NSF Workshop on Multidisciplinary Complex Systems Research

The Effect of Following on Bidirectional Flow

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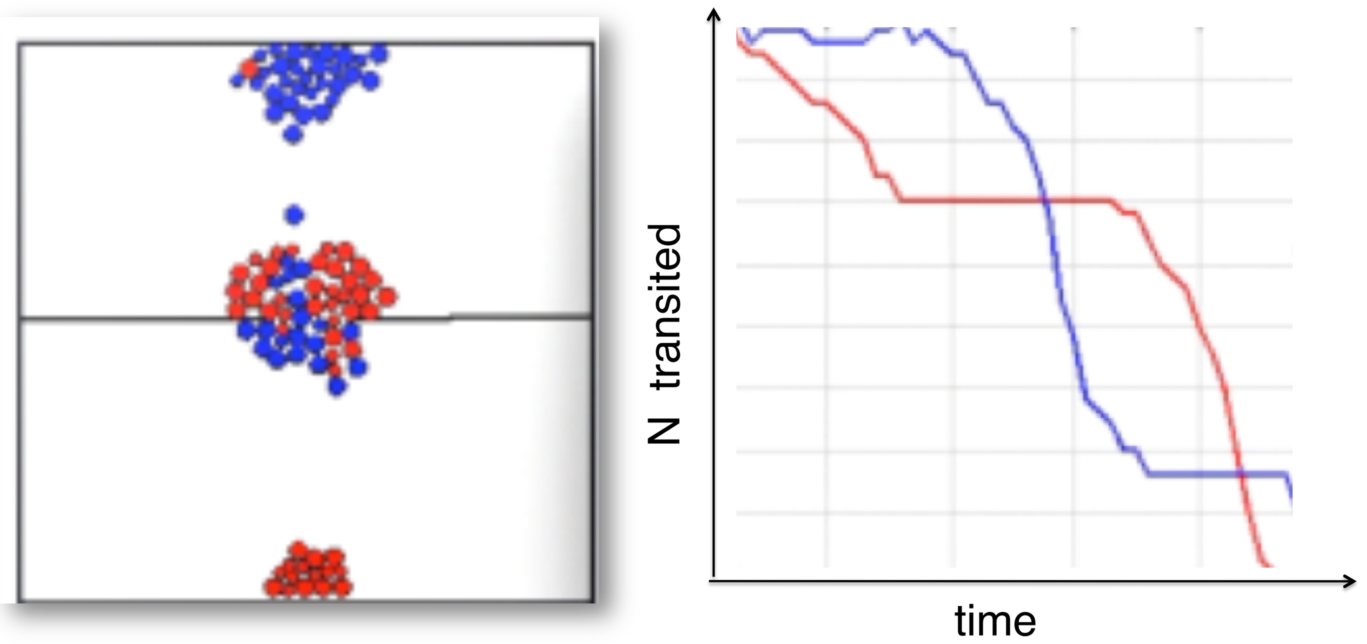
Introduction

Force-based simulations of self-propelled particles (spps) show fascinating, self-organized behaviors. In practical terms, they can mimic pedestrian dynamics, and guide thinking about urban design and crowd safety. We employ Helbing-Monlár-Farkas-Vicsek social forces. Two species of spps experience psychosocial and physical contact forces as they undergo bidirectional flow. Velocities are directed to achieve the goal of passing through a doorway to traverse a corridor.



