

# 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.

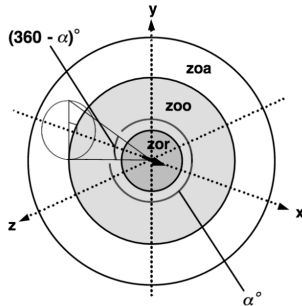
**Vicsek model**

- 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.  $\alpha$  = 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  $\geq 1$  particle (the "informed" one/ "scout") and merge orientation and attraction zone.

## THEORY

**New parameters:** weight of bias  $\omega$ , bias direction  $g_i$ , proportion of bias *prop*

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

# 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:  $v_{n+1} = v_n + \tau \cdot \frac{dv_n}{dt}$
- update of desired direction of travel  $d_i$  in each zone:

$$\mathbf{d}_i(t + \Delta t) = - \sum_{j \neq i} \frac{\mathbf{c}_j(t) - \mathbf{c}_i(t)}{|\mathbf{c}_j(t) - \mathbf{c}_i(t)|} \quad \mathbf{d}_i(t + \Delta t) = \sum_{j \neq i} \frac{\mathbf{c}_j(t) - \mathbf{c}_i(t)}{|\mathbf{c}_j(t) - \mathbf{c}_i(t)|} + \sum_{j=1} \frac{\mathbf{v}_j(t)}{|\mathbf{v}_j(t)|}$$
$$\mathbf{d}_i'(t + \Delta t) = \frac{\hat{\mathbf{d}}_i(t + \Delta t) + \omega \mathbf{g}_i}{|\hat{\mathbf{d}}_i(t + \Delta t) + \omega \mathbf{g}_i|}$$

with position vector  $\mathbf{c}_i(t)$ , direction vector  $\mathbf{v}_i(t)$

# 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

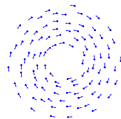


# Module 1: Effective leadership and decision-making in animal groups on the move (Couzin et al): czn2

**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

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

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

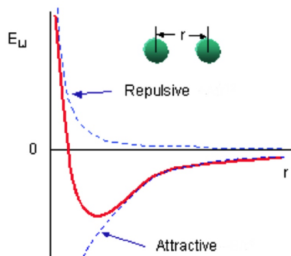
where  $U$  is a pairwise interaction potential and  $\alpha, \beta > 0$  are values for propulsion and friction forces.

# 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

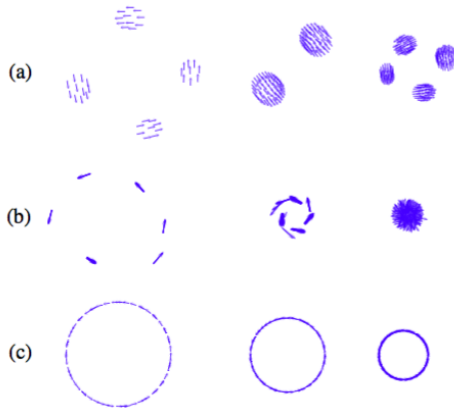
# Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse (D'Orsogna et al)

## **SIMULATION**

INSERT one example simulation

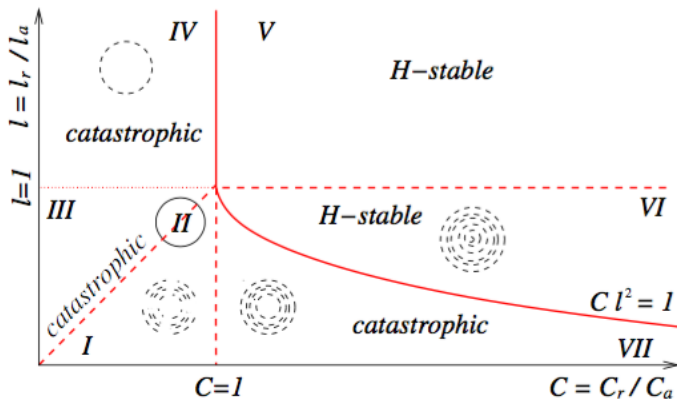
# Module 2: Self-Propelled Particles with Soft-Core Interactions: Patterns, Stability, and Collapse

