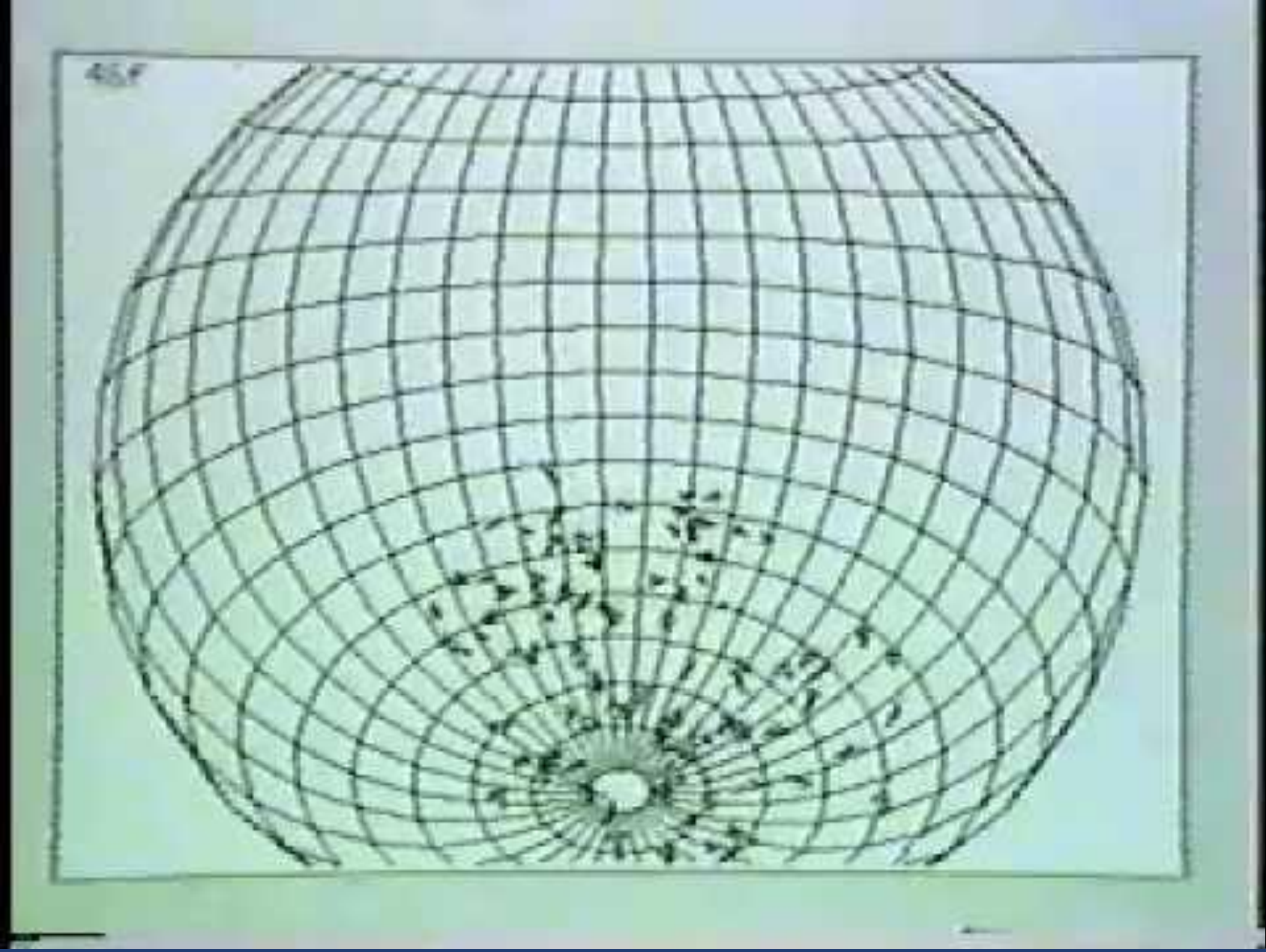


Universidad Zaragoza
1542
CC BY NC SA

Universidad Zaragoza
1542
BY NC SA

Coordinated Motion (Flocking)
The “boids” approach

- C.W. Reynolds (1987), Flocks, herds and schools: A distributed behavioral model. SIGGRAPH’87, 25–34 (http://www.red3d.com/cwr/boids/)
- R. Olfati-Saber (2006), Flocking for Multi-Agent Dynamic Systems: Algorithms and Theory. IEEE Tr. Automatic control 51(3): 401-420
- E. Ferrante et al (2012), Self-organized flocking with a mobile robot swarm: a novel motion control method. Adaptive Behavior 20(6):460-477

Universidad Zaragoza 1542
CC BY NC SA

What is flocking?

