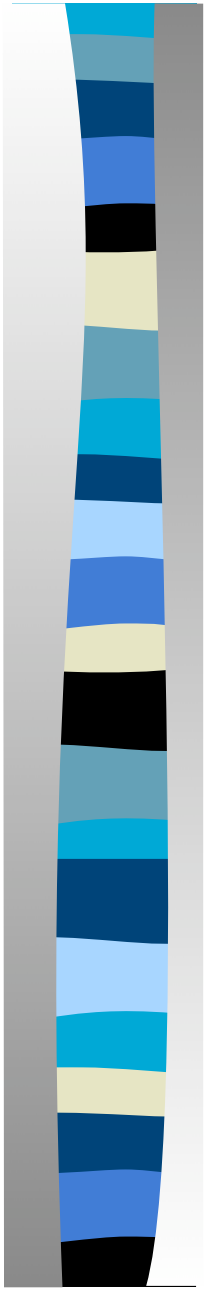


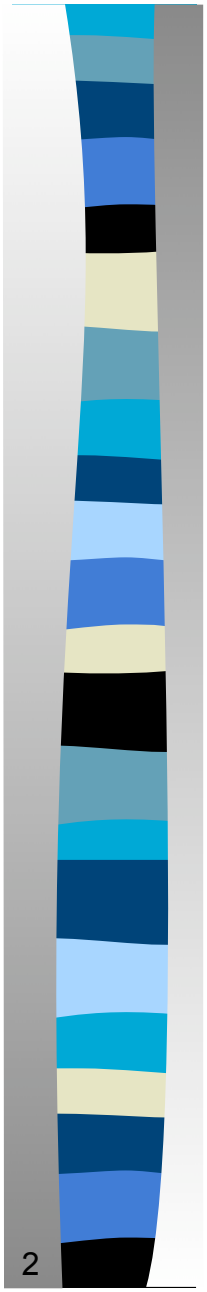
Swarm Intelligence and Swarm Robotics: The Swarm-bot experiment

Marco Dorigo

FNRS Research Director

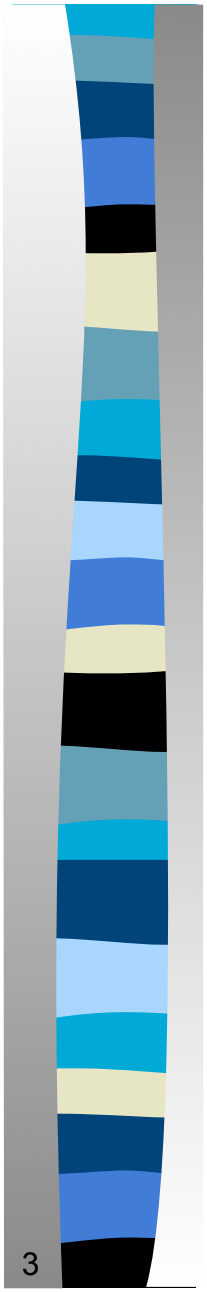
IRIDIA

Université Libre de Bruxelles



What is swarm robotics?

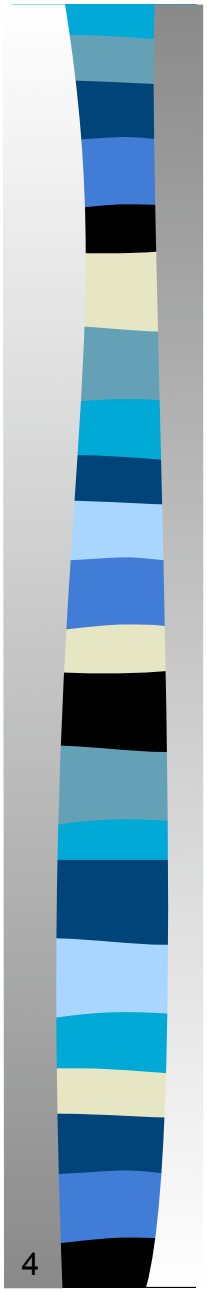
Swarm robotics is the application of swarm intelligence principles to the control of groups of robots



What is swarm intelligence?

