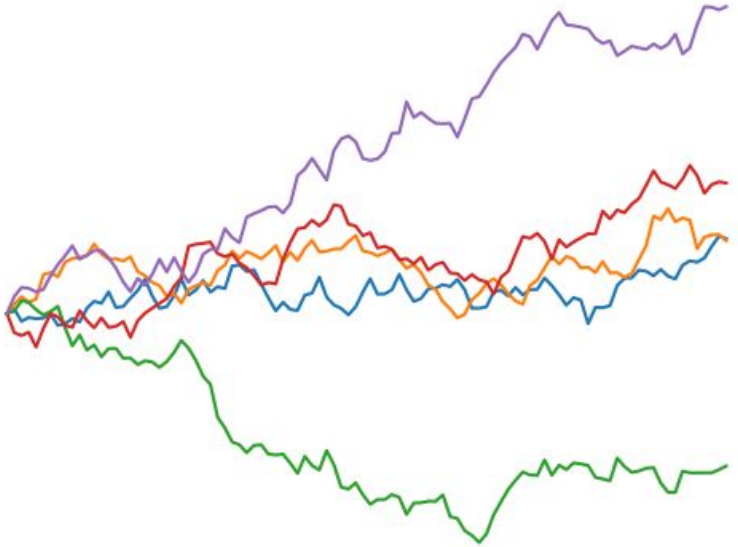
Noise Analysis

Noise might improve flow by breaking jams

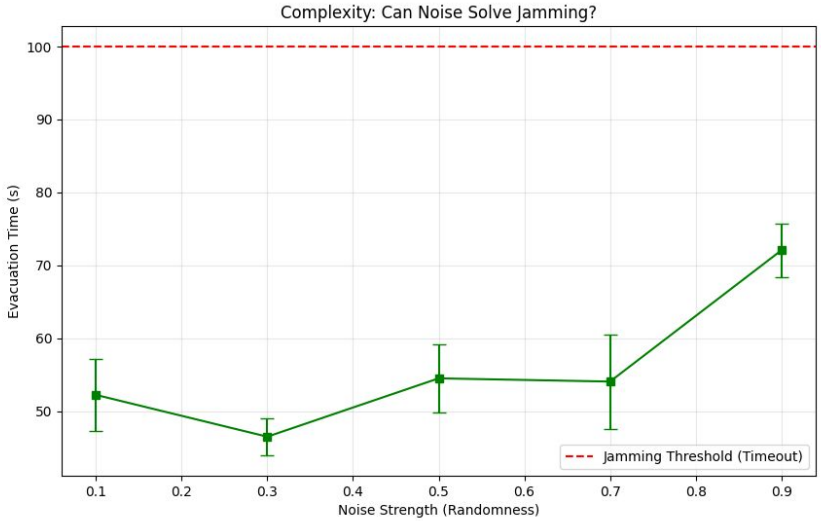
- Noise is generated as a added velocity for every agent for every step by a wiener process

- Implemented 1D

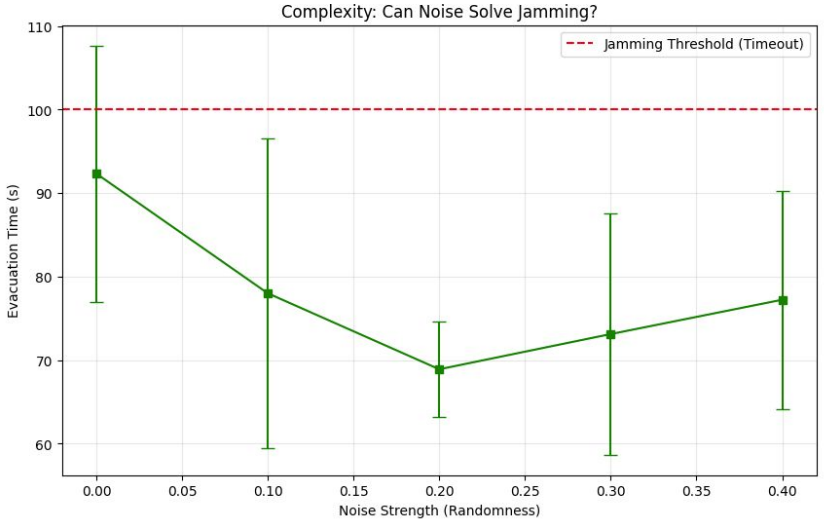
def NoiseEffectExperiment
- run 5 times
- different values of noise integration