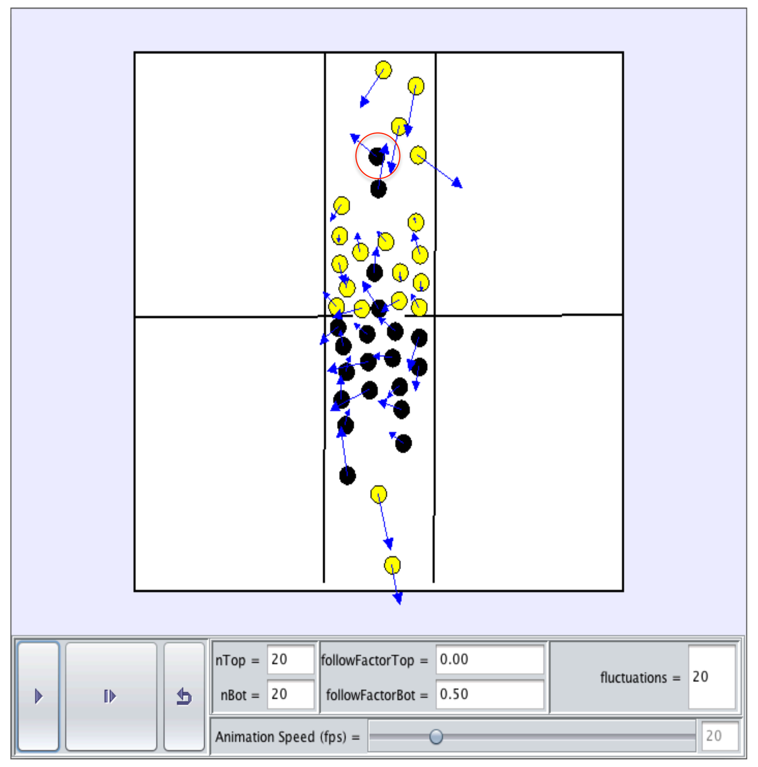
Red/blue sips with goal to flow down/up. There are spontaneous oscillations at a narrow doorway, and final states can show shows "trapping" – isolated spps caught in counter-flow and transported against direction of desired velocity.

Here, we study the **follow factor α**, the degree to which a particle **matches its direction of motion** to the average of **nearby, same-species particles.**

Characterization of dynamics

- N transited vs. time
- Efficiency
- Current and current density
- Velocity-based information entropy
- Burst size statistics
- Time lag statistics