- **Swarm intelligence** is an artificial intelligence technique based around the study of **collective behavior in decentralized, self-organized** systems
- Swarm intelligence systems are typically made up of a **population of simple agents** interacting **locally** with one another and with their environment
- Although there is **normally no centralized control structure** dictating how individual agents should behave, **local interactions** between such agents often **lead to the emergence of global behavior**
- Examples of systems like this can be found in nature, including ant colonies, bird flocking, animal herding, and fish schooling

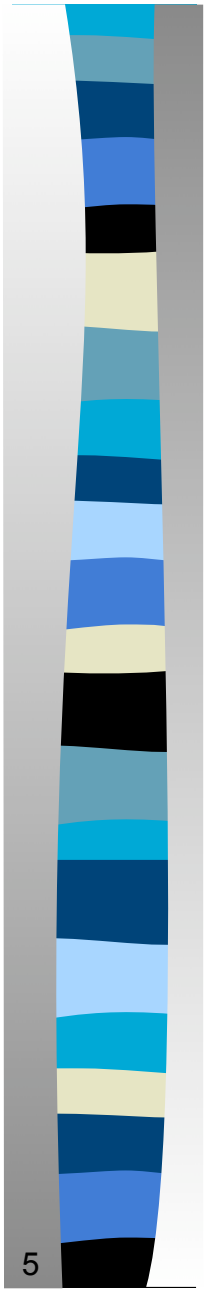
From "Wikipedia, Swarm Intelligence"



Swarm intelligence

Distinguish between

- **Scientific swarm intelligence**
- **Engineering swarm intelligence**

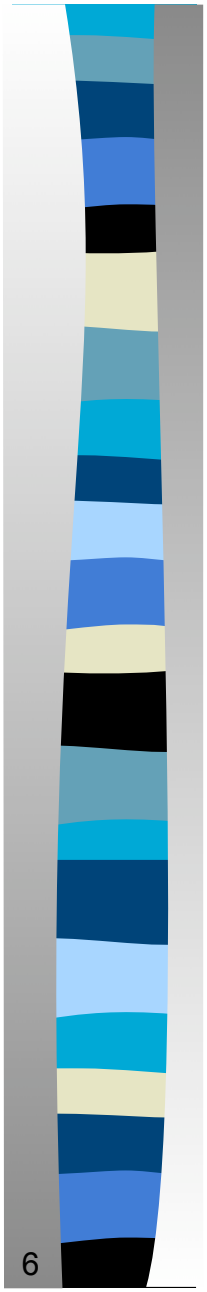


Swarm intelligence

Distinguish between

- **Scientific swarm intelligence**

is concerned with the understanding of natural swarm systems

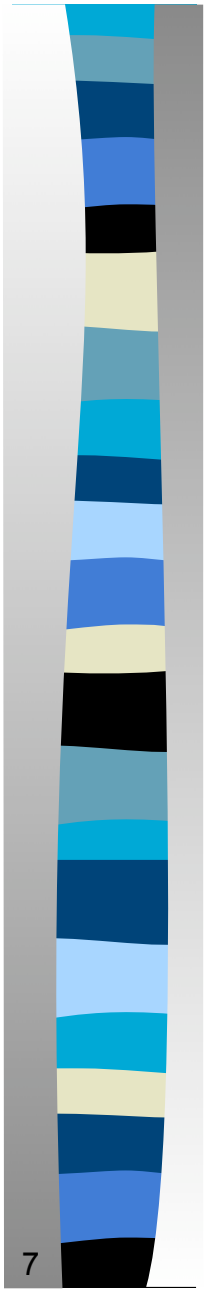


Swarm intelligence

Distinguish between

- **Engineering swarm intelligence**

is concerned with the design and implementation of artificial swarm systems



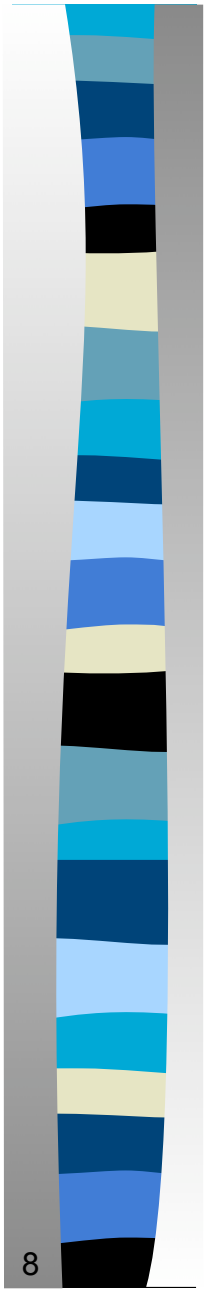
Swarm intelligence

Engineering swarm intelligence

takes inspiration from

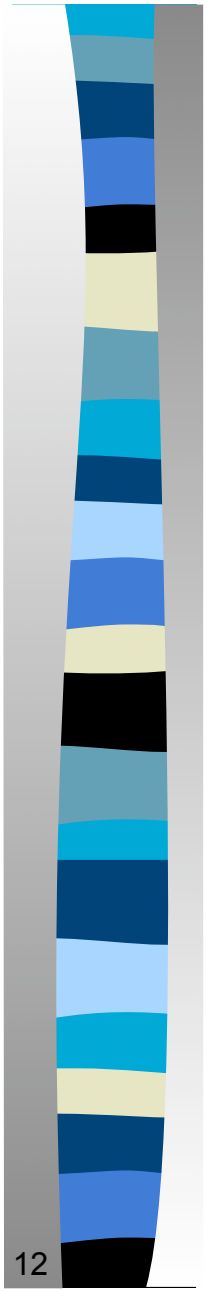
scientific swarm intelligence studies to