- A form of collective behavior: "Aggregation in motion", sometimes with a common group objective
- Emerging in groups of many members interacting locally
- Fascinating in nature (by land, sea and air): even (real) penguins, which are **birds**, **do it**, both by land and sea (not air)  ¯_(ツ)_/¯

Universidad Zaragoza 1542

CC BY NC SA

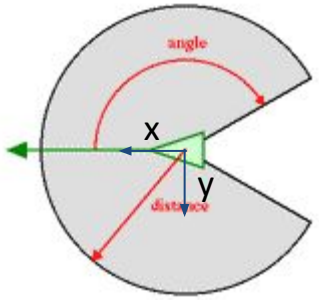
Applications

- Massive distributed sensing using mobile sensor networks in an environment: exploration and monitoring of wide areas
  (to know them better, either to protect or destroy them)
- Parallel delivery of payloads
- Reference models for biology

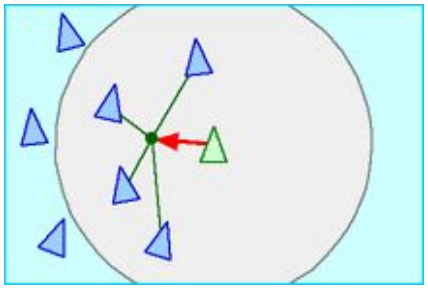
Universidad Zaragoza
1542
BY NC SA

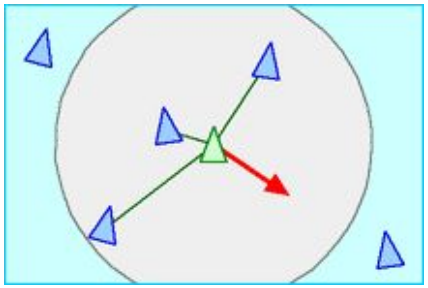
Reynold's heuristics [C.W. Reynolds (1987)]

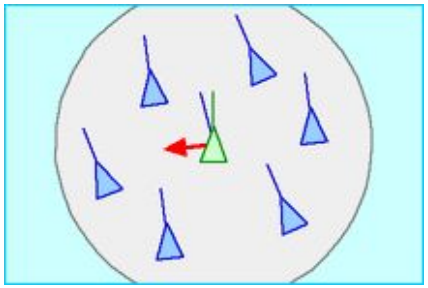
- Flock-members can perceive the range and bearing of their mates nearby (and their orientation)



- Cohesion: stay close to nearby mates (head centroid)
- Separation: well, not TOO close $\sum(d_i e^{j\phi_i})^{-1}$
- Alignment "consensus": match heading with mates







Universidad Zaragoza 1542
CC BY NC SA

Criticism

- Adjustment of attraction/repulsion?
- Ad-hoc obstacle avoidance?
- A definite common goal?
- Perceiving heading?
- Fragmentation? Collapse? Convergence? Stability? R. Olfati-Saber (2006) III and IV
- Are they flocking or not? Formally: *What is flocking?*

