Swarm Robotics – an overview –

Vito Trianni, PhD
Institute of Cognitive Sciences and Technologies
National Research Council
vito.trianni@istc.cnr.it

swarm robotics

- *swarm robotics* studies robotic systems composed of a multitude of interacting units
    - homogeneous systems or few heterogeneous groups
    - each unit is relatively simple and inexpensive
- individual limitations, absence of global information
    - limitations can be physical or functional
    - access to local and incomplete information only
- decentralised control
    - no *single point of failure*
    - *redundancy* is built-in in the system
- expected properties:
    - parallelism
    - scalability
    - robustness
    - flexibility
    - adaptivity

swarm robotics

- simple individuals and simple behaviours
- complexity results from cooperation
- research mainly focuses on:
    - development of specific hardware to support communication and physical interactions
    - development and test of swarm control systems
- *problem:* how to define individual rules?
- *solution:* inspiration from super-organisms observed in Nature


Super-Organisms

a catalogue of collective behaviours

- aggregation
- coordinated movement
- collective exploration and area coverage
- collective decision-making
- self-assembly

aggregation

- *definition*:
  the process that leads a group of agents (robots) to cluster in a specific location
    - precondition: random (uniform) distribution of agents in space
    - postcondition: formation of one or more clusters
- prerequisite of several collective behaviours
    - creation of functional groups
    - group size control

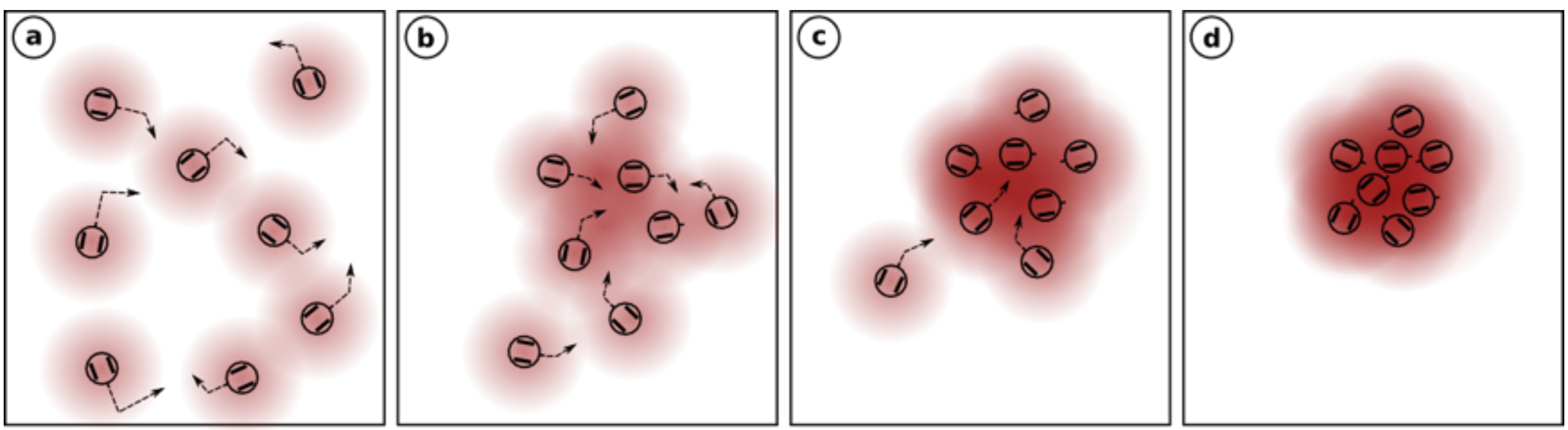
aggregation: variants

- presence or not of environmental heterogeneities (light, humidity, corners)
- homogeneous environment ⇨ agents need to create heterogeneities
    - explicit communication
    - embodiment
- self-organising mechanisms
    - *positive feedback*: amplification of heterogeneities
    - *negative feedback*: physical constraints


Dictyostelium discoideum

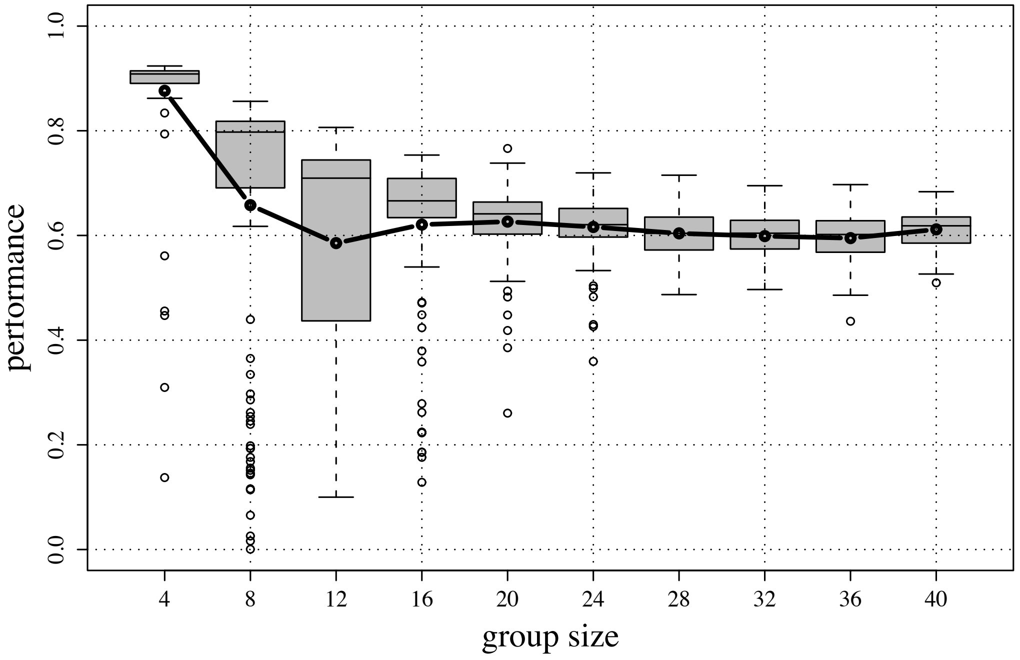
implementation #1

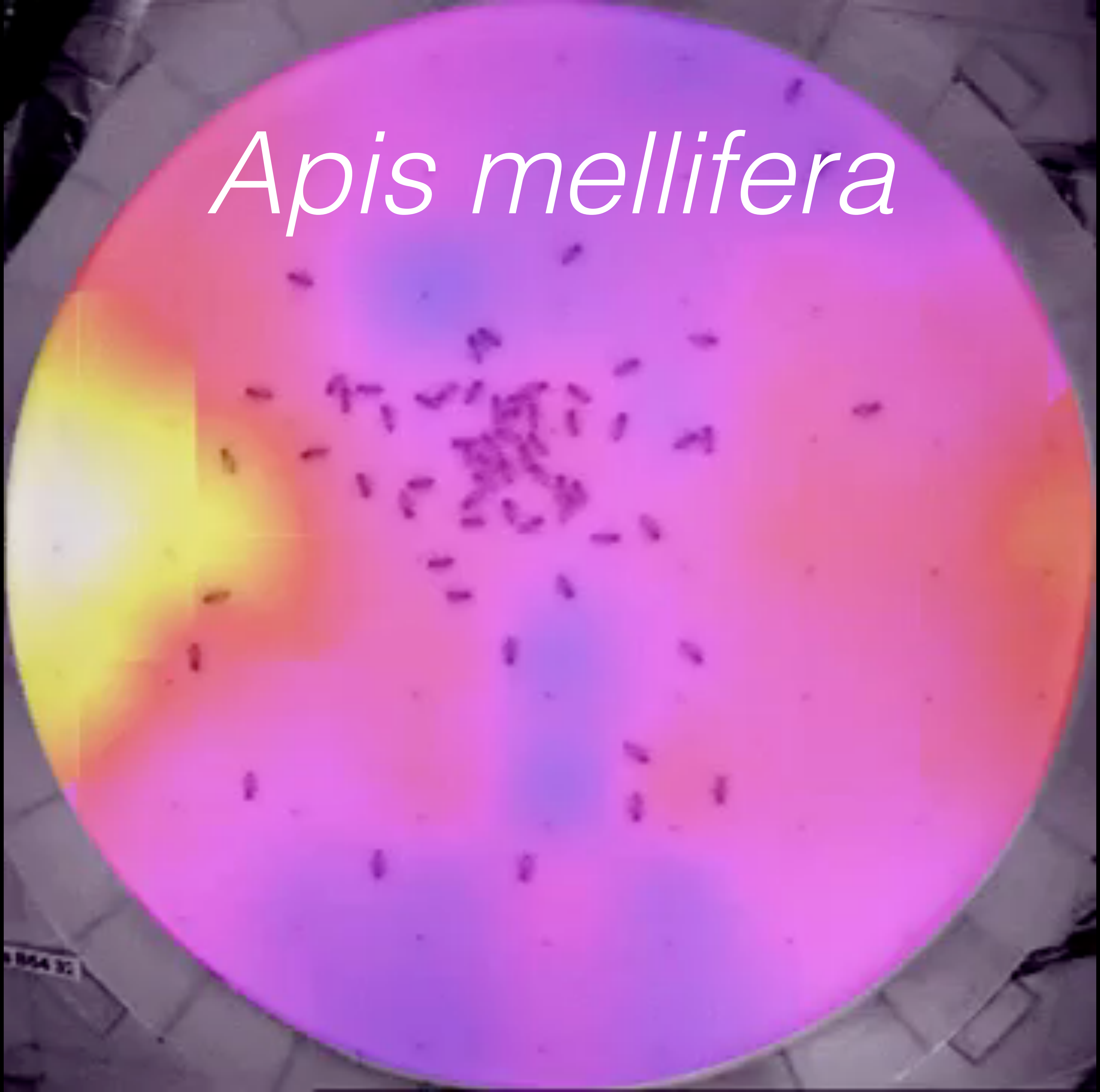
- every agent emits a signal that diffuses in space
- signals of neighbouring agents sum up
  to become more attractive
- a positive feedback leads to the formation of a single cluster