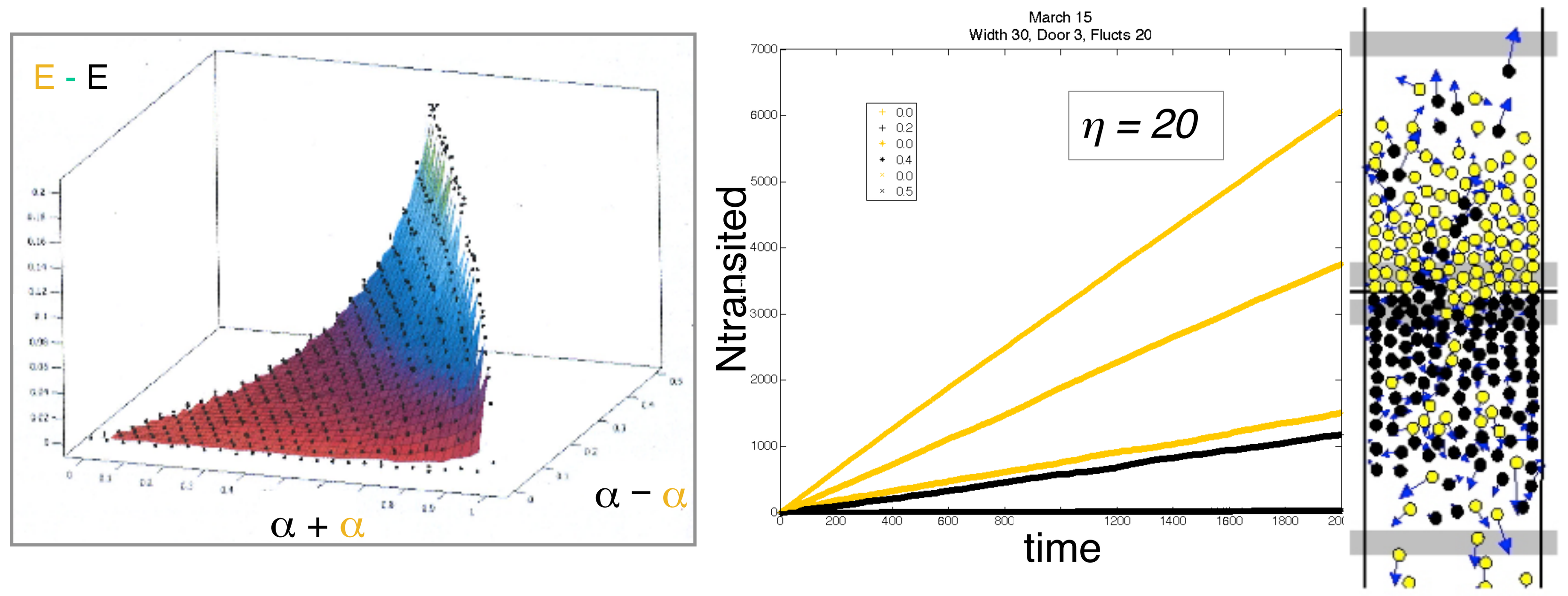
Simulation method



User interface for molecular dynamics simulations, written in EJS (Escobar and Christian). Velocity vectors are shown in blue. R, radius of red circle, is range for same-species neighbors which influence a given spp's direction of motion.