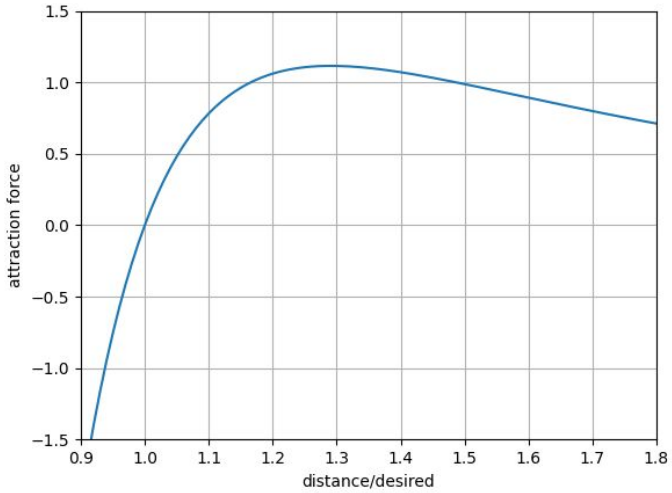
Universidad Zaragoza 1542
CC BY NC SA

Steering vector

- Gradient of attraction/repulsion potential

  R. Olfati-Saber (2006) II.C and II.D

  E. Ferrante et al (2012) 2.1



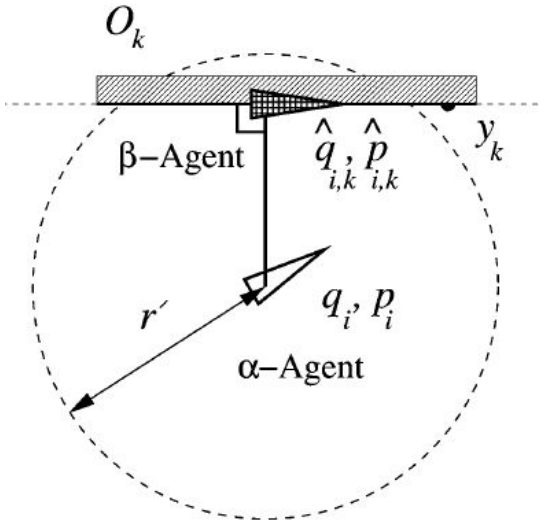
Universidad Zaragoza
1542
BY NC SA

Steering vector

- Gradient of attraction/repulsion potential

  R. Olfati-Saber (2006) II.C and II.D

  E. Ferrante et al (2012) 2.1



- Obstacles? “Shadow-mate”
- Use alignment, or not?
- Perception range?

  Neighbors also in Voronoi’s sense ⇒ perception ≲ twice good distance
- Goal? (A few) “Informed agents”

Universidad Zaragoza 1542

CC BY NC SA

Motion control (nonholonomic)

(v,ω)? From the steering vector $\mathbf{s}=(s_x,s_y)$:

- Magnitude independent (MIMC):
  - Make $\|\mathbf{s}\|=1$
  - $v=\max(0,s_x)\cdot v_{max}$
  - $\omega=K\cdot\text{atan}(s_y/s_x)$
- Magnitude dependent (MDMC):
  - $v=K_v\cdot s_x+v_{min}$
  - $\omega=K_\omega\cdot s_y$

E. Ferrante et al (2012) 2.3

CC BY NC SA

Measuring success?

Think about it...
Which performance indices would you use?

A curiosity: Animal behavior scientists have been investigating flocking since 1927... without an adequate definition of flocking!

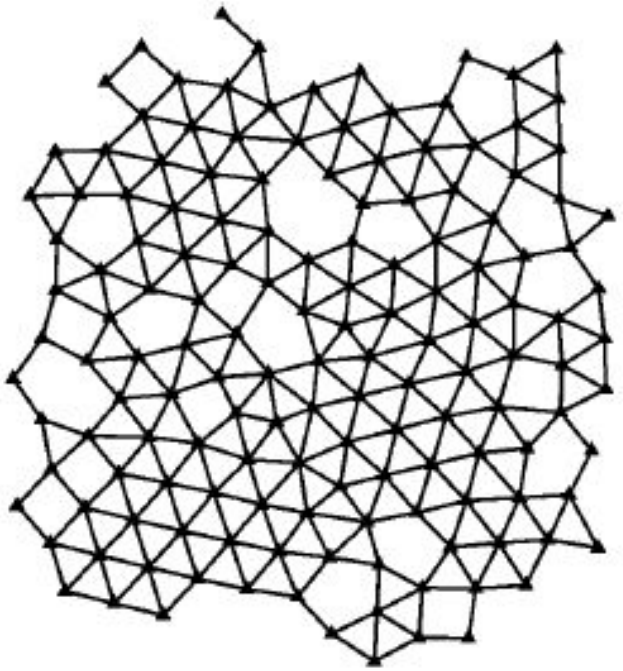
B. L. Partridge (1982), “Rigid definitions of schooling behavior are inadequate,” Animal Behavior, 30: 298–299.

