

# Escape Panic: Dynamical Simulations & Empirical Investigations

Helbing, D., I. Farkas, T. Vicsek[2000]. “Simulating dynamical features of escape panic”. Nature 407, 487-490

Helbing, D., A. Johansson, and H.Z. Al-Abideen [2007]. “The Dynamics of Crowd Disasters: An Empirical Study”. arXiv.org:physics/0701203

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1585

# Characteristics of Escape Panic

- Behaviors:
  - (1) People try to move fast
  - (2) People push and shove
- At bottlenecks:
  - (3) Uncoordinated passage through bottlenecks
- At exits:
  - (4) Arching, clogging
  - (5) Jam builds
  - (6) Pressure builds
  - (7) People are injured, become obstacles

# Characteristics of Escape Panic

- Herd instinct:
  - (8) Imitate local group behavior
  - (9) Overlook, underutilize alternative exits

# Basis of Simulation

There are a number of pedestrians, each with a certain mass, each of whom wants to move with a certain speed in a certain direction. So, they modify their current velocity over a certain time.

$$\begin{aligned}
 m_i \frac{d\mathbf{v}_i}{dt} &= m_i \frac{v_i^0(t) \mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i} \\
 &= m_i \frac{\Delta \mathbf{v}_{\text{desired, actual}}(t)}{\tau_i}
 \end{aligned}$$

# Avoiding Others, Walls

**W**

**j**

Simultaneously, they are avoiding walls and other pedestrians.

This avoidance is modeled by 'interactive forces':  $f_{(\text{thing1})(\text{thing2})}$

The forces to avoid every other pedestrian and all walls are summed, producing:

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

Total change in motion = change to reach desired velocity +  
avoiding people +  
avoiding walls

# Parameters for Calculating Avoidance

$d_{ij}$  Distance between 2 pedestrians' centers of mass

$r_{ij} = r_i + r_j$  Combined radii of 2 pedestrians

$(r_{ij} - d_{ij})$  is *compression*, in range  $(-\infty, r_{ij})$

$r_{ij} < d_{ij} \rightarrow r_{ij} - d_{ij} < 0$  Negative: space cushion, no compression

$r_{ij} = d_{ij} \rightarrow r_{ij} - d_{ij} = 0$  Zero: touching (just barely)

$r_{ij} > d_{ij} \rightarrow r_{ij} - d_{ij} > 0$  Positive: compressed

$\mathbf{n}_{ij}$  Normalized (unit) vector pointing from  $j$  to  $i$

$\mathbf{t}_{ij}$  Tangential direction

$\Delta v_{ji}^t = (v_j - v_i) \cdot \mathbf{t}_{ij}$  Tangential velocity difference

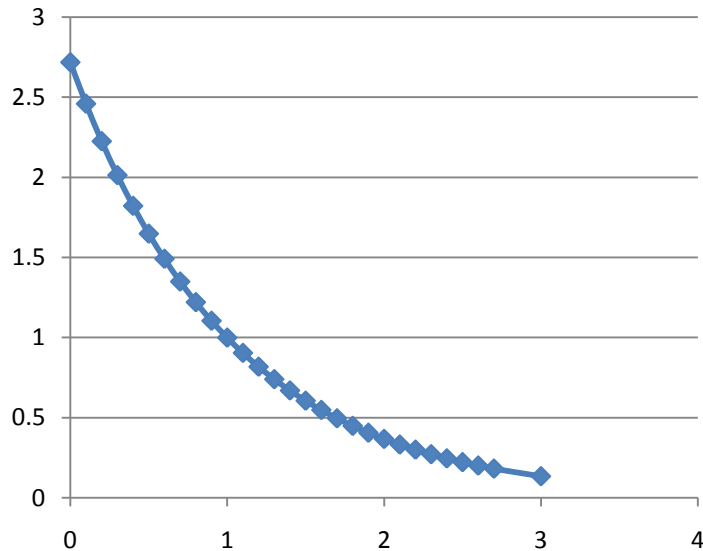
# General Avoidance

General Avoidance: 
$$\mathbf{f}_{ij} = A_i \exp\left[\frac{(r_{ij} - d_{ij})}{B_i}\right] \mathbf{n}_{ij}$$