experiments with robots #1

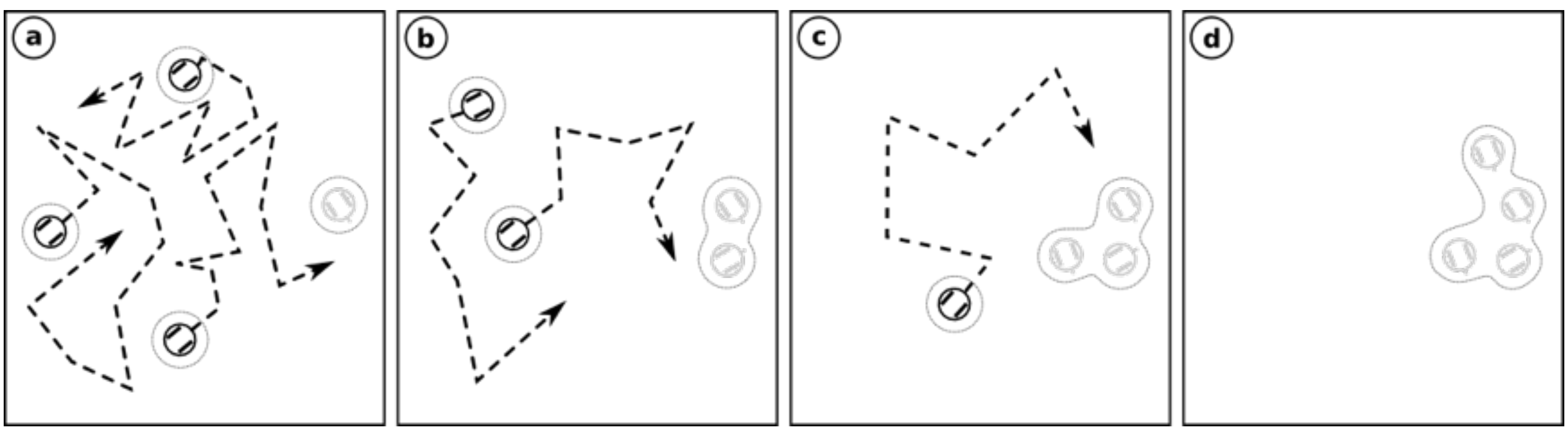
- robots can emit sounds
- artificial evolution to synthesise the control system
- test of scalability of the obtained solution

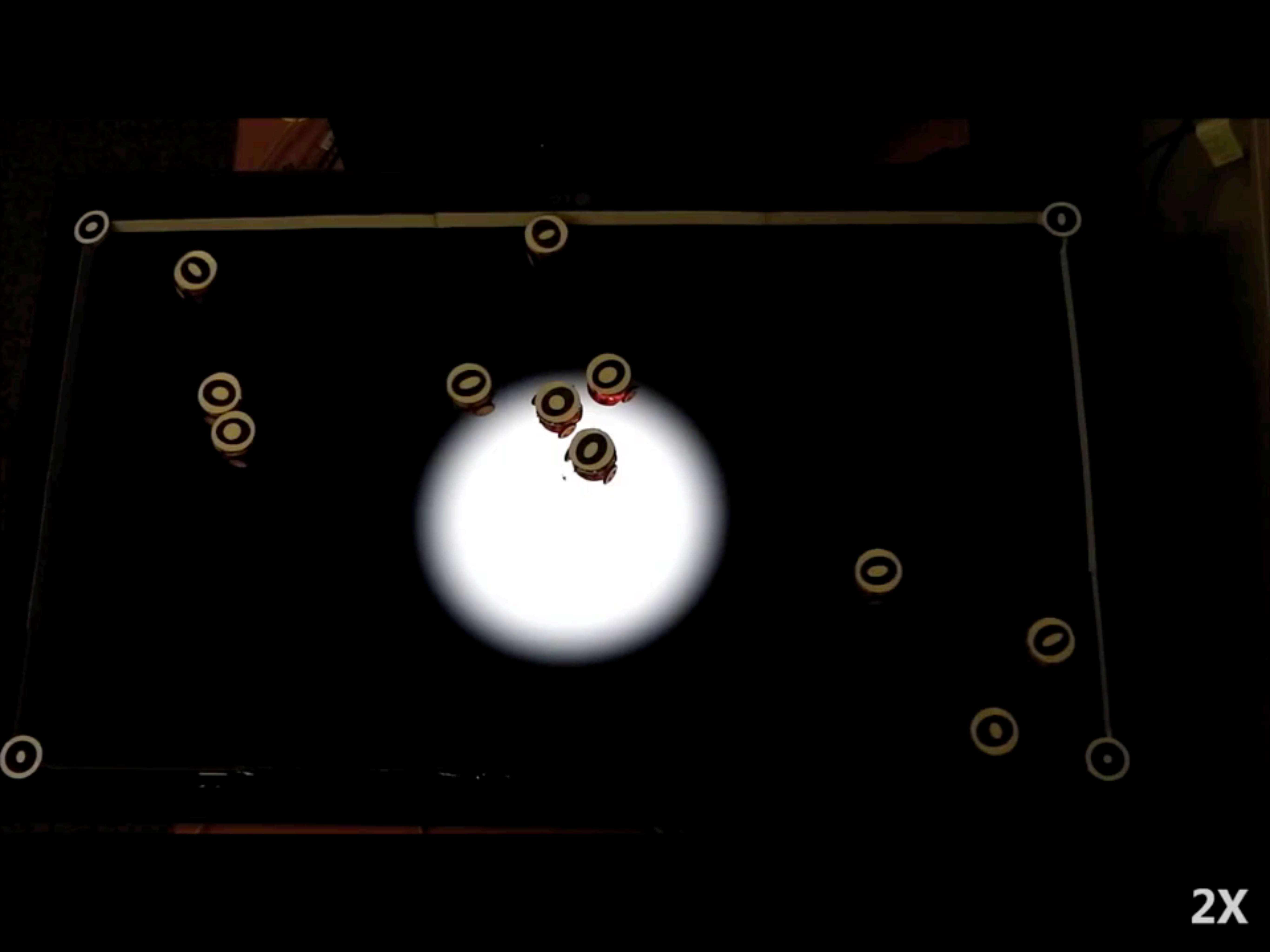



Apis mellifera

implementation #2

- agents move randomly in the environment
- agents stop upon encounters with other agents
- the stopping time depends on the group size

