

Data Science Course

Understanding swarm behaviour

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Presentation Overview

- Review past models (simple speed coupling, couzin model, vicsek model)
- Module 1: Effective leadership and decision-making in animal groups on the move (Couzin et al)
- Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

Review past models (simple speed coupling, vicsek model, couzin model)

Simple speed coupling: weighted speed

Particle adapts a fraction of its nearest neighbour's speed.

Review past models (simple speed coupling, vicsek model, couzin model)

Vicsek model

- introduce interaction zones: repulsion and alignment
- add noise

Review past models: simple speed coupling, vicsek model, couzin model

Couzin model

- different zones of neighbourhoods: repulsion, orientation, attraction

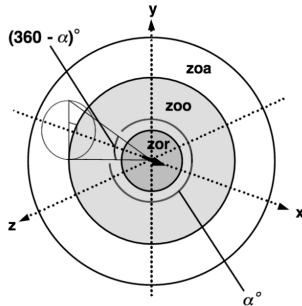


Figure: Representation of an individual in the model centred at the origin: zor = zone of repulsion, zoo = zone of orientation, zoa = zone of attraction. α = field of perception

Module 1: Effective leadership and decision-making in animal groups on the move (Couzin et al): czn2

We introduce a bias: orientation of ≥ 1 particle (the "informed" one/ "scout") and merge orientation and attraction zone.

THEORY

New parameters: weight of bias, proportion of bias, group direction

Goal: Which parameter sets give a nice group movement, and how does the behaviour change when we change the parameters?

update of d_i in each zone:

$$\mathbf{d}_i(t + \Delta t) = - \sum_{j \neq i} \frac{\mathbf{c}_j(t) - \mathbf{c}_i(t)}{|\mathbf{c}_j(t) - \mathbf{c}_i(t)|}$$

$$\mathbf{d}_i(t + \Delta t) = \sum_{j \neq i} \frac{\mathbf{c}_j(t) - \mathbf{c}_i(t)}{|\mathbf{c}_j(t) - \mathbf{c}_i(t)|} + \sum_{j=1} \frac{\mathbf{v}_j(t)}{|\mathbf{v}_j(t)|}$$

$$\hat{\mathbf{d}}_i'(t + \Delta t) = \frac{\hat{\mathbf{d}}_i(t + \Delta t) + \omega \mathbf{g}_i}{|\hat{\mathbf{d}}_i(t + \Delta t) + \omega \mathbf{g}_i|}$$

Module 1: Effective leadership and decision-making in animal groups on the move (Couzin et al): czn2

IMPLEMENTATION

- periodic boundary conditions
- virtual interaction of agents
- explicit Euler method: $v_{n+1} = v_n + \tau \cdot f(t_n, v_n)$

Module 1: Effective leadership and decision-making in animal groups on the move (Couzin et al): czn2

SIMULATION on specific parameter set

Module 1: Effective leadership and decision-making in animal groups on the move (Couzin et al): czn2

QUANTIFICATION

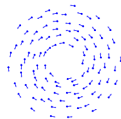
- Accuracy
- Group elongation
- Two scouts

Module 1: Effective leadership and decision-making in animal groups on the move (Couzin et al): czn2

SIMULATION optimised

Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

Motivation: Simulate swarming of multiagent systems in order to understand the operating principles of natural swarms, e.g. swarming behaviour of *M. xanthus* cells.



We choose a **kinetic theory** based approach.

The model traits are:

- self-propulsion
- friction
- interaction between particles: repulsion and attraction

Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

Consider N interacting, self-propelled particles governed by the following equations of motion

$$\frac{d\vec{x}_i}{dt} = \vec{v}_i \quad (1)$$

$$F = m \frac{d\vec{v}_i}{dt} = (\alpha v - \beta |\vec{v}_i|^2) \vec{v}_i - \vec{\nabla}_i U(\vec{x}_i) \quad (2)$$

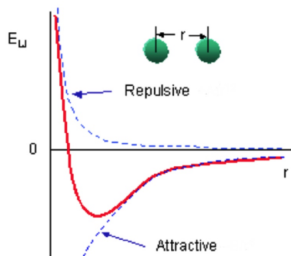
where U is a pairwise interaction potential and $\alpha, \beta > 0$ are values for propulsion and friction forces.

Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

For U we choose the *Morse potential*

$$U(\vec{x}_i) = \sum_{j \neq i} \left[\underbrace{-C_a e^{-|\vec{x}_i - \vec{x}_j|/l_a}}_{\text{attraction}} + \underbrace{C_r e^{-|\vec{x}_i - \vec{x}_j|/l_r}}_{\text{repulsion}} \right] \quad (3)$$

where C_a , C_r denote attractive and repulsive strengths and l_a , l_r their respective length scales.



Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

IMPLEMENTATION

- rigid boundary conditions
- no virtual interactions
- initial conditions of random distribution
- explicit Euler method to solve the ODEs

Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

SIMULATION

INSERT one example simulation

Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse

(D'Orsogna et al)

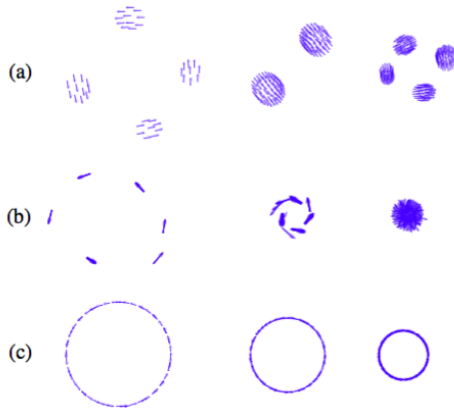


Figure: Catastrophic geometry.
(a) Clumps. (b) Ring Clumping. (c) Rings.

Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

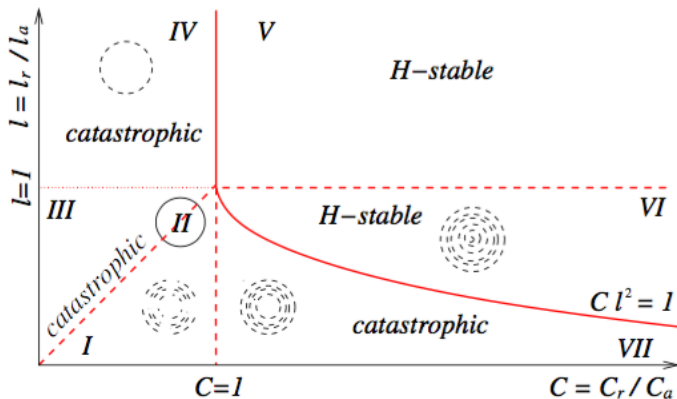


Figure: H-stability phase diagram of the Morse potential

Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

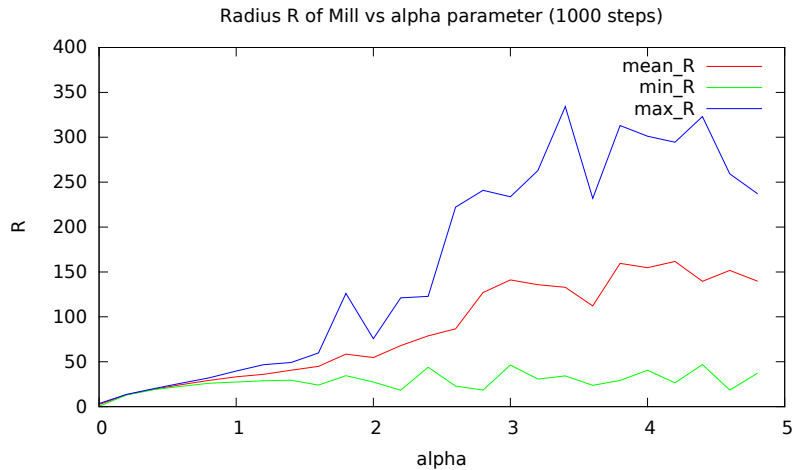
INSERT own simulations

Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

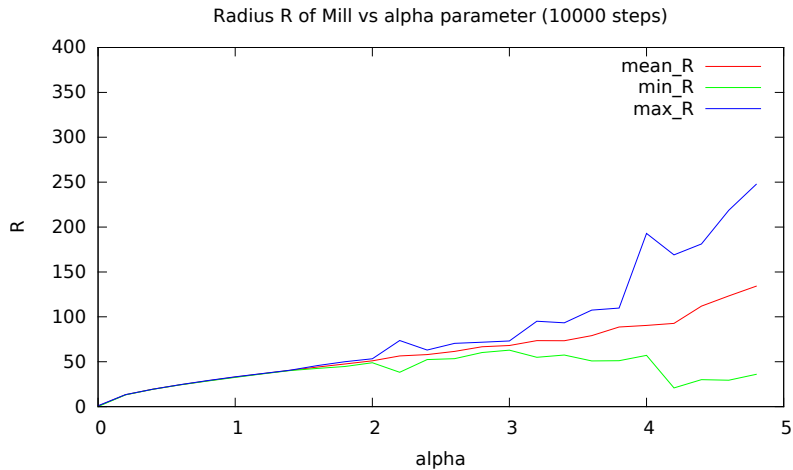
QUANTIFICATION

- parameter sets for different regions
- testing interesting trends, e.g. $R \propto \frac{\alpha m}{\beta N}$ (from setting $F_{centrifugal} = F_{centripetal}$)