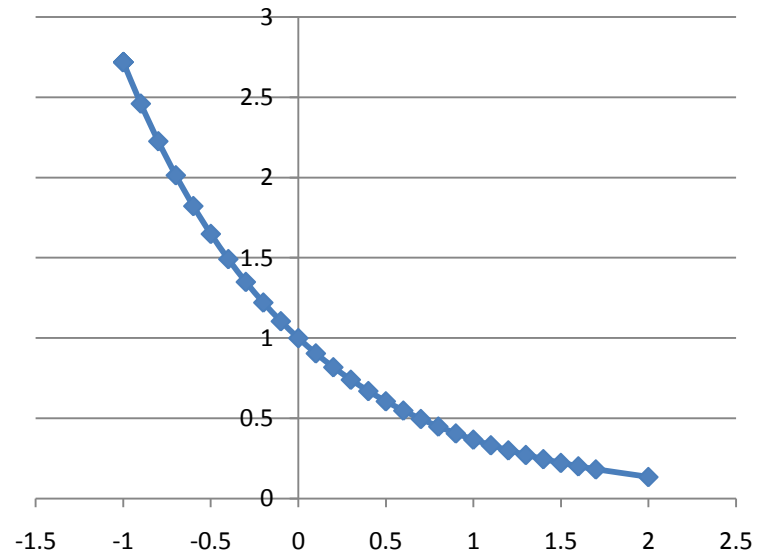
$A_i, B_i$

Constants

**exp(r-d), in units of r**



**exp(r-d), in units of r  
(actual separating space)**



# Contact: Decompression, Friction

$k(r_{ij} - d_{ij})\mathbf{n}_{ij}$       Decompression force

$\kappa(r_{ij} - d_{ij})\Delta v_{ji}^t \mathbf{t}_{ij}$       Sliding friction force

- (2) Pushing,  
Shoving

$k, \kappa$  Constants (very large)

$g(x)$  Returns 0 for nonpositive  $x$ ; otherwise,  $x$

$$\mathbf{f}_{ij} = \left\{ A_i \exp \left[ \frac{(r_{ij} - d_{ij})}{B_i} \right] + k g(r_{ij} - d_{ij}) \right\} \mathbf{n}_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ji}^t \mathbf{t}_{ij}$$

Total avoidance =

general avoidance +

decompressing (if applicable) +

sliding friction (if applicable)

# Assigning Variable Values

Some values derived from observation:

relaxed :  $v_i^0 \approx 0.6 \text{ m/s} \approx 1.3 \text{ miles/hour} \approx 45 \text{ minute mile}$

normal :  $v_i^0 \approx 1 \text{ m/s} \approx 2.2 \text{ miles/hour} \approx 27 \text{ minute mile}$

nervous :  $v_i^0 \approx 1.5 \text{ m/s} \approx 3.4 \text{ miles/hour} \approx 18 \text{ minute mile}$

panic :  $v_i^0 \approx 5 \text{ m/s} \approx 11.2 \text{ miles/hour} \approx 5 \text{ minute mile}$

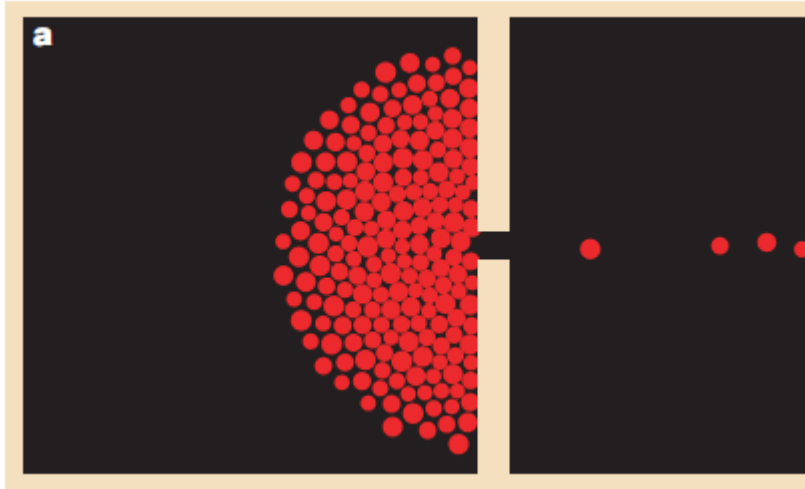
severe panic :  $v_i^0 \approx 10 \text{ m/s} \approx 22.4 \text{ miles/hour} \approx 2.7 \text{ minute mile}$