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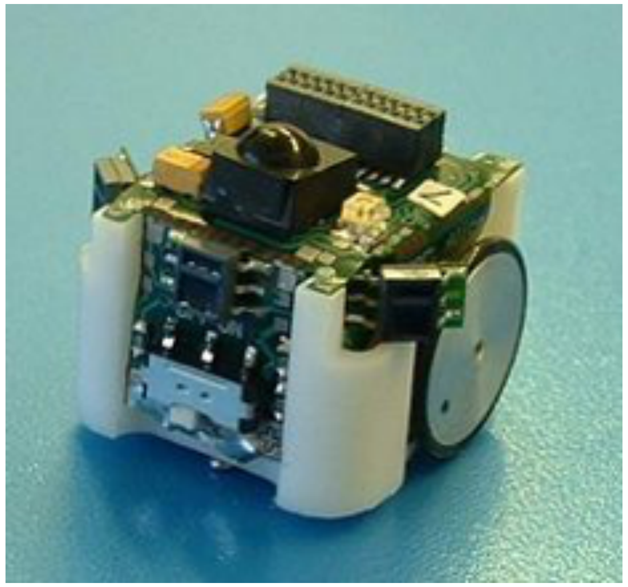
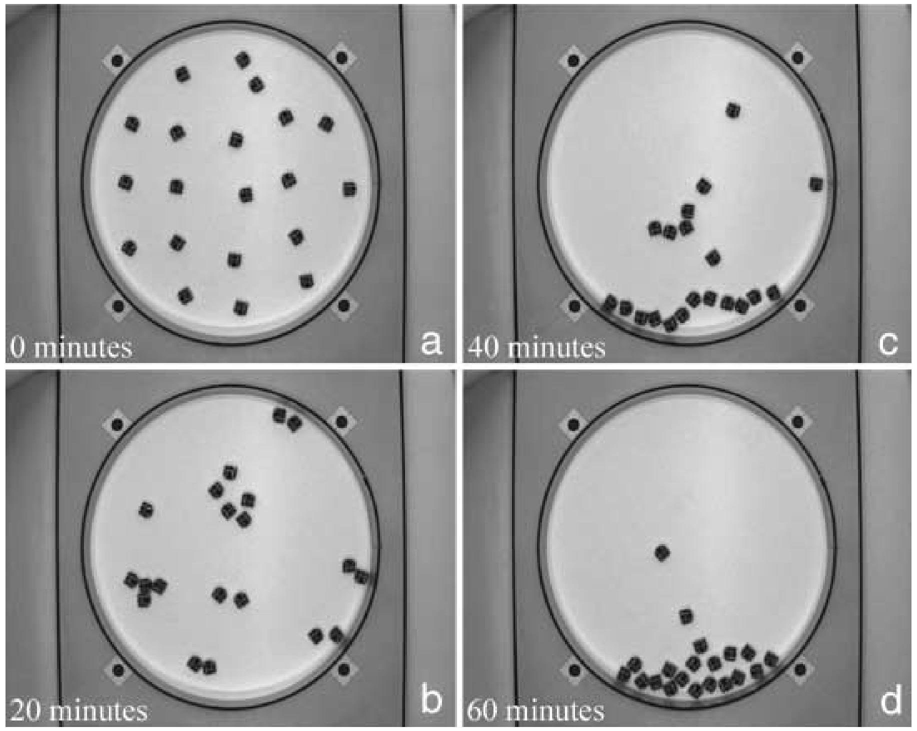
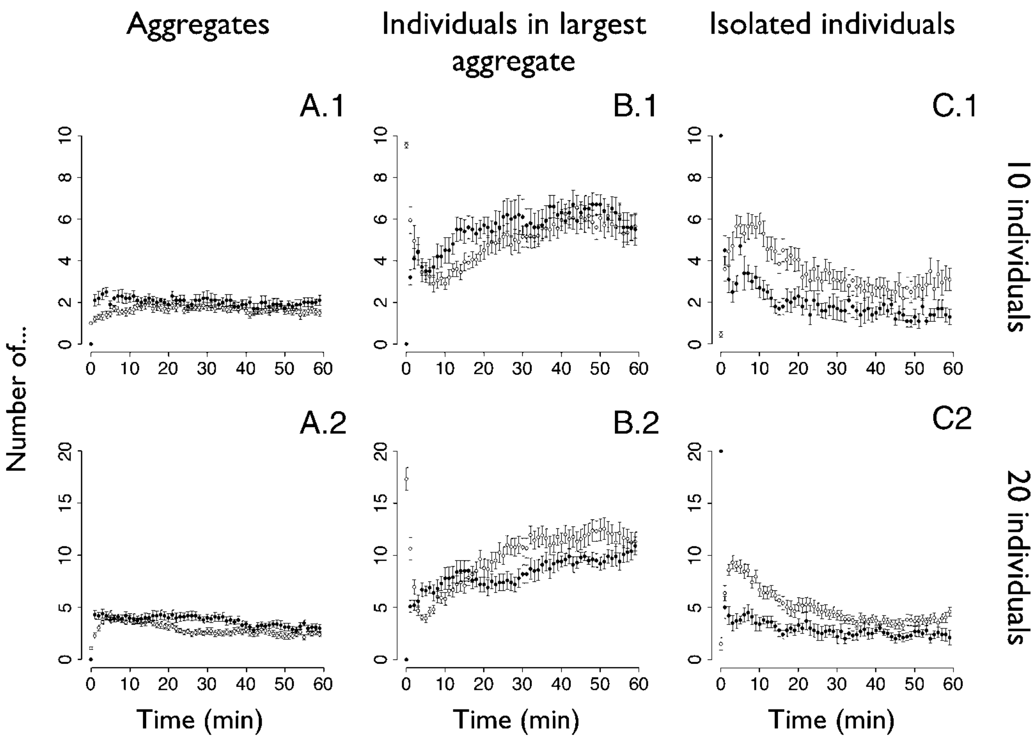
experiments with robots #3

- experiments made using the mini-robots "Alice"
- no predefined locations
- meant to model cockroaches







coordinated movement

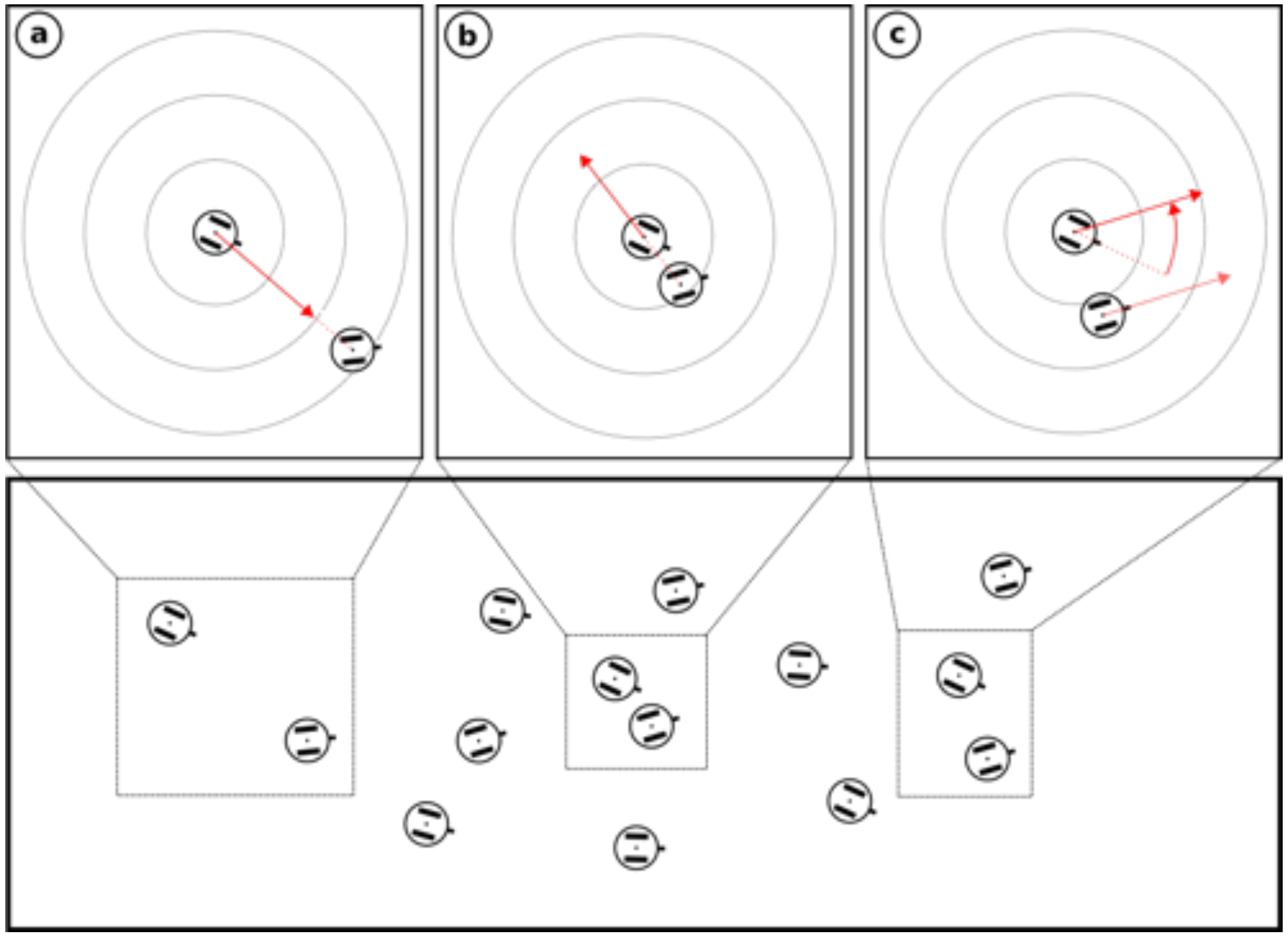
- *definition*:
  the process that leads a group of agents to move in a coherent and ordered way
    - precondition: every agent moves in a random direction
    - postcondition: agents are *polarized*, move with the same speed and change direction as a group
- supports group movements as well as coordinated responses to external perturbations