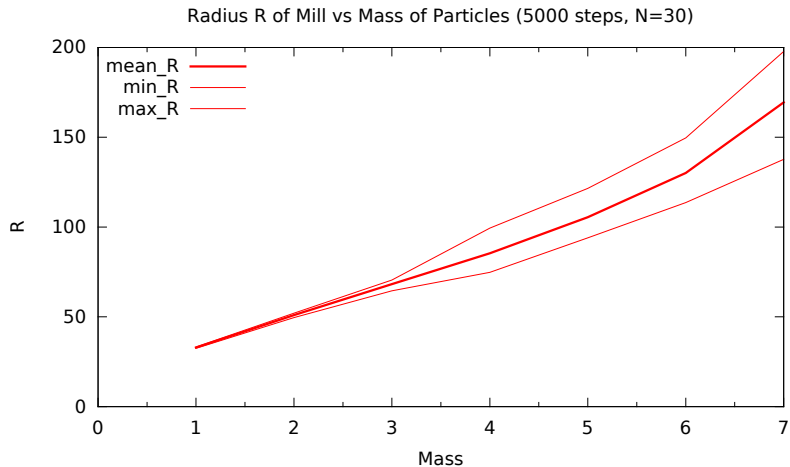
Quantification mill



Quantification `mill`



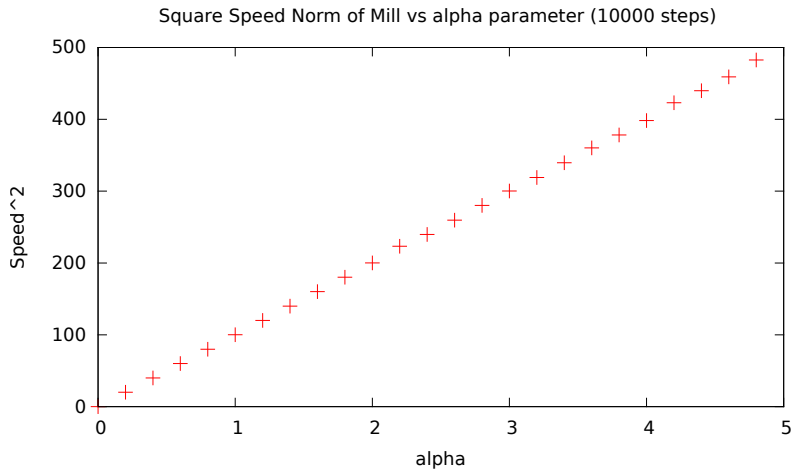
Quantification mill



Quantification mill

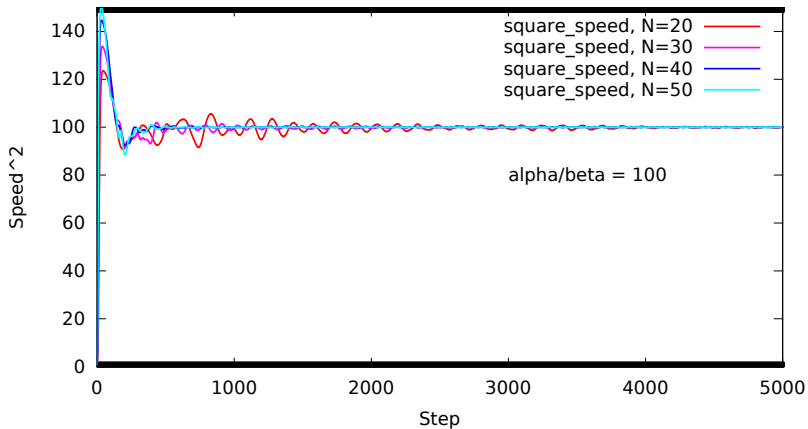
- parameter sets for different regions
- testing interesting trends, e.g. $R \propto \frac{\alpha m}{\beta N}$ (from setting $F_{centrifugal} = F_{centripetal}$)
- $|\vec{v}|^2 \xrightarrow{t \rightarrow \infty} \alpha/\beta$ coming from $(\alpha - |\vec{v}|^2\beta)\vec{v} = 0$ for steady state

Quantification mill



Quantification mill

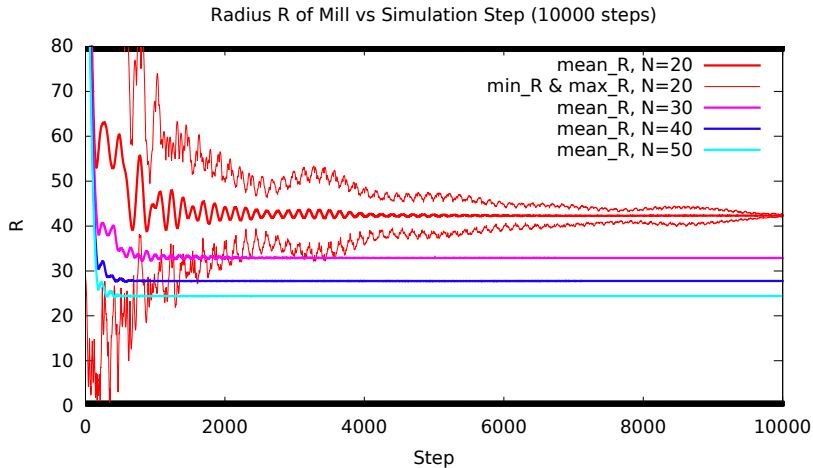
Square Speed Norm of Mill vs Simulation Step (10000 steps)