Results: Noise



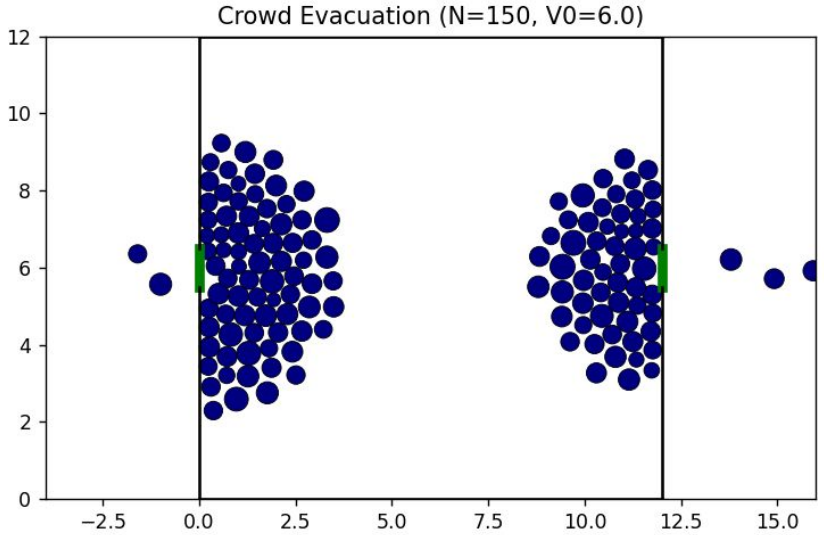
Parameters: r_mean = 0.25, noise_constant = 4