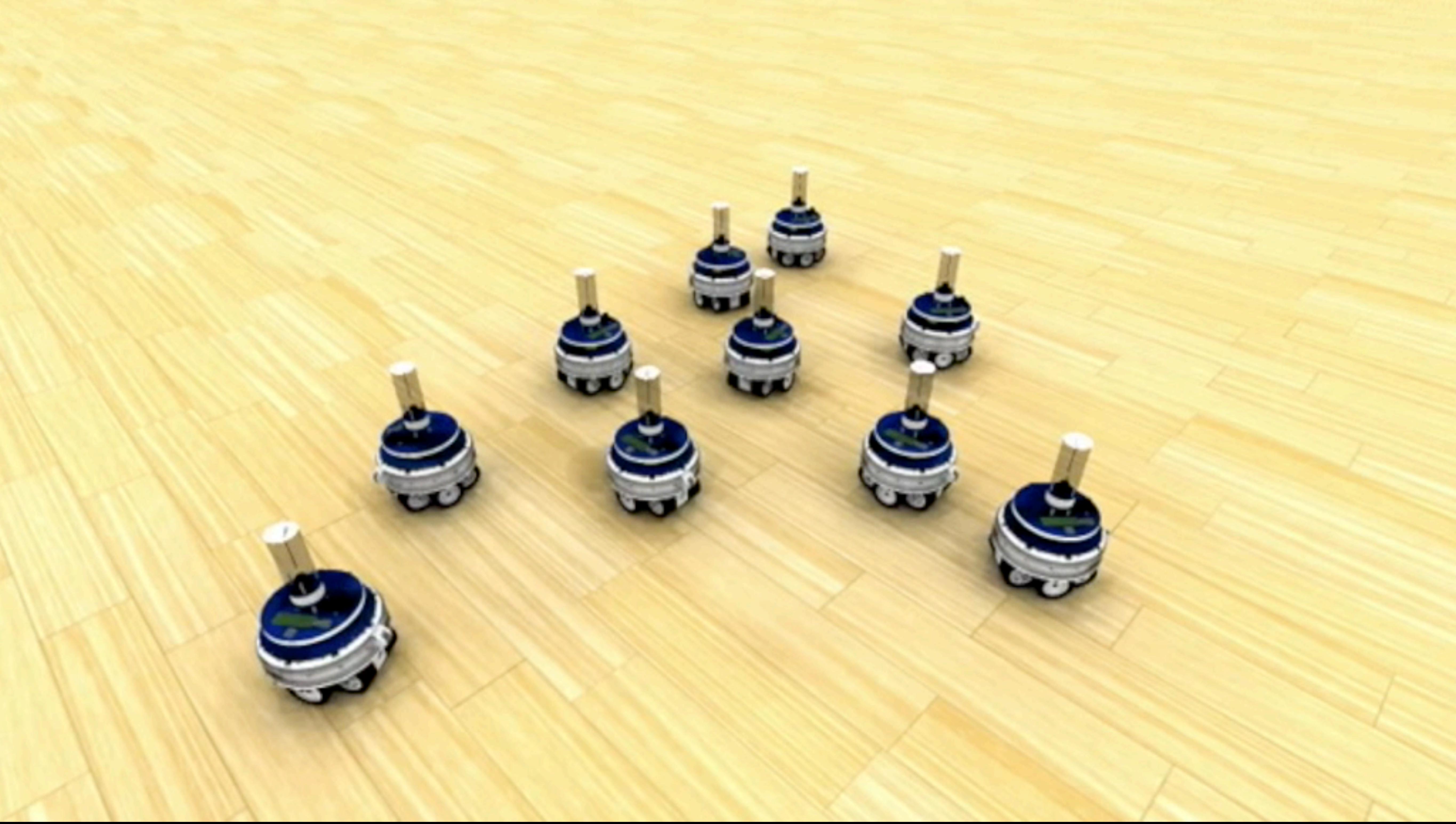
coordinated movement: variants

- a single agent has sufficient information to lead the entire group (centralised approach)
- no agent is more informed than the others (self-organised approach)
- mixed approaches: informed + *naïve* agents

implementation #1

- three simple local rules
  - aggregation
  - repulsion
  - alignment
- rule are executed looking at position and orientation of neighbours





implementation #2

- robots are physically connected and must move in a coordinated way
- robots perceive traction forces exhorted on one another
- artificial evolution of optimal controller
- robust and adaptive solution (obstacle/fall avoidance)

collective exploration and area coverage

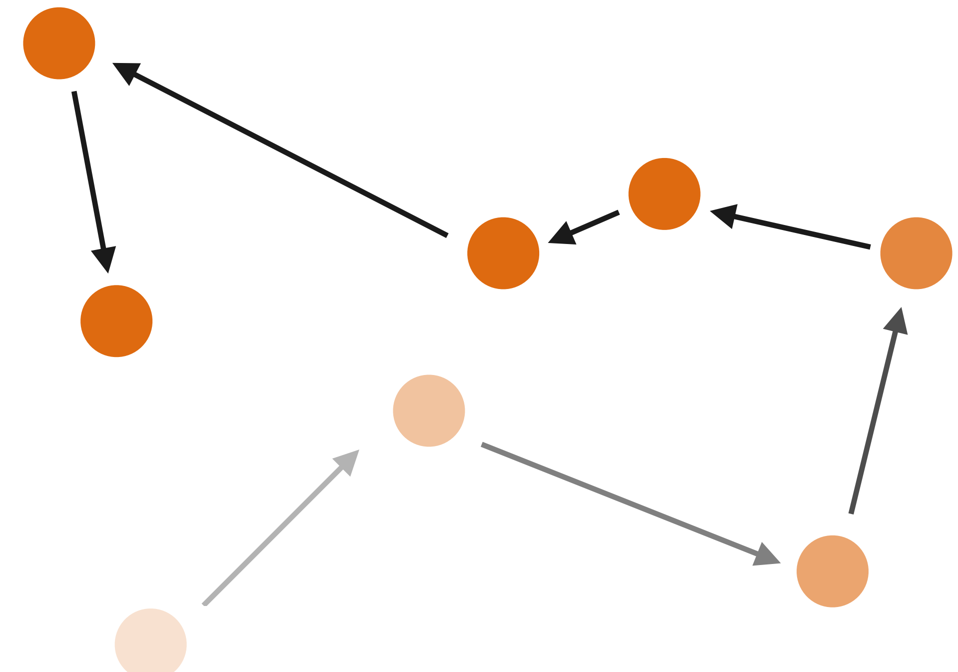
- *definition*:
  the process that leads a group of agents to disperse in the environment in search of resources
  - precondition: agents are distributed in the environment with some task-dependent rule (e.g., start from a home location)
  - postcondition: resources are identified and tracked
- allows to identify and diffuse information relevant for the behaviour of the entire group