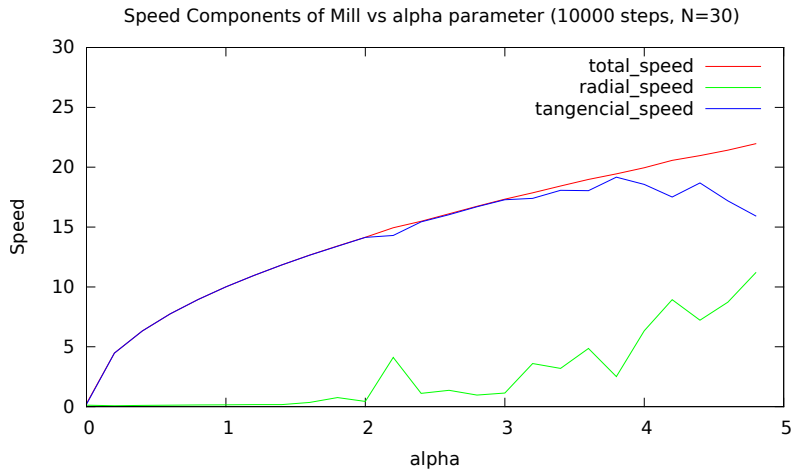
Quantification mill

- parameter sets for different regions
- testing interesting trends, e.g. $R \propto \frac{\alpha m}{\beta N}$ (from setting $F_{centrifugal} = F_{centripetal}$)
- $|\vec{v}|^2 \xrightarrow{t \rightarrow \infty} \alpha/\beta$ coming from $(\alpha - |\vec{v}|^2\beta)\vec{v} = 0$ for steady state
- confirmation of ring formation
 - $R_{max}, R_{mean}, R_{min}$ converge to same value
 - $v_{radial} \rightarrow 0$ and $v_{tangential} \rightarrow |v_i|$ for $t \rightarrow \infty$

Quantification mill

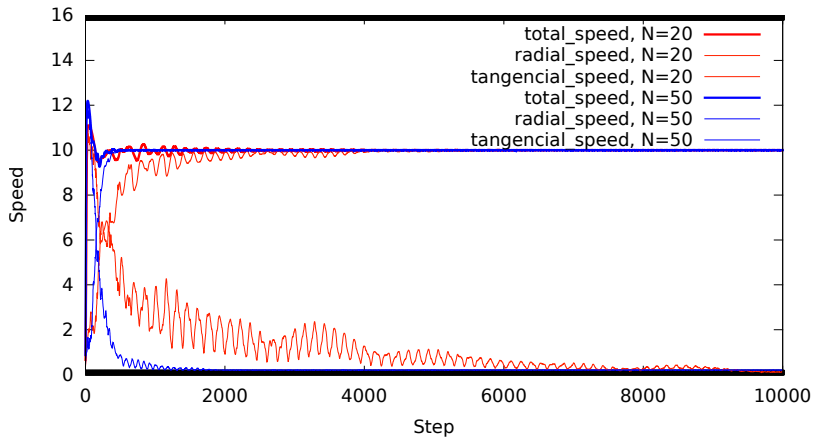


Quantification mill



Quantification mill

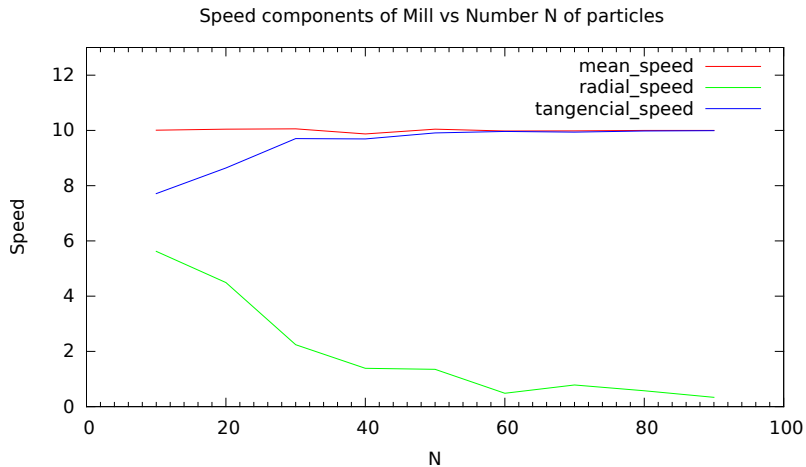
Speed Components of Mill vs Simulation Step (10000 steps)



Quantification mill

- parameter sets for different regions
- testing interesting trends, e.g. $R \propto \frac{\alpha m}{\beta N}$ (from setting $F_{centrifugal} = F_{centripetal}$)
- $|\vec{v}|^2 \xrightarrow{t \rightarrow \infty} \alpha/\beta$ coming from $(\alpha - |\vec{v}|^2\beta)\vec{v} = 0$ for steady state
- confirmation of ring formation
 - $R_{max}, R_{mean}, R_{min}$ converge to same value
 - $v_{radial} \rightarrow 0$ and $v_{tangential} \rightarrow |v_i|$ for $t \rightarrow \infty$
- influence of increasing N on the shape

Quantification mill



Quantification mill