Parameters: r_mean = 0.27, noise_constant = 8

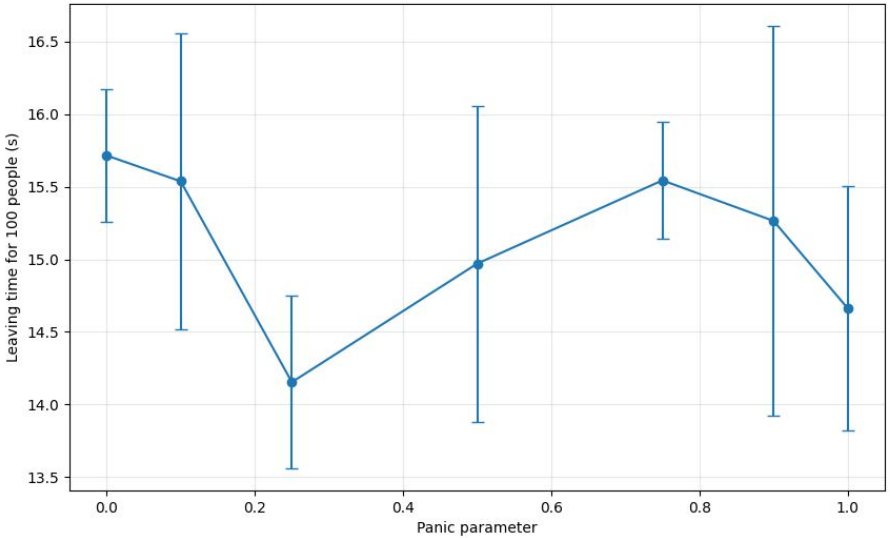
Panic & Herding

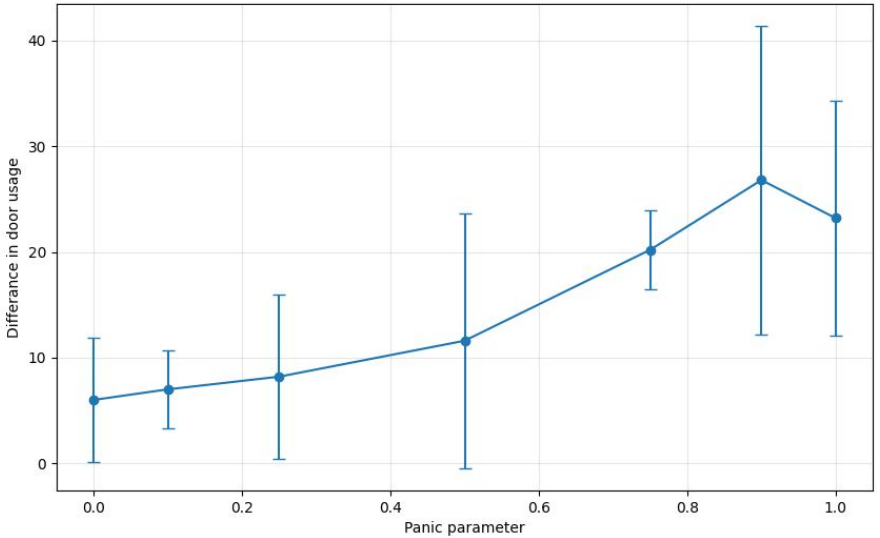
- Expand the model to two doors
- Invisible doors
- Desired direction:
  - Random
  - Influenced by neighbors
- Panic Parameter



$$\mathbf{e}_i^0(t) = \mathrm{Norm}[(1-p)\mathbf{e}_i(t) + p\langle \mathbf{e}_j(t)\rangle_i]$$

Results: Panic & Herding





Low panic:
Slow; individuals find exits randomly.
High Panic:
Slow; herding happens at one door, leads to jamming.

Conclusion

- Implemented crowd dynamics through Social Force Model

- Bigger individuals cause jamming
- The “Faster-is-Slower” effect
- Friction causes clogging
- Noise improves, then decreases the flow
- Panic causes herding, and thus jamming

- Future work: room shapes and extend two door system

References

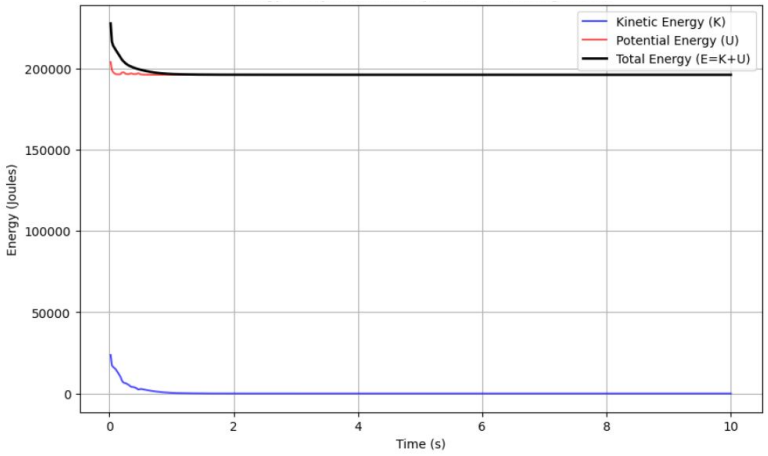
- Helbing, D., Farkas, I. & Vicsek, T. Simulating dynamical features of escape panic. *Nature* 407, 487–490 (2000).