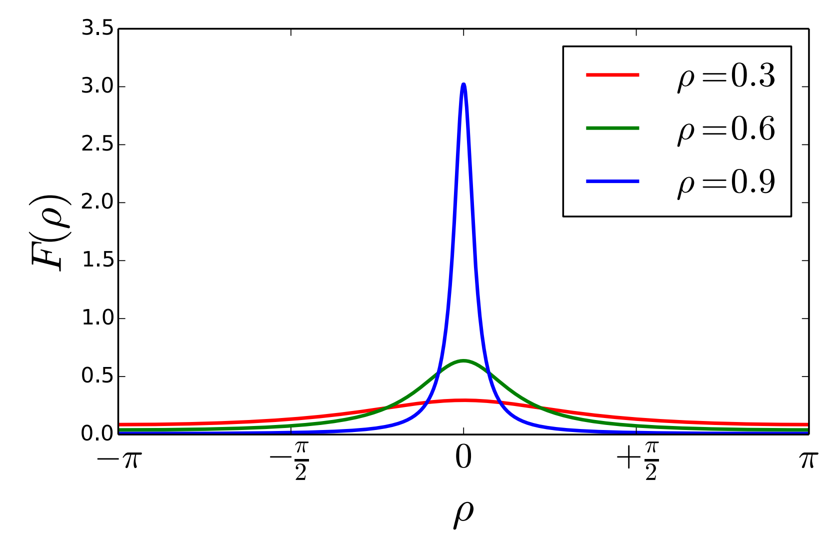
collective exploration: variants

- presence or not of a reference area (home location or central place)
- open or closed search area
- presence or not of obstacles and varying topology (e.g., open space vs. maze)

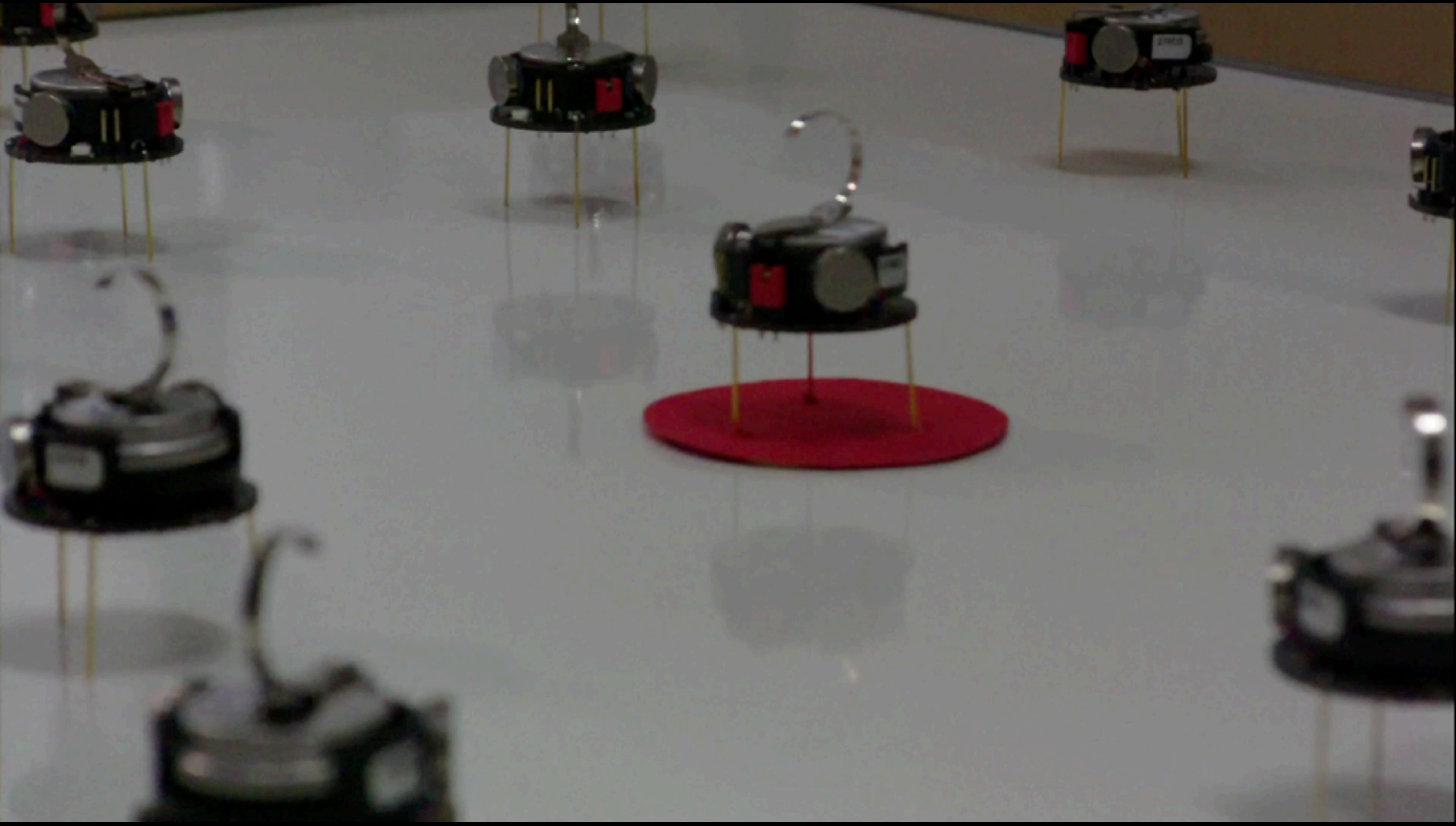
implementation #1

- simple random exploration
- alternate straight steps and random turns
- correlated movements if turning angles drawn from a wrapped Cauchy distribution
- straight walks lengths drawn from a Lévy distribution
- trade-off between exploration and diffusion of information