(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)

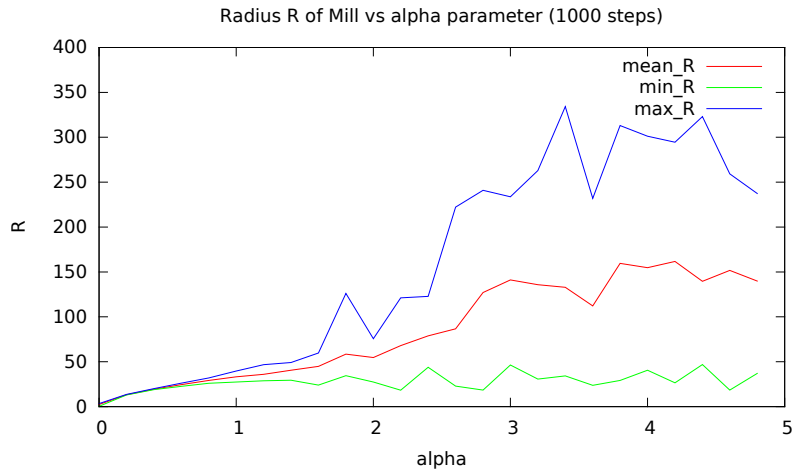
INSERT own simulations

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

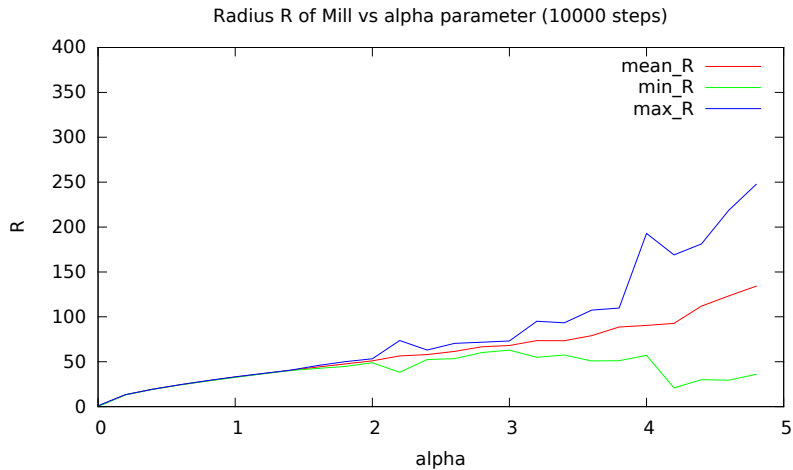
## QUANTIFICATION

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

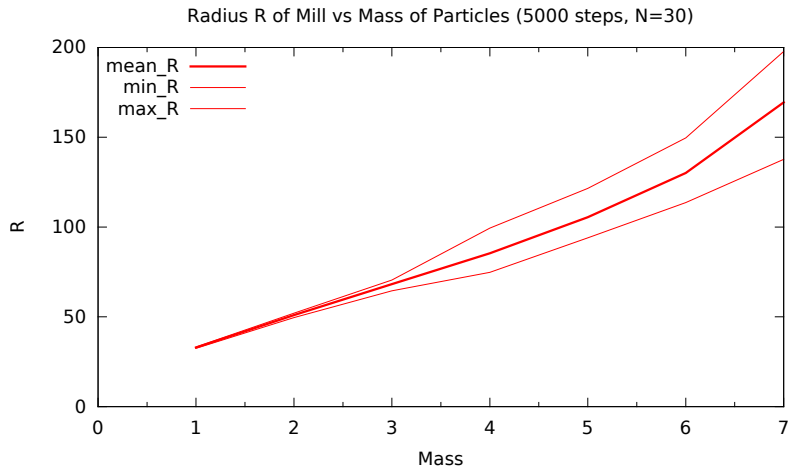
# Quantification mill



# Quantification `mill`



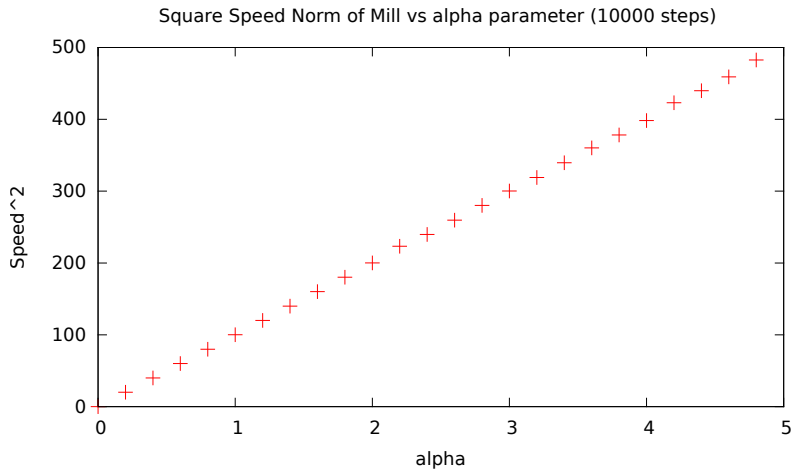