Appendix 1: Evaluating ΔT

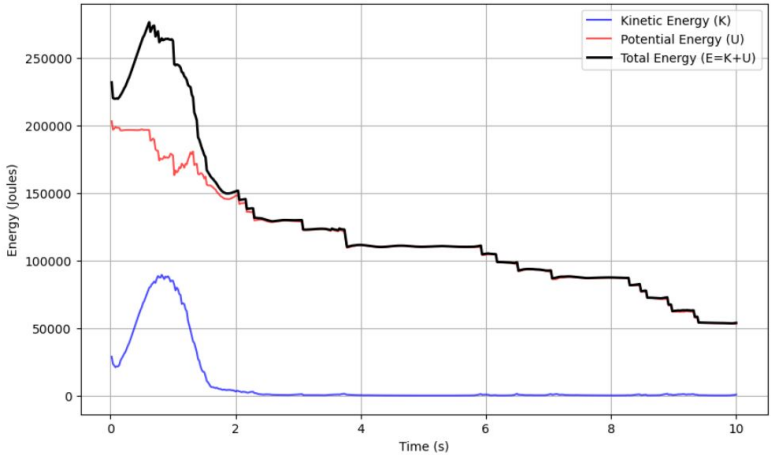
- **Harmonic Constraint:** $dt < 2\sqrt{\frac{m}{K_1}} \simeq 0.05$
- **Damping Constraint:** $dt < \frac{m}{K_2 \times 15\% \, R_{MAX}} \simeq 0.004$
- **Wall Constraint:** $dt < \frac{10\% \, R_{MIN}}{v_{MAX}} \approx 0.002$