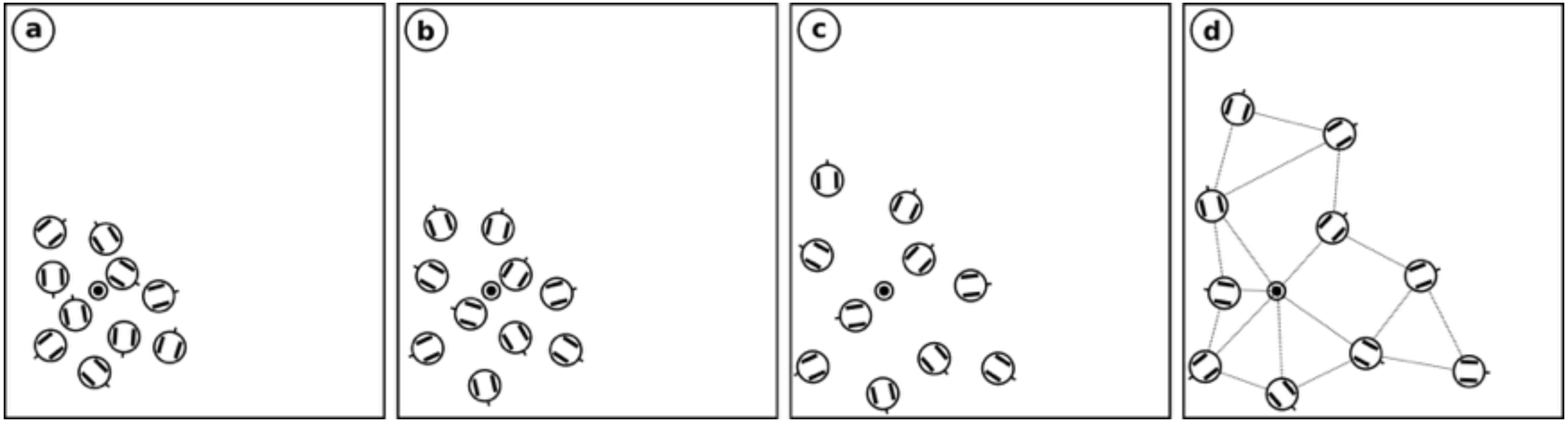


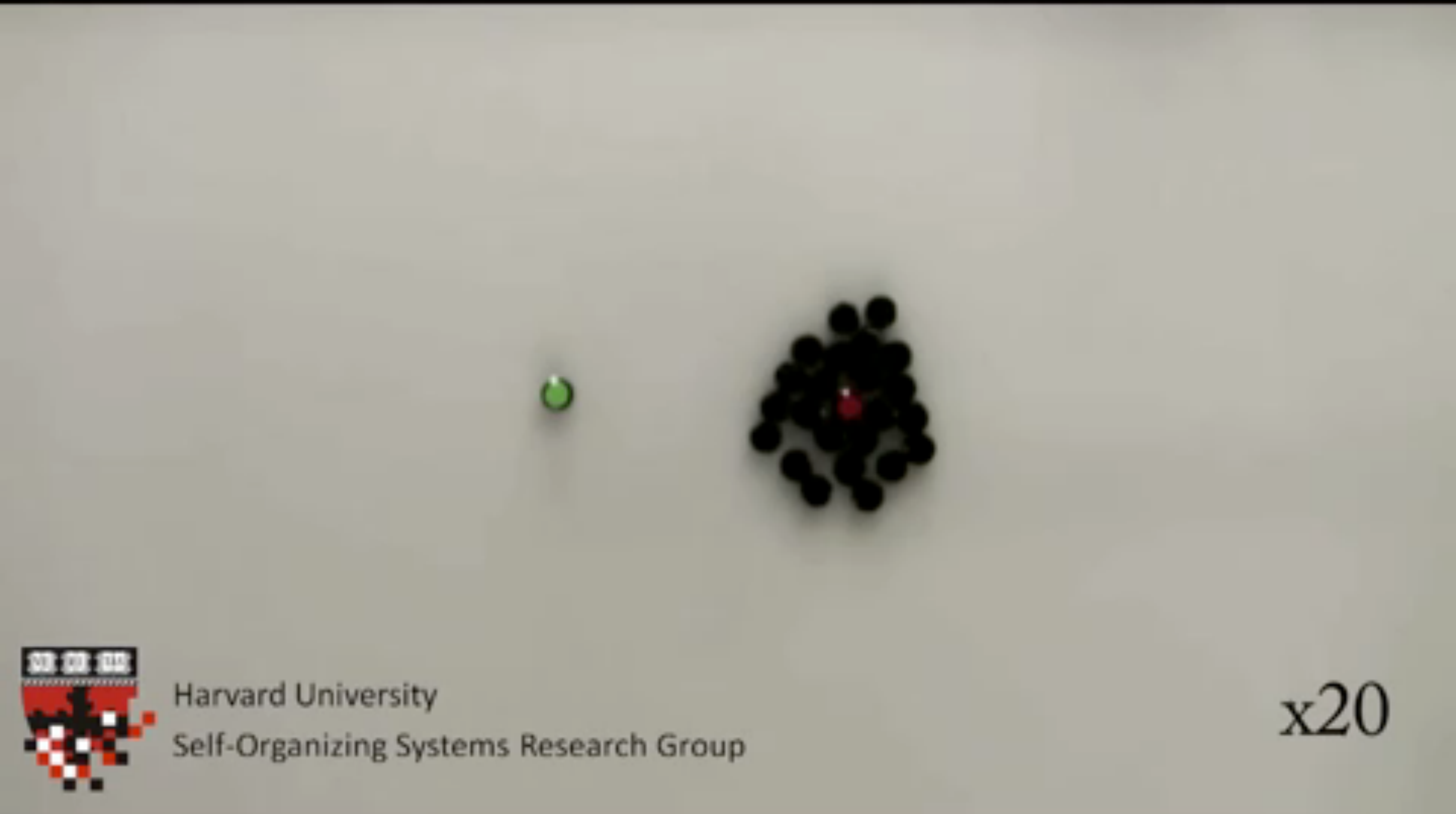
$$P_\alpha(\delta) \sim \delta^{-(\alpha+1)}, \quad 0 < \alpha \leq 2$$



implementation #2

- creation of a connected network of agents that expand starting from the home location
- maximum coverage around the home location
- creation of a navigable structure

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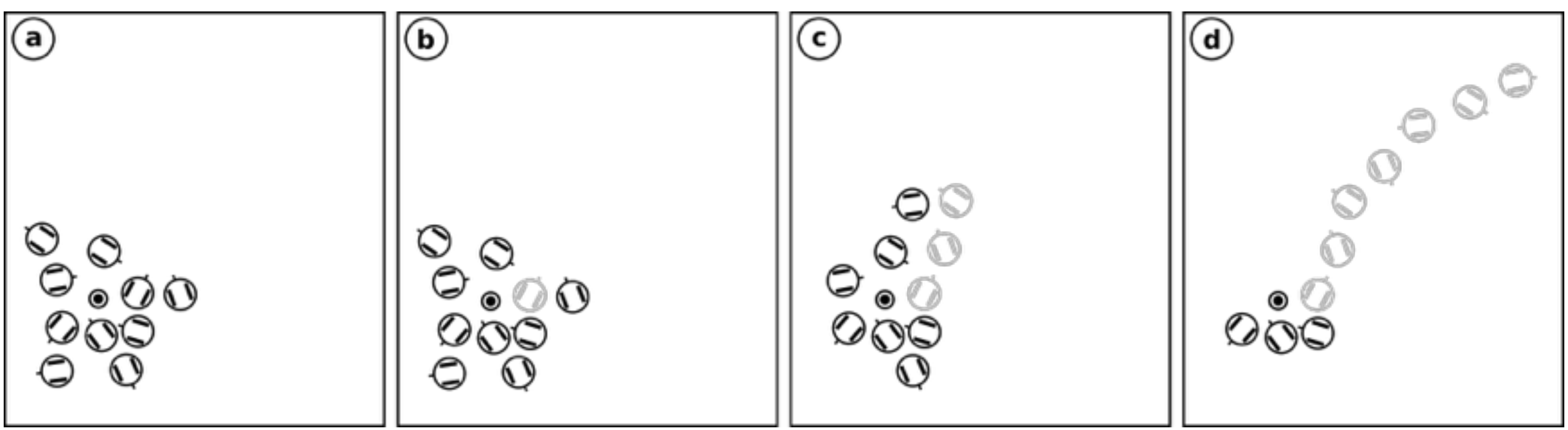
implementation #3

- creation of chains extending from the central place
- maximisation of search distance
- creation of a navigable structure



collective decision making

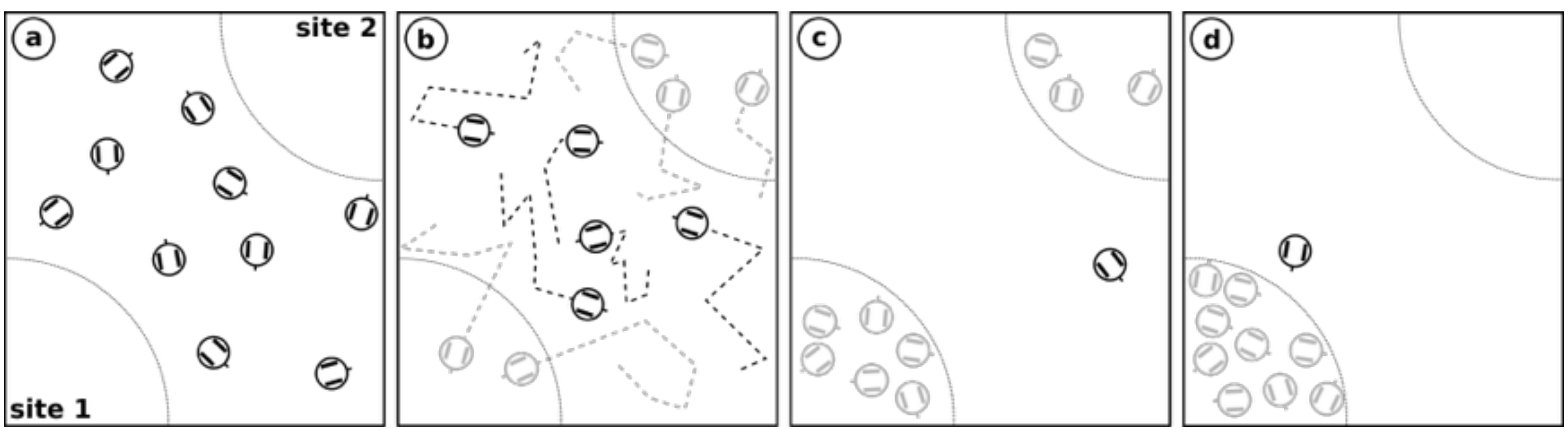
- *definition*:
  the process that leads a group to identify
  the best option out of several alteratives
    - precondition: agents have partial and noisy information about the available alternatives
    - postcondition: the entire group (or a large majority) shares the same choice
- groups stay focused and coherent, limit dissipation of energies among different alternatives