# Quantification mill



# Quantification mill

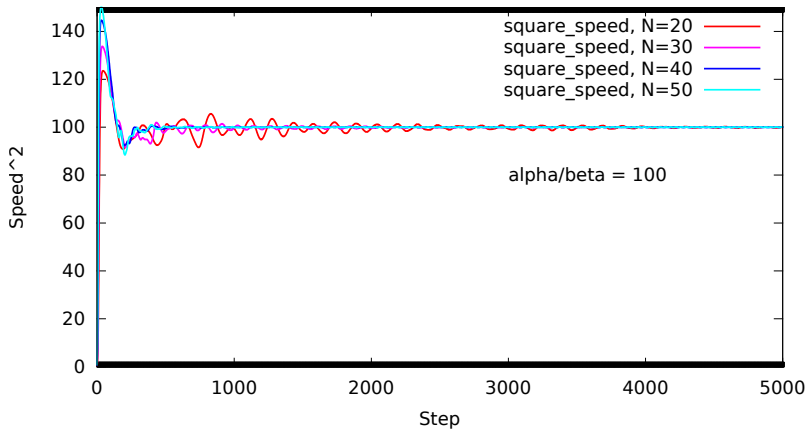
- parameter sets for different regions
- testing interesting trends, e.g.  $R \propto \frac{\alpha m}{\beta N}$  (from setting  $F_{centrifugal} = F_{centripetal}$ )
- $|\vec{v}|^2 \xrightarrow{t \rightarrow \infty} \alpha/\beta$  coming from  $(\alpha - |\vec{v}|^2\beta)\vec{v} = 0$  for steady state