• (1) Moving fast

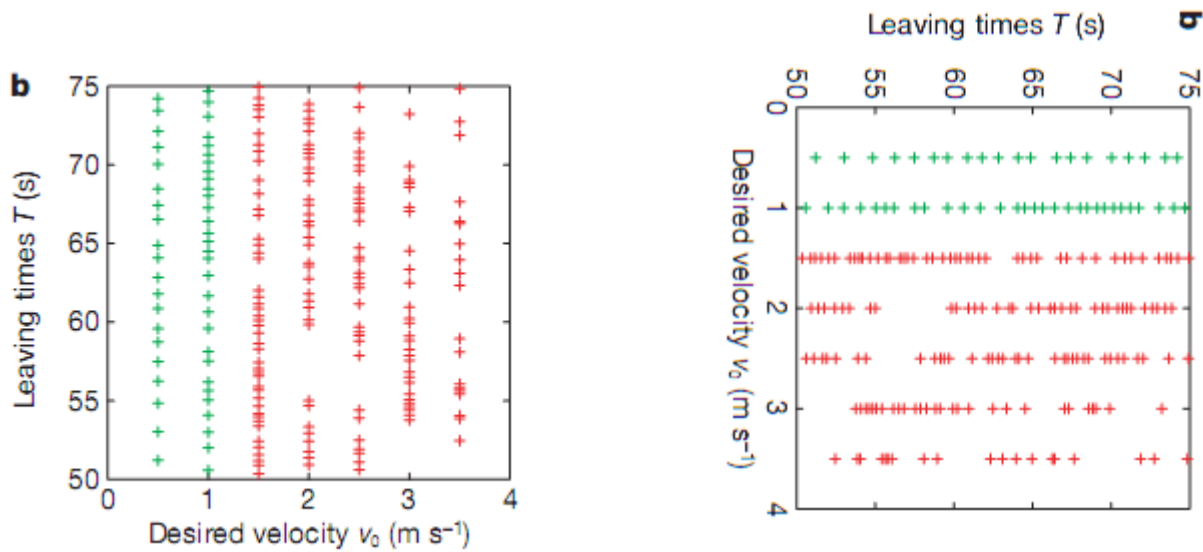
Other values calculated to reproduce observed behaviors