Universidad Zaragoza 1542
CC BY NC SA

Flocking or not? R. Olfati-Saber (2006) IX

Ideal geometry of a flock:

Equal (good) distances to neighbors (a lattice)



Universidad Zaragoza 1542

CC BY NC SA

Flocking or not? R. Olfati-Saber (2006) IX

Ideal geometry of a flock:

Equal (good) distances to neighbors (a lattice)

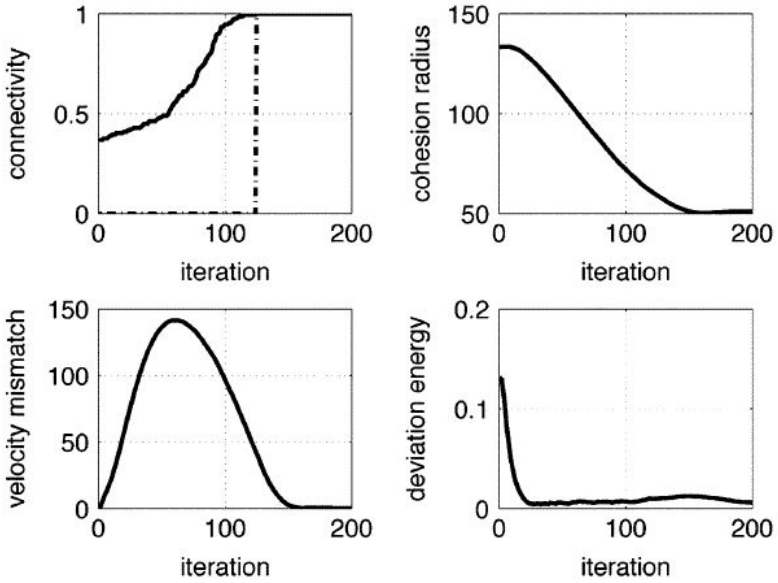
Flocking?

- Proximity net remains (almost) connected
- Cohesion radius (maximum distance to centroid) remains finite
- Deviation (wrt. lattice) energy remains small
- Velocity mismatch remains small