# Quantification mill



# Quantification mill

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

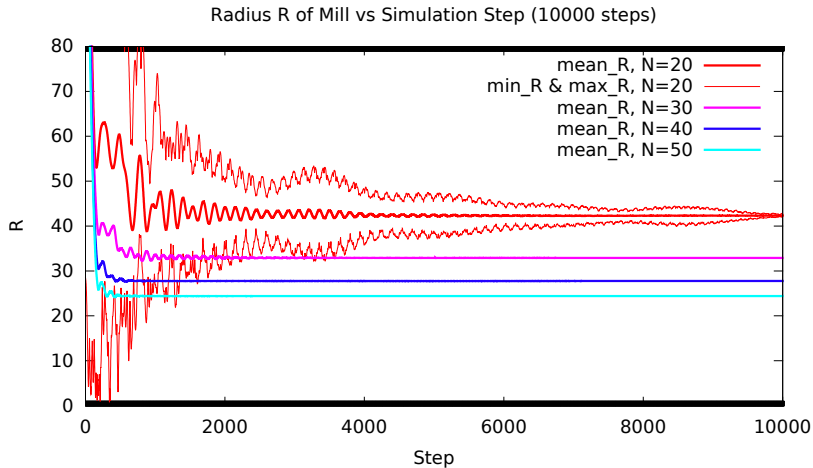




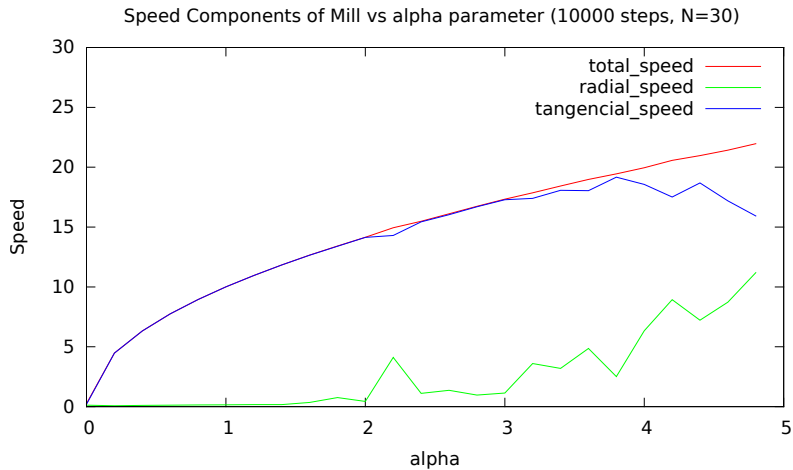
# Quantification mill

- parameter sets for different regions
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- $|\vec{v}|^2 \xrightarrow{t \rightarrow \infty} \alpha/\beta$  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

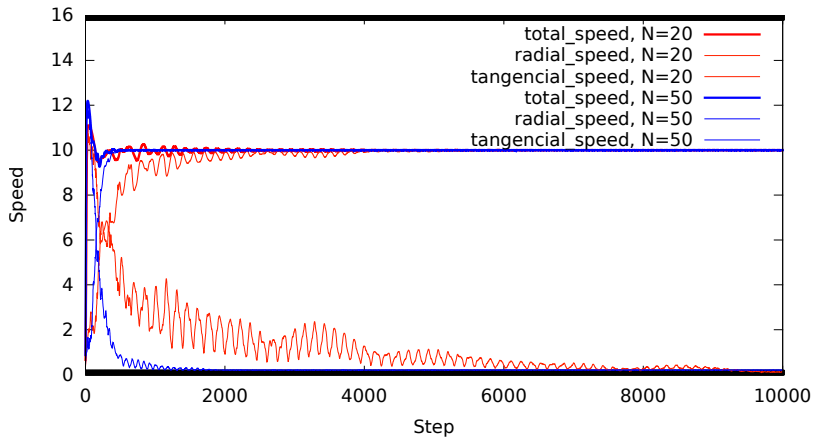


# Quantification mill



# Quantification mill

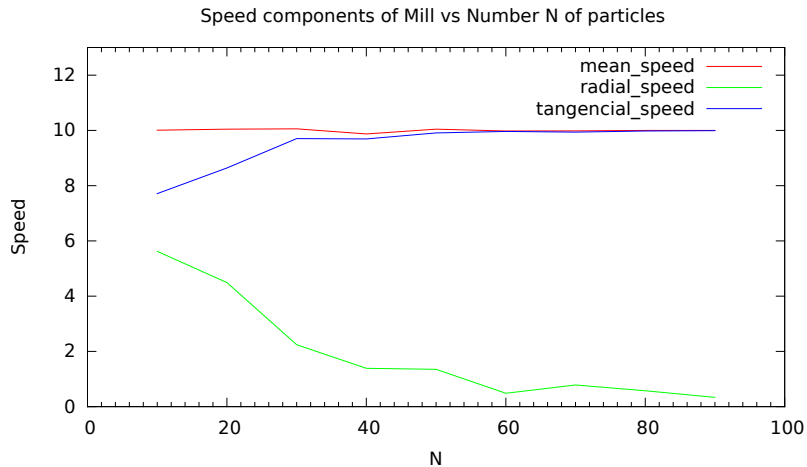
Speed Components of Mill vs Simulation Step (10000 steps)



# 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