Simulated pedestrians have variant radii, otherwise identical

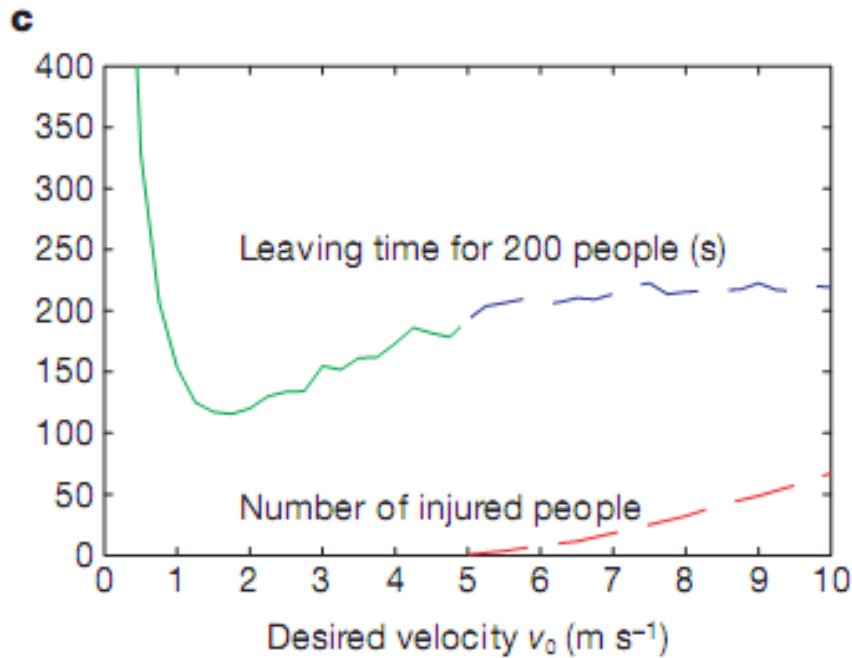
# Result: Clogging



- (4) Clog
- (5) Builds
- (6) High pressure
- (7) Injury



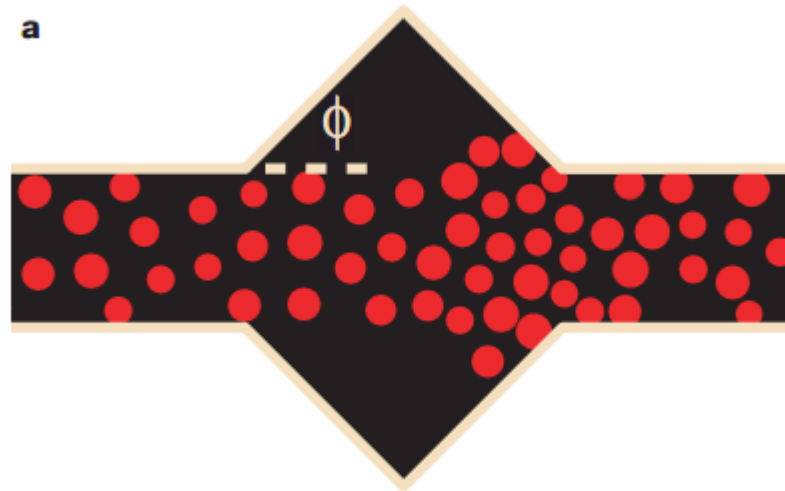
# Result: Faster Is Slower



Therefore, clogged pedestrians who panic and increase their desired speed only worsen the situation.

# Result: Faster Is Slower

- (3) Bottleneck problems



A wide section of hallway paradoxically produces a bottleneck effect, increasing with pedestrian speed.

Note that introducing a column in front of an exit also paradoxically facilitates flow by breaking the arching clog. (“Removing the keystone”)

# Panic Parameter ( $p_i$ ): Herding

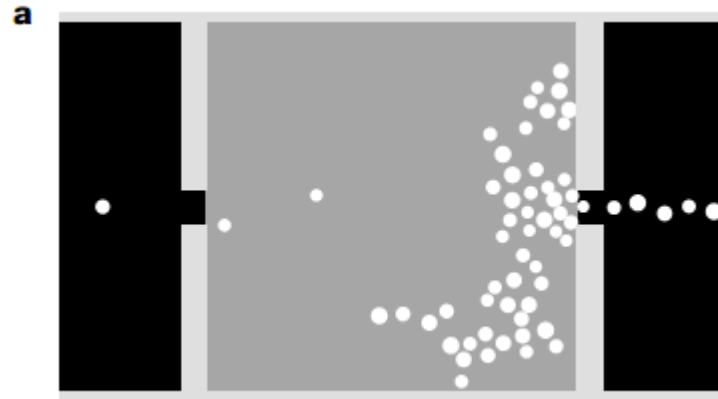
$$e_i^0(t) = \mathbf{e}_i \quad \text{Individual direction}$$

$$e_i^0(t) = \left\langle \mathbf{e}_j^0(t) \right\rangle_i \quad \text{Average direction (of neighbors (j) in radius (R_i))}$$

$$e_i^0(t) = (1 - p_i) \mathbf{e}_i + (p_i) \left\langle \mathbf{e}_j^0(t) \right\rangle_i$$