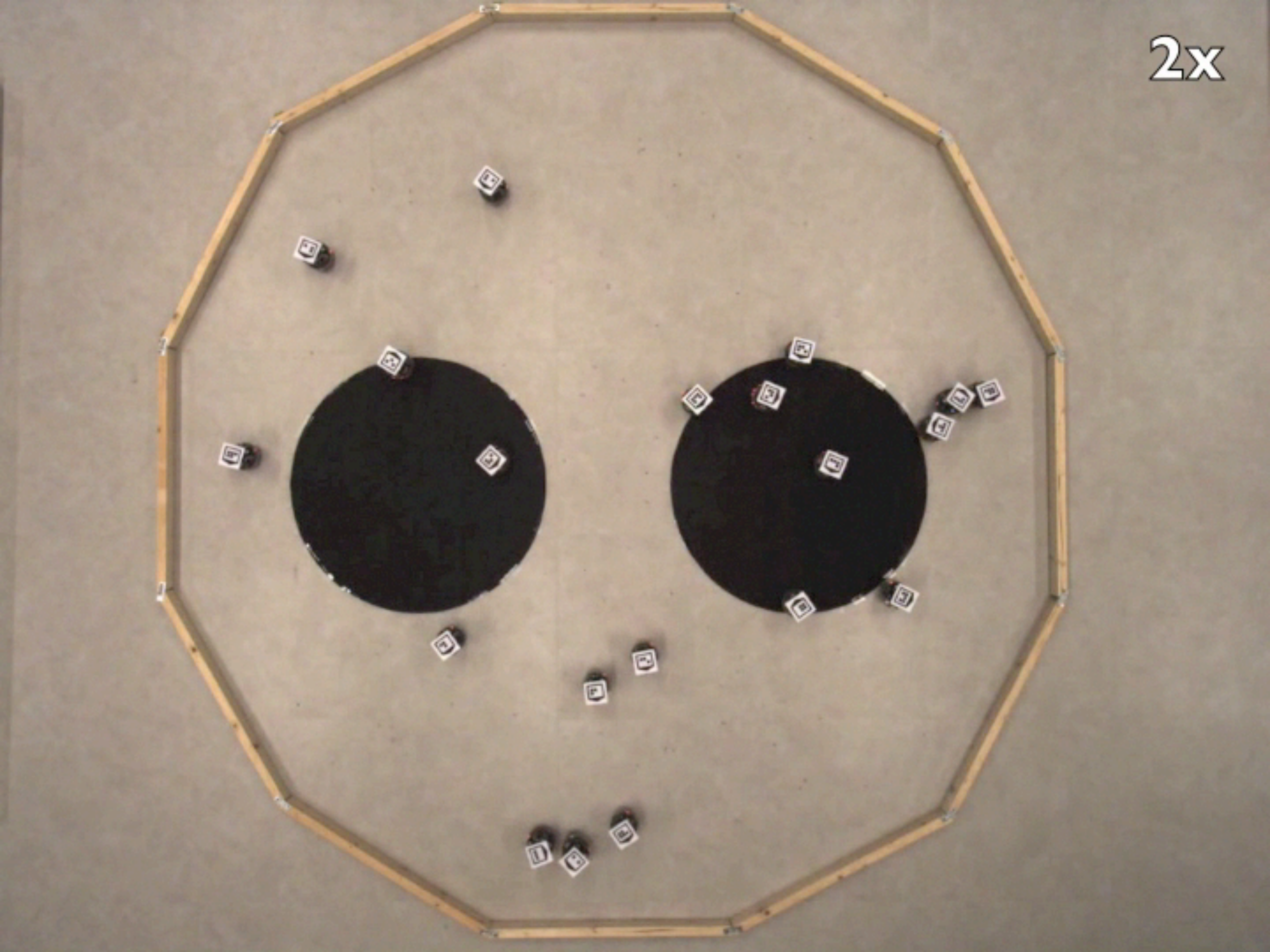
collective decisions: variants

- simple propagation of information
- averaging of opinions (i.e., wisdom of the crowd)
- amplifications of the best choices

implementation #1

- competition between two alternatives
- aggregation depends on the number of individuals
- amplification of random fluctuations

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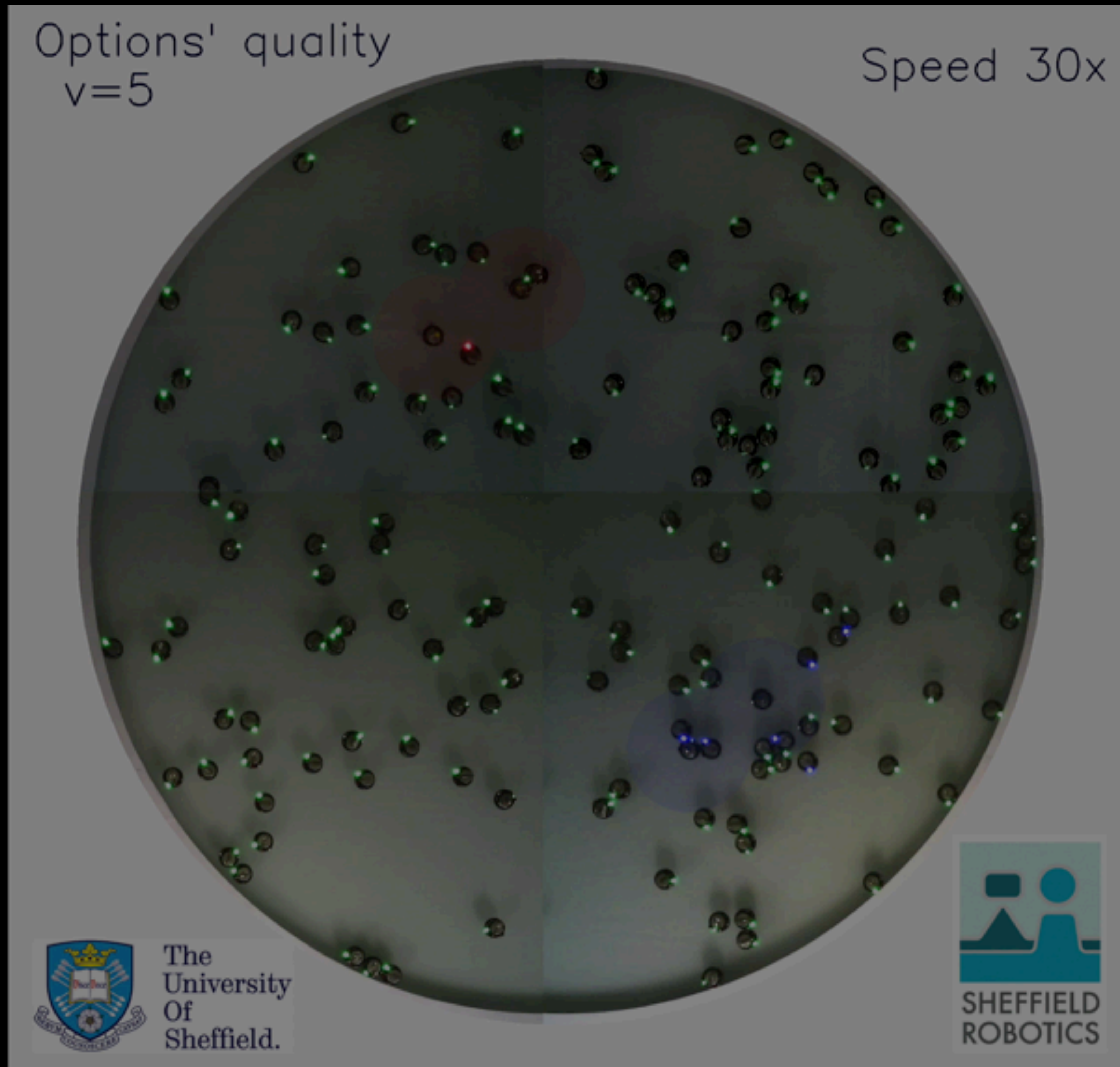
implementation #2