Results: Efficiency and Ntransited

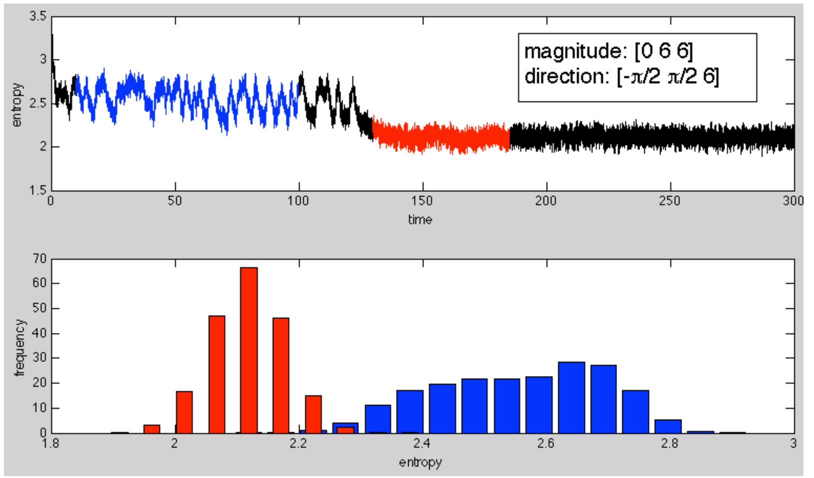
$$E = \langle v \rangle / v_{desired}$$

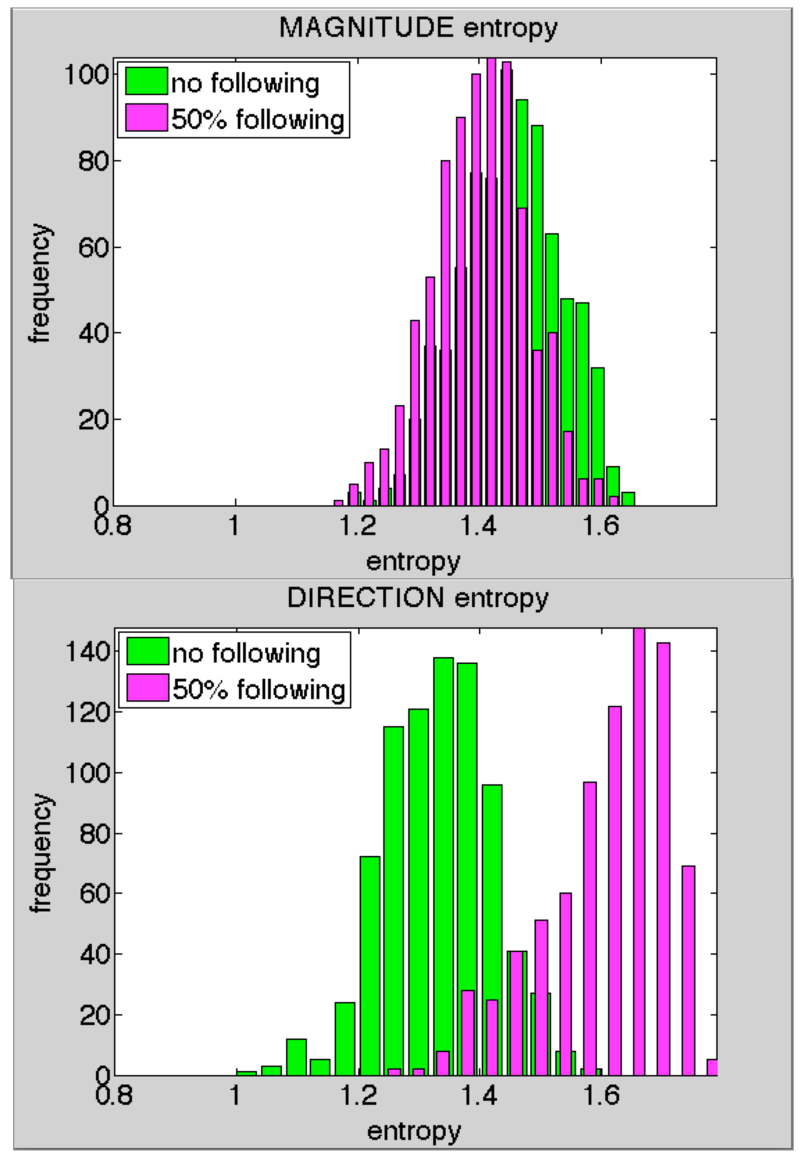


In these figures, yellow/black spps goal is to flow down/up.
*In all cases, α for **black** spps ≥ α for **yellow** spps*

Results: Information Entropy

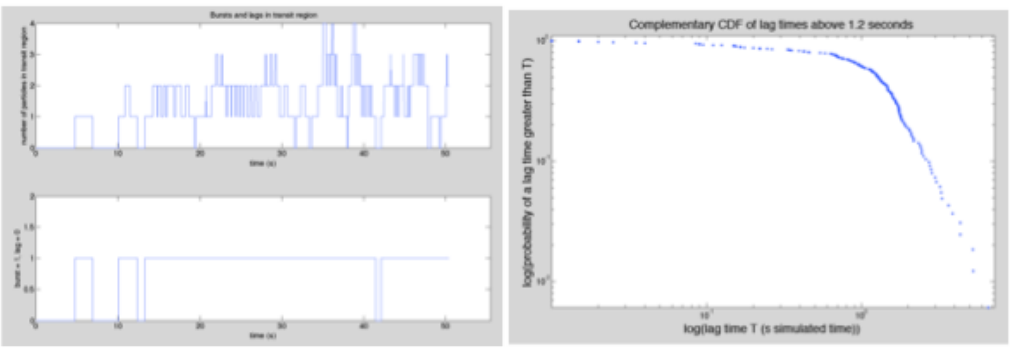
$$S = -\Sigma_i\ p_i\ ln\ p_i$$

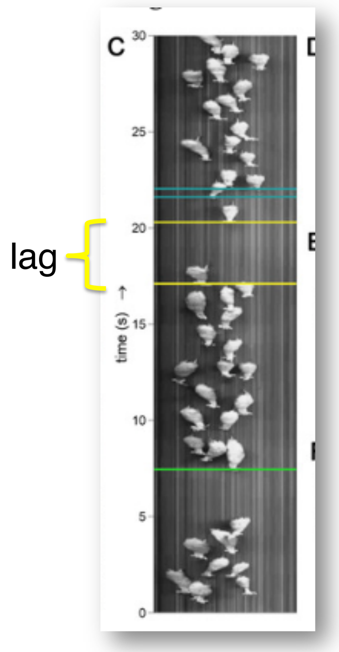




Top: Time series and histogram of entropy for one species of spp. Red and blue are epochs when particles jammed and flowing respectively. Middle and Bottom: Entropy based on magnitude and direction of velocity for bidirected spps with α = 0 (green) and α = 0.5 (purple).

