Data Science Course Understading 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.

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Vicsek model

- introduce interaction zones: repulsion and alignment
- add noise

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Couzin model

 different zones of neighbourhoods: repulsion, orientation, attraction

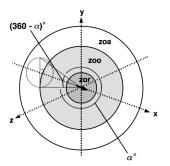


Figure: Representation of an individual in the model centred at the origin: zor = zone of repulsion, zoo = zone of orientation, zoa = zone of attraction. $\alpha = field$ of perception

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:

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

IMPLEMENTATION

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

SIMULATION on specific parameter set

QUANTIFICATION

- Accuracy
- Group elongation
- Two scouts

SIMULATION optimised

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

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

$$\frac{d\vec{x_i}}{dt} = \vec{v_i} \tag{1}$$

$$F = m \frac{d\vec{v_i}}{dt} = (\alpha v - \beta |\vec{v_i}|^2) \vec{v_i} - \vec{\nabla_i} U(\vec{x_i})$$
 (2)

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

For *U* we choose the *Morse potential*

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

where C_a , C_r denote attractive and repulsive strengths and I_a , I_r their respective length scales.

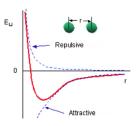


Figure: Plot of the Morse potential

IMPLEMENTATION

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

SIMULATION

INSERT one example simulation

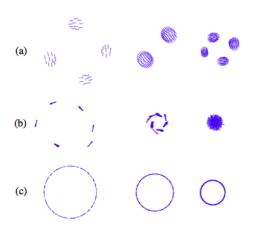


Figure: Catastrophic geometry.
(a) Clumps. (b) Ring Clumping. (c) Rings.

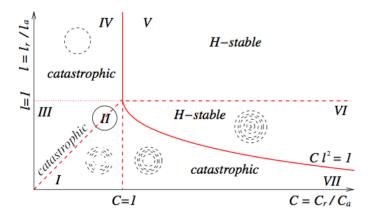
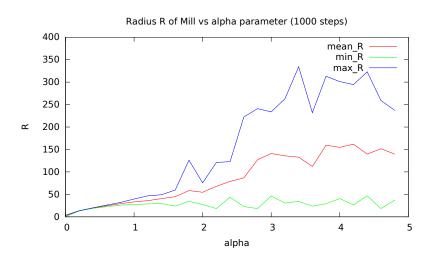


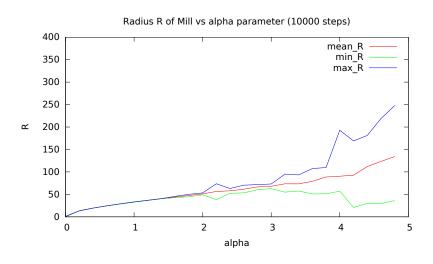
Figure: H-stability phase diagram of the Morse potential

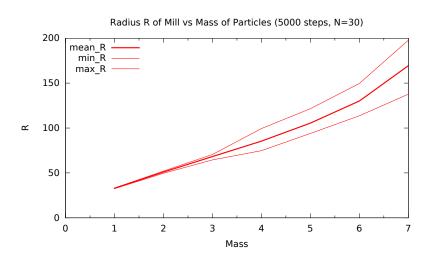
INSERT own simulations

QUANTIFICATION

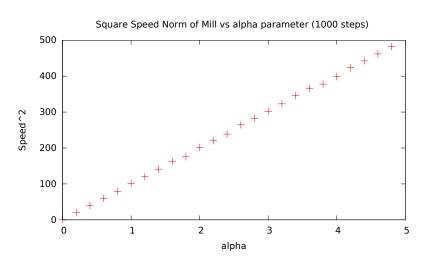
- parameter sets for different regions
- testing interesting trends, e.g. $R \propto \frac{\alpha m}{\beta N}$ (from setting $F_{centrifugal} = F_{centripetal}$)

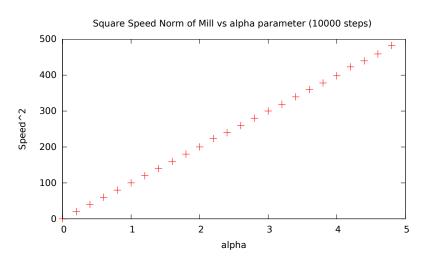


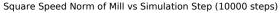


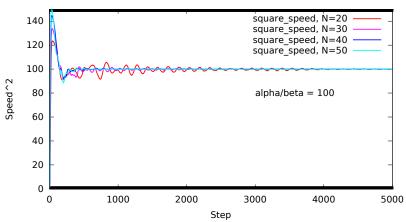


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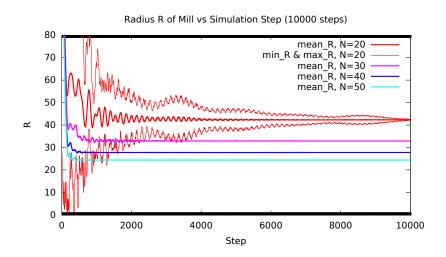


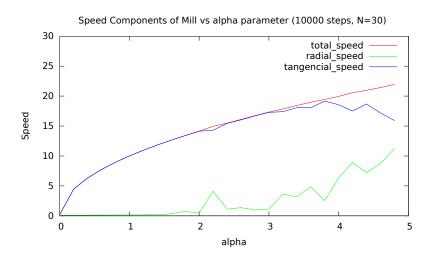


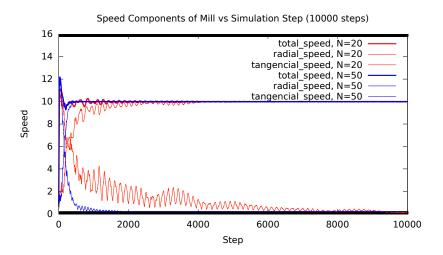




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 - R_{max} , R_{mean} , R_{min} converge to same value
 - $v_{radial} o 0$ and $v_{tangential} o |v_i|$ for $t o \infty$







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- 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