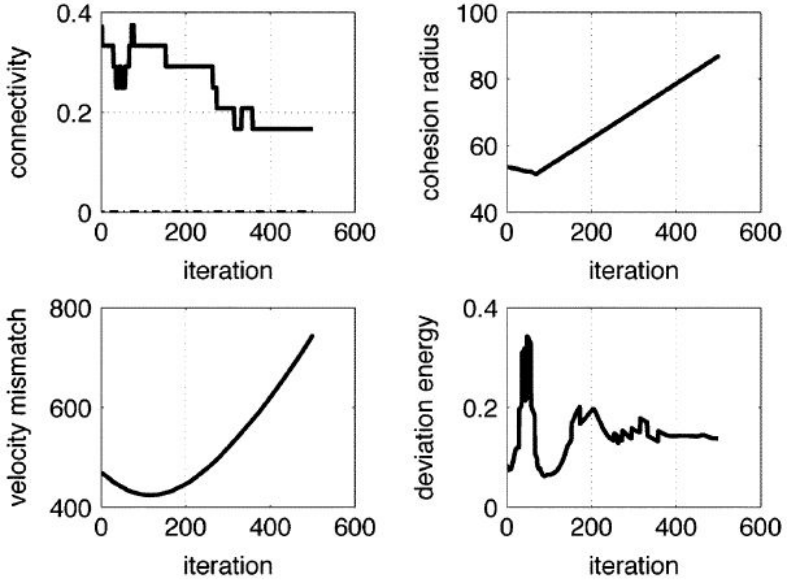
Universidad Zaragoza 1542

CC BY NC SA

Flocking



Not Flocking



Universidad Zaragoza
1542
CC BY NC SA

Other metrics E. Ferrante et al (2012) 4.1

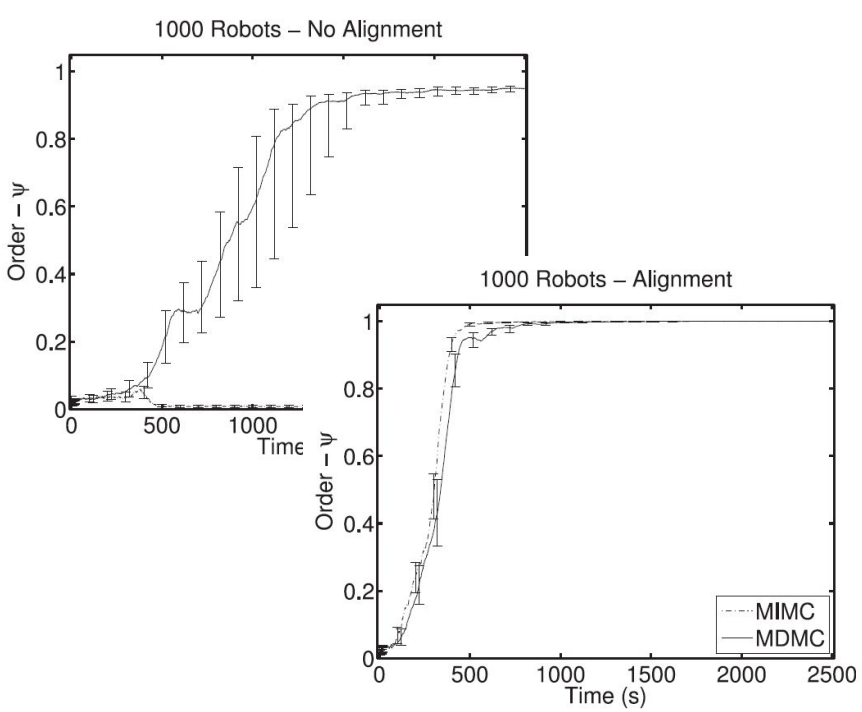
Steady-state values and settling time of:

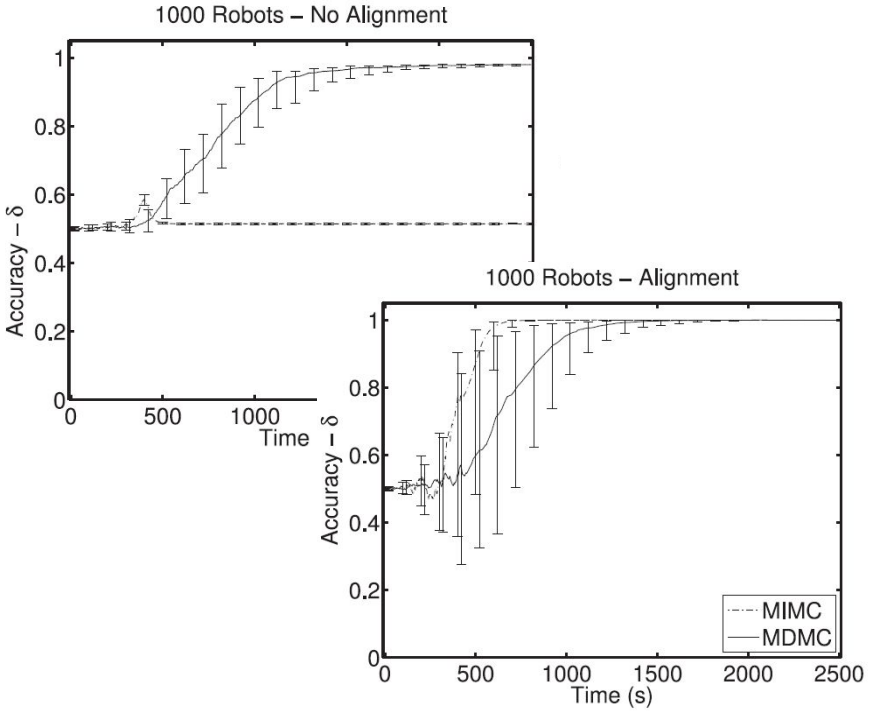
- Order (ψ, 0 to 1)
  - Degree of agreement of the orientations
  - Size of the sum all heading vectors divided by N
- Accuracy (δ, 0 to 1)
  - Angle difference between heading sum and goal
  - 1-0.5·(1-ψ·cos(difference))