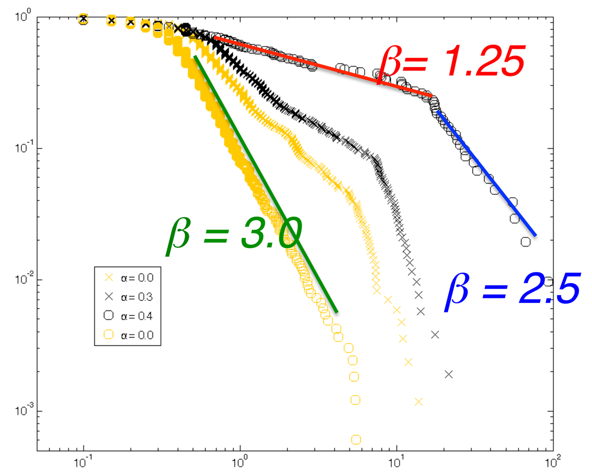
Results: Burst size and Time Lag Statistics



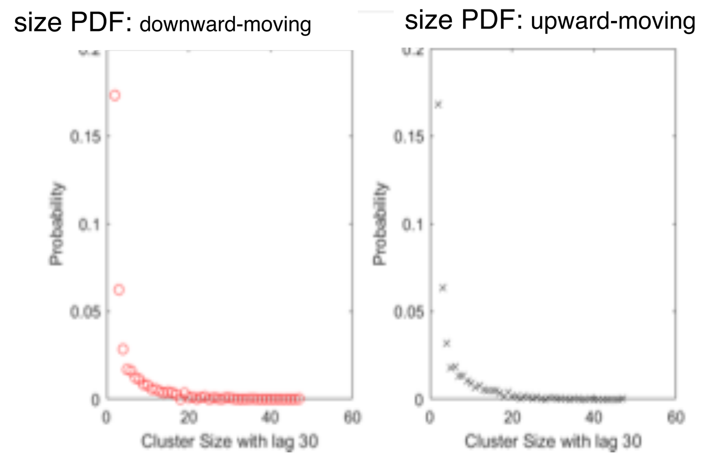


Top left: number of spps in "transit region" immediately beyond doorway. Bottom left: identification of lags (no spps in transit region for a time period exceeding a short-time threshold). Right: complimentary cumulative distribution function (cCDF) of lag times.

Zuriguel et al, 2014



cCDF with possible power law behavior, and transient jamming of spps with higher α: $P(T \geq \tau) \sim \tau^{\beta+1}$ with $\beta < 2$



Probability distribution functions (PDF)of burst sizes. To define time lag between bursts, polynomial fits to PDF were done with lag time as a parameter, until fit coefficients became consistent.

Equation of motion

$$m_i \frac{d\vec{v}_i}{dt} = \Sigma_{j,w}\vec{F}_{granular} + \vec{F}_{desire} + \Sigma_{j,w}\vec{F}_{psychosocial} + \eta_i$$

$$\vec{F}^{\ ij}_{granular} = kg(D_{ij} - r_{ij})\ \hat{n}_{ij}\ - \kappa g(D_{ij} - r_{ij})\Delta v^t_{ij}\ \hat{t}_{ij}$$

$$g(x) = \begin{cases} 0 & x < 0 \\ x & x \geq 0 \end{cases}$$

$$\frac{1}{m_i}\vec{F}^{\ i}_{desire} = \frac{v_i^o \hat{e}_i^o(t) - \vec{v}_i(t)}{\tau_i}$$

$$\Sigma_j \vec{F}^{\ ij}_{psychosocial} = A_i e^{(D_{ij} - r_{ij})/B_i}\ \hat{n}_{ij}$$

$$\hat{e}_i^o = (1-\alpha)\hat{e}_{goal,\ i} + \alpha\ \hat{e}_{neighbors,\ i}$$

Conclusions

- **In bidirectional flow, having two species with *different* propensities to follow affects transport.**
- Particles with a significantly **higher α** can be **dramatically slower** in reaching their goal. However, this result is sensitive to the level of noise, η as well as parameters chosen in the force model.
- **Information entropy** characterizes a less organized, more turbulent motion of the "followers".
- cCDF sometimes reveals **two time scales.** At short times, **jamming** of "follower" spps occurs, and at long times, flow is reinstated. Entropy is also an indicator of a jammed state.

Acknowledgements

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