nest-site selection in honeybees

- a bee swarm needs to select the new nesting site
- scout bees identify the available alternatives and share information through the ‘waggle dance’
- different alternatives compete with each other (cross-inhibition)
- need to break deadlock when equally good alternatives exist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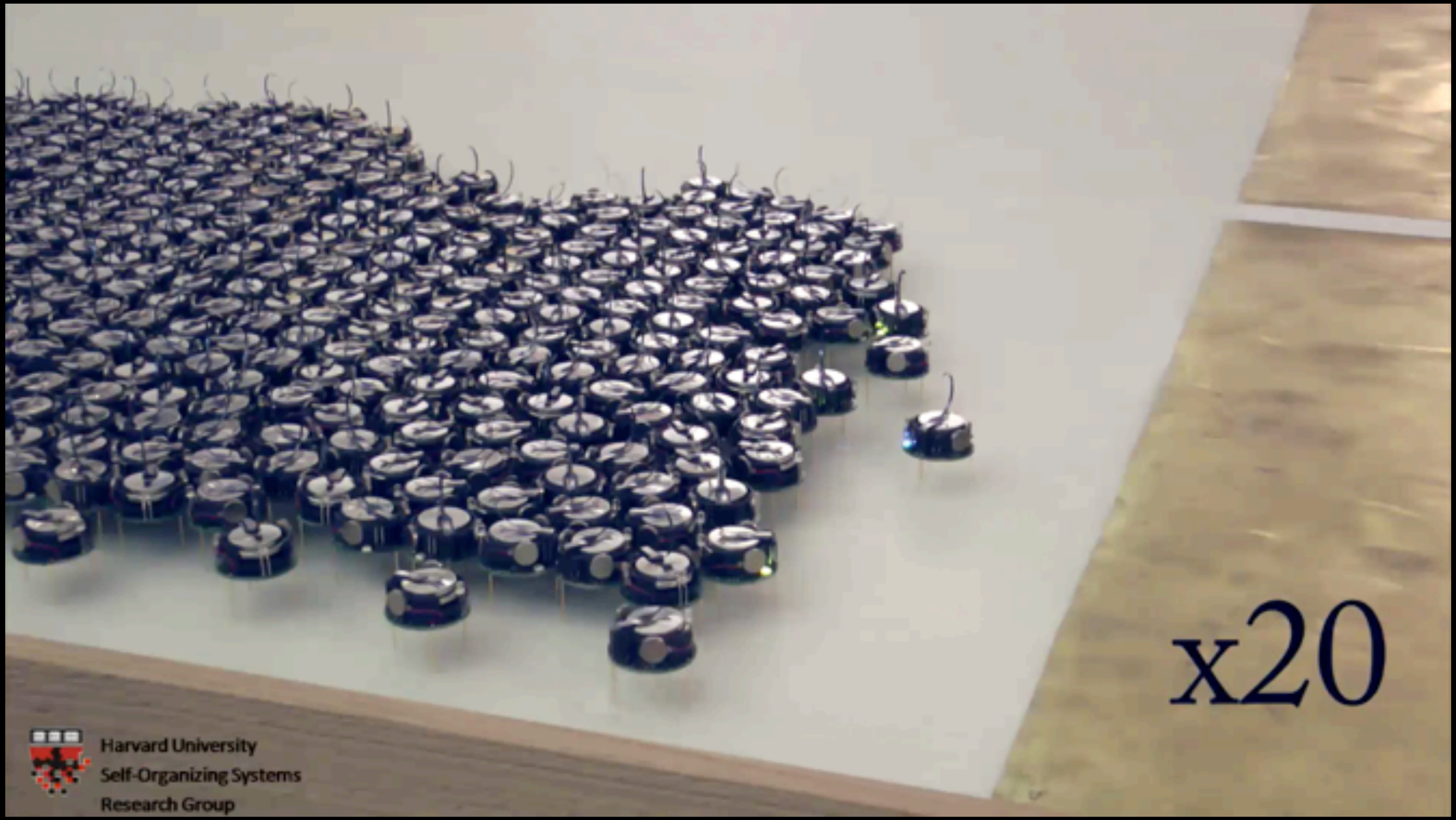
SHEFFIELD ROBOTICS

self-assembly

- *definition*:
  the process that leads a group of agents to from a physical structure upon assembly
    - precondition: agents are isolated and dispersed in space
    - postcondition: agents are assembled in a specific shape
- allows to build structures composed by the agents themselves

self-assembly: variants

- physical or virtual connection among agents
- shapes are pre-defined or emergent from the agents-environment interactions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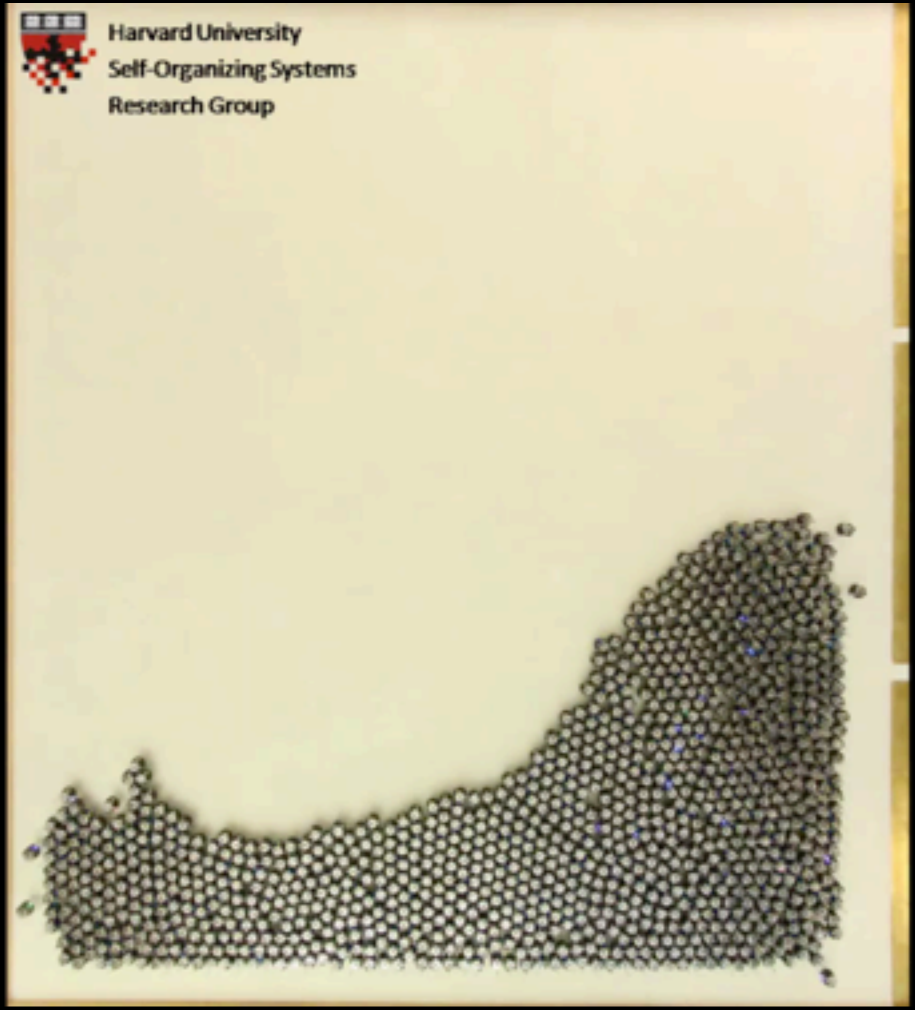
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putting everything together
heterogeneous swarms

thanks for your attention

- References:
    - Trianni, V., & Campo, A. (2015). Fundamental Collective Behaviors in Swarm Robotics. Springer Handbook of Computational Intelligence (pp. 1377–1394).
    - Dimidov, C., Oriolo, G., & Trianni, V. (2016). Random Walks in Swarm Robotics: An Experiment with Kilobots. Swarm Intelligence: 10th International Conference, ANTS 2016, Brussels, Belgium, September 7-9, 2016
- Resources:
    - DICE — Distributed Cognition Engineering
      http://laral.istc.cnr.it/dice-project/
    - SAGA — Swarm Robotics for Agricultural Applications
      http://laral.istc.cnr.it/saga/
- Master thesis available!
  vito.trianni@istc.cnr.it / albani@dis.uniroma1.it