Universidad Zaragoza 1542

Results [E. Ferrante et al (2012)](#) 4 and 5

Order and accuracy w/wo heading perception



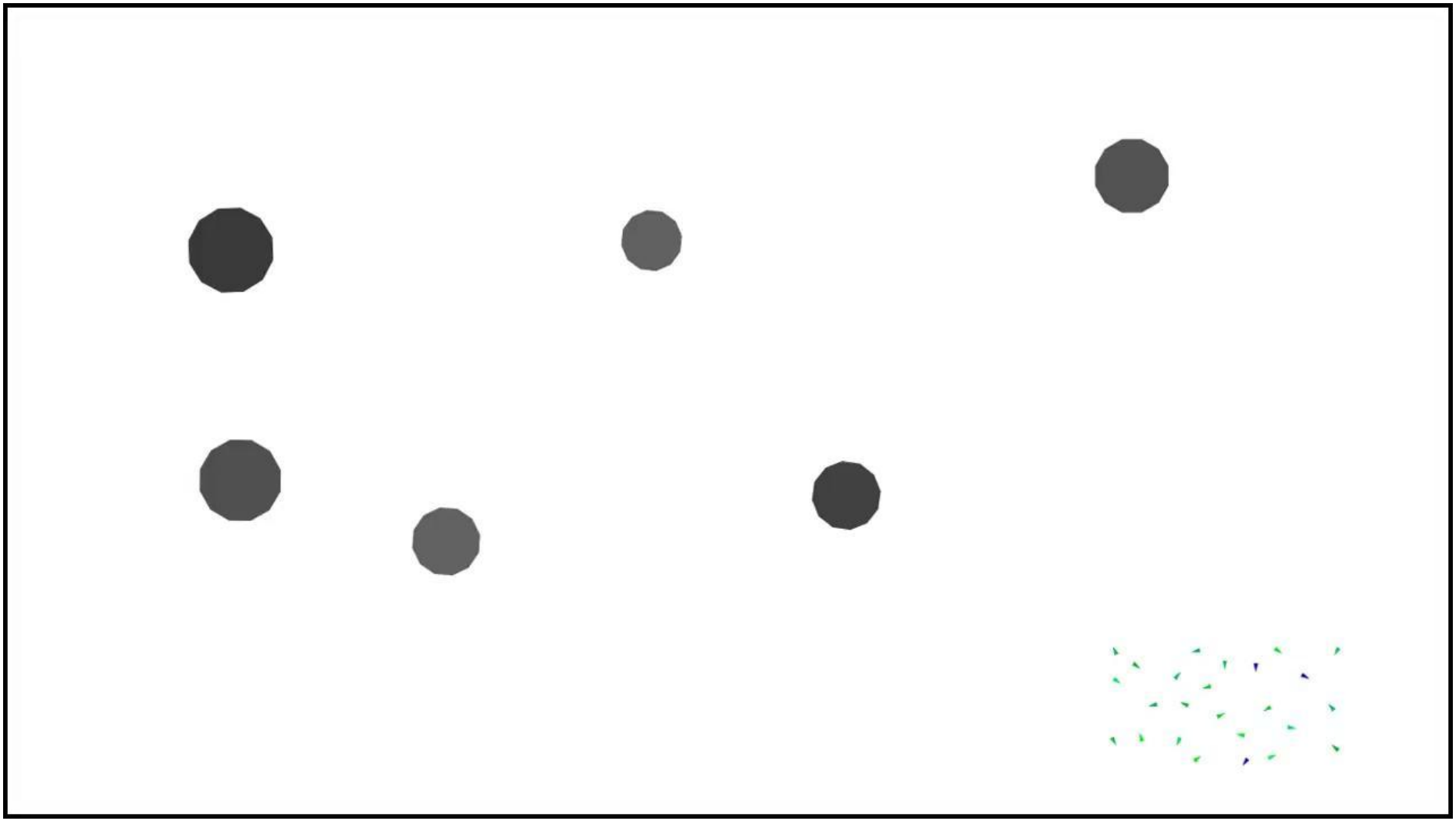


Universidad Zaragoza
1542
CC BY NC SA