$$\Rightarrow \Delta t = 0.02, \quad dt = 0.0013$$

Appendix 2: Energy & Stability

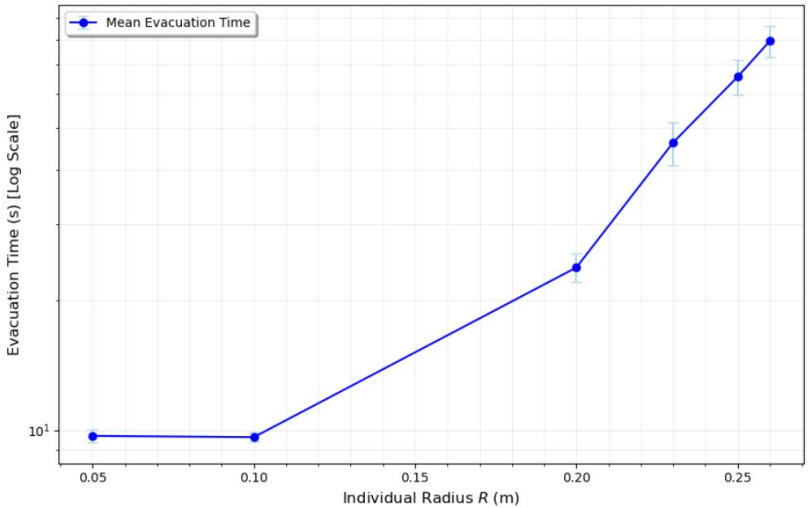


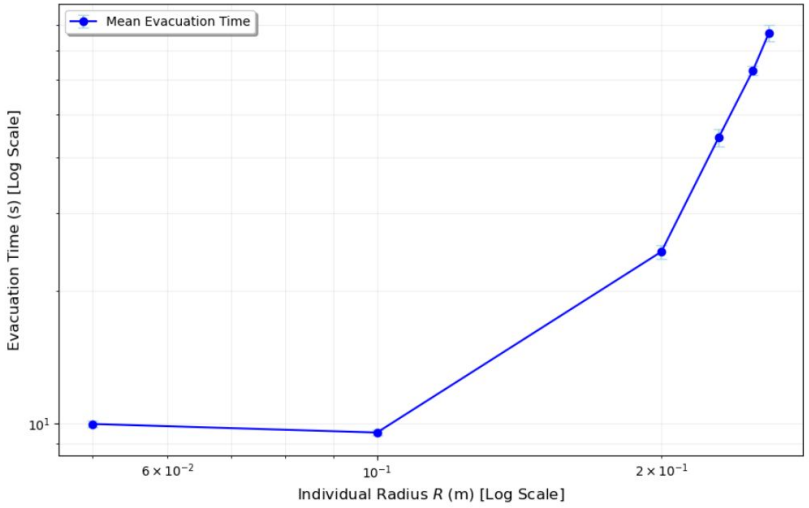
$$desired\ velocity = 0$$



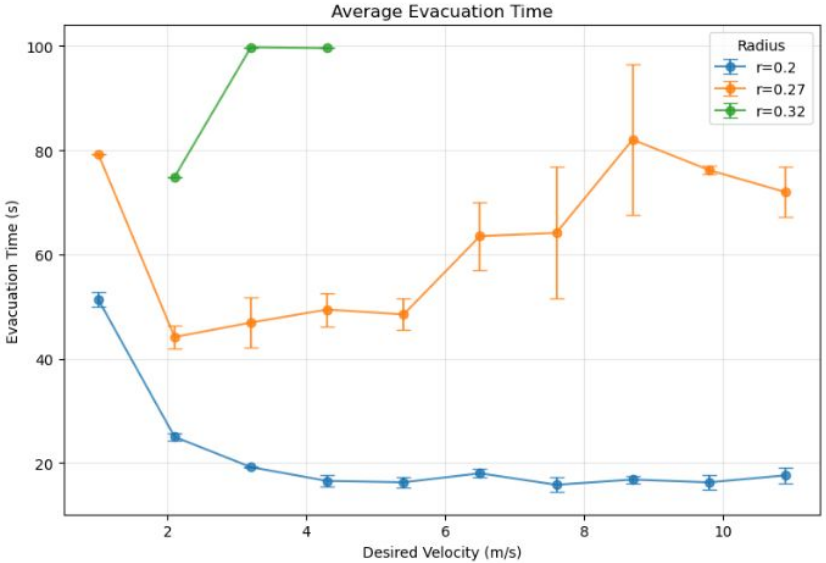
$$desired\ velocity = 9\frac{m}{s}$$

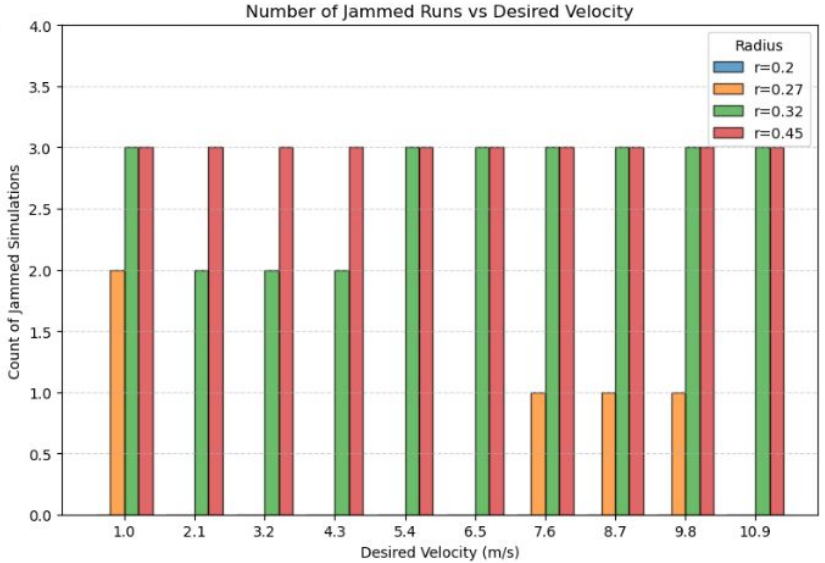
Appendix 3: logarithmic Time vs Radius



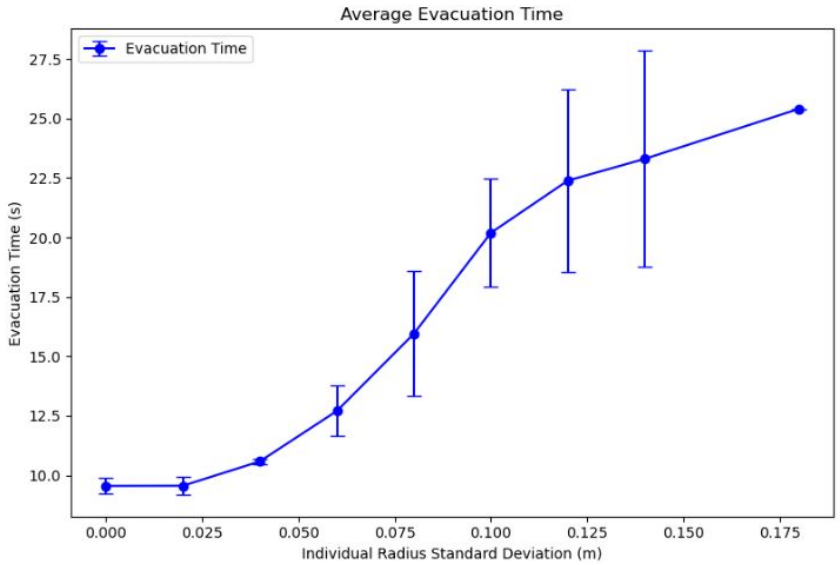


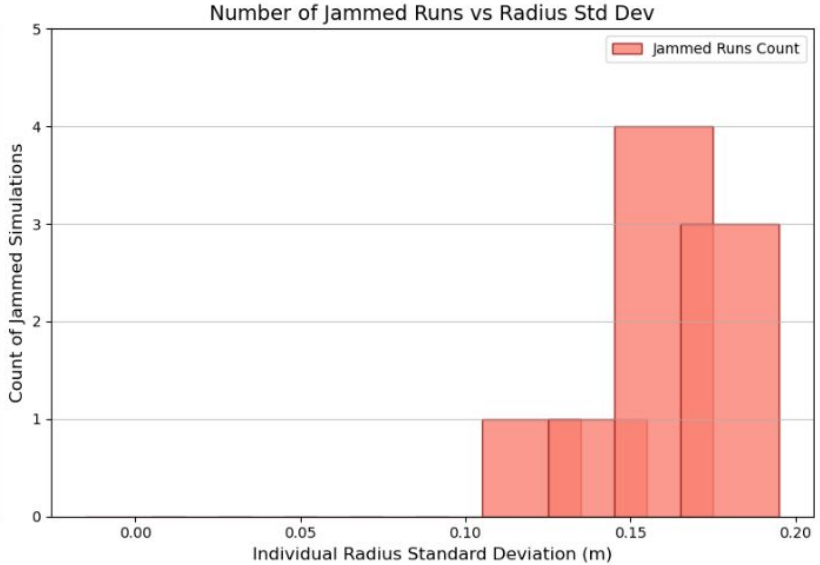
Appendix 4: Desired Velocity





Appendix 5: Results: Radius Standard Deviation



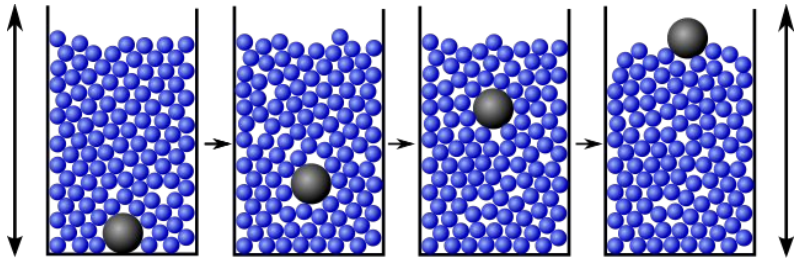


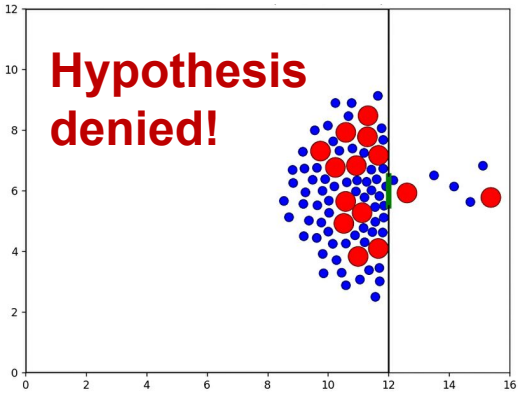
→ heterogeneity increases time (big particles stop the flow)

Appendix 6: Results: The "Brazilian Nut Effect"

Mechanism:
Classical segregation is driven by vibrational "noise" creating transient gaps that allow percolation against gravity.

Our System Dynamics:
The system is driven by a strong motivational force, not vertical vibration. When jammed there is insufficient fluctuation energy for smaller agents to sift through the interstitial spaces.





img: https://plus.maths.org/content/maths-minute-brazil-nut-effect