Swarm Robotics
– an overview –

Vito Trianni, PhD
Institute of Cognitive Sciences and Technologies
National Research Council
vito.trianni@istc.cnr.it
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
- robustness
- scalability
- 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 $\Rightarrow$ 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

![Graph showing performance vs group size]
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
experiments with robots #2

- BEECLUST algorithm
- aggregation in specific locations
- adaptive to changes in the environment
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
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 alternatives
  
  • 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
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
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
putting everything together
heterogeneous swarms
thanks for your attention

• References:

• 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