Basic Boids

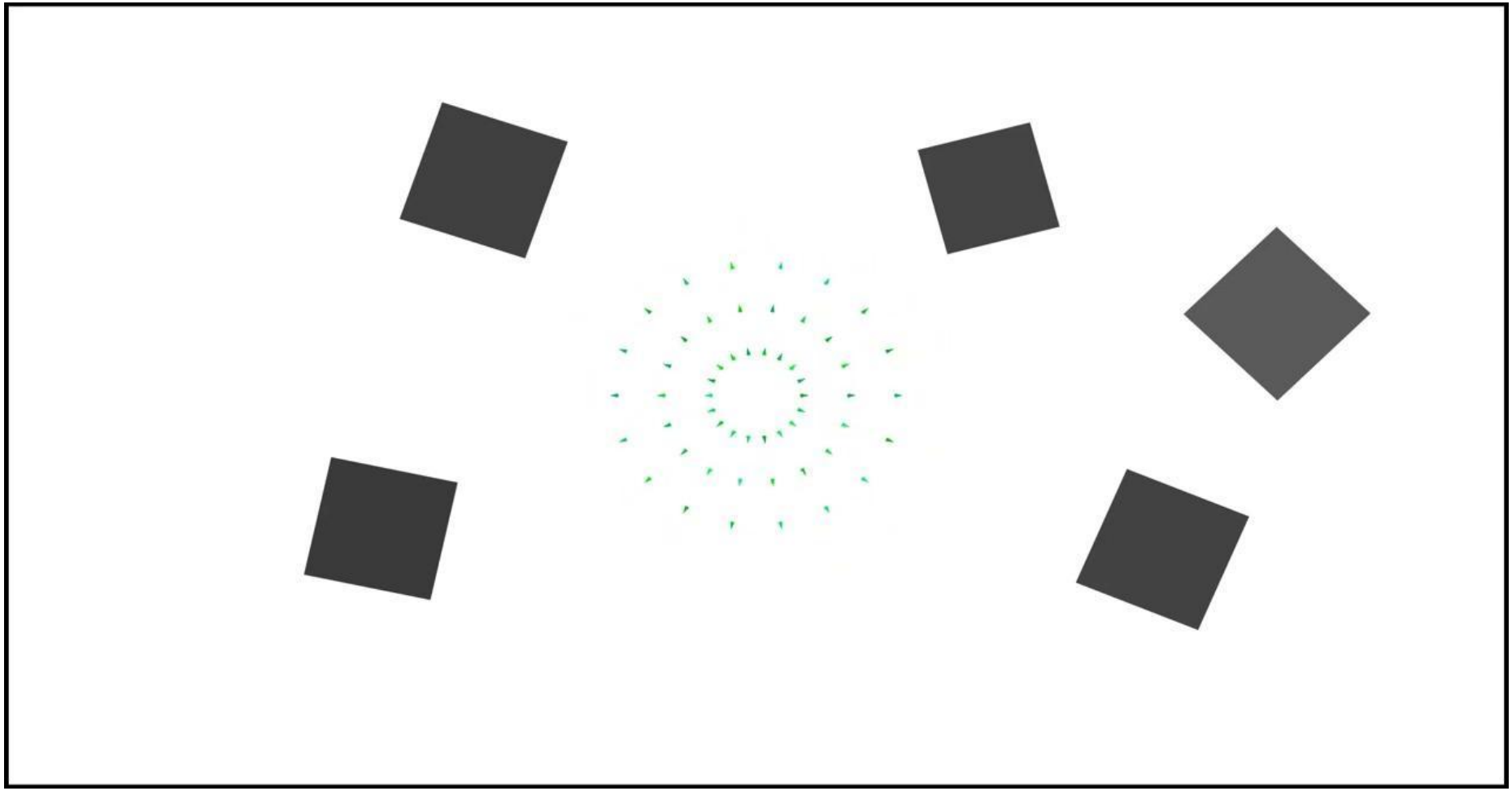
Universidad Zaragoza
1542
CC BY NC SA

Extended Boids



Universidad Zaragoza
1542
CC BY NC SA

Wowids



Universidad Zaragoza
1542
CC BY NC SA