0%	100%	(normalized to unit vector)
10%	90%	
...	...	
90%	10%	
100%	0%	

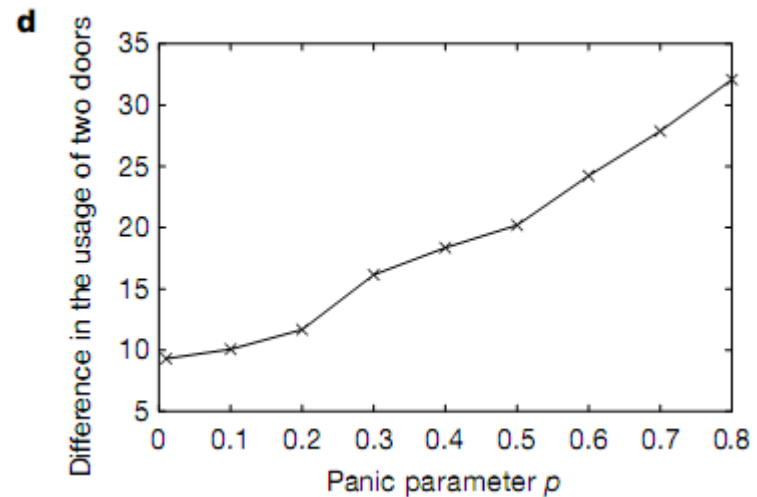
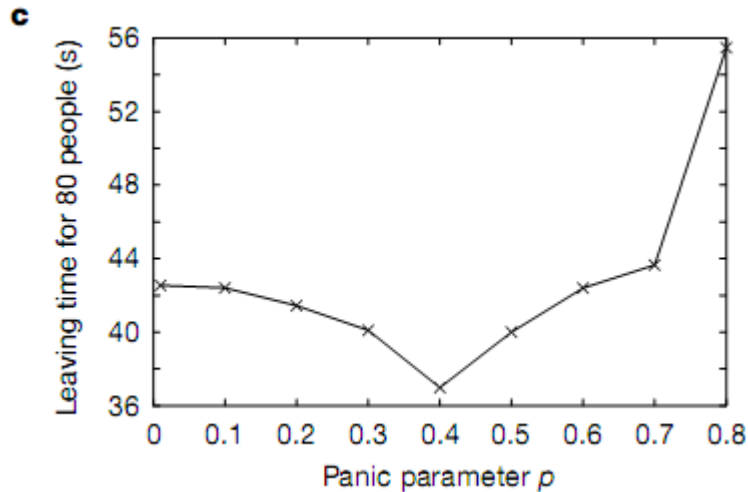
# Results: Panic in Moderation, Please



- (8) Herding
- (9) Overlooking exits

Moderate panic produces the best results.

Excessive herding leads to slow release times, underutilization of alternate exits, and clustering in the corner.



# Actual Crowd Disasters, Briefly

- Differing dynamics:
  - Smooth flow
  - Stop and go (cyclical)
  - Turbulent (irregular flows – chaotic)
- Generic fluid-dynamic flow-density equation [ $Q(\rho) = \rho V(\rho)\rho$ ]
  - Works well at low densities
  - Fails to describe the turbulent dynamics emerging at higher densities
    - Wide variance in regional density (up to twice average)
    - Clustering within flow – propulsive force *increases* at extreme densities
- Particle model described earlier
  - Works well for smooth flow, stop and go traffic
  - Fails to account for turbulent effects

# Actual Crowd Disasters: Prevention

- Crowd accident of January 12, 2006:
  - occurred 10 minutes after turbulent crowd motion began
  - occurred 30 minutes after average flow dropped below critical threshold
  
- Preventative Strategies:
  - Expand capacity
  - Avoid 2-way flows
  - Disallow loitering
  - Scheduling
  - Monitoring crowd activity, density - especially in critical places