design problem-solving devices



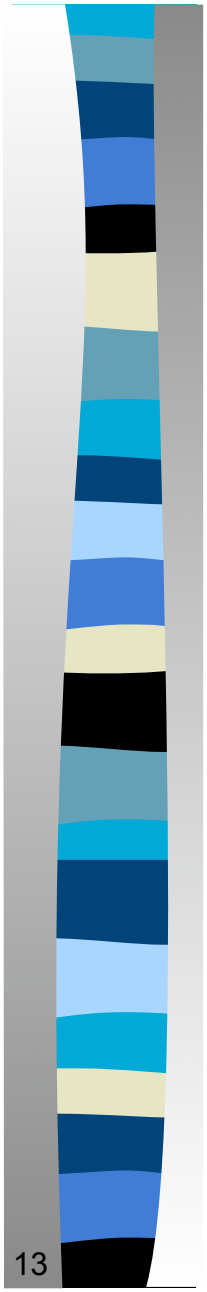
Characteristics of swarm intelligence systems

- Multi-agent
- Individuals are modeled as having stochastic behavior
- Individuals use only local information
- Self-organized and distributed control



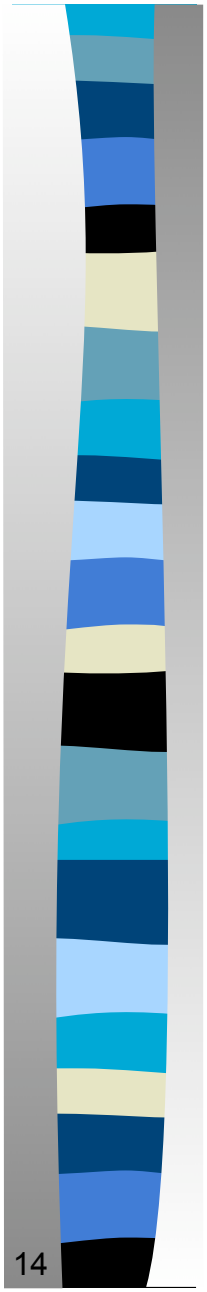
Examples

- Foraging
  - ➠ ant colony optimization
    (routing, combinatorial optimization)
- Division of labor
  - ➠ adaptive task allocation
- Cemetery organization and brood sorting
  - ➠ data clustering
- Self-assembly and cooperative transport
  - ➠ robotic implementations



Research method

- Observe a social behavior
- Build a simple model to explain it
- Use the model of the social behavior as a source of inspiration for solving a practical problem that has some similarities with the observed social behavior

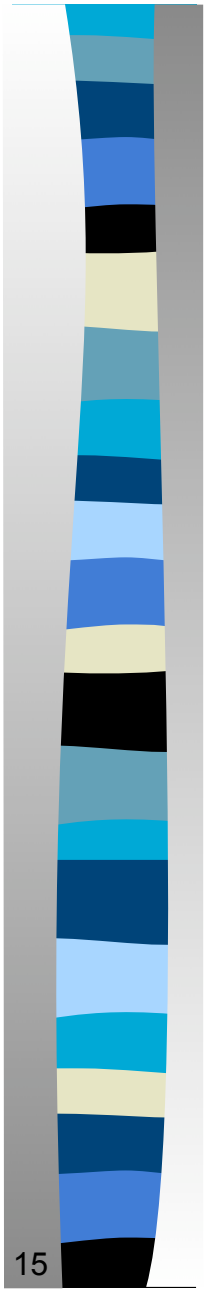


Research method

- Observe a social behavior
- Build a simple model to explain it

] biologists

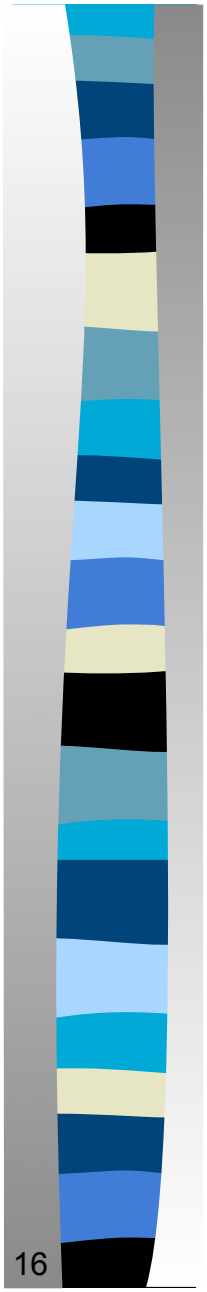
- Use the model of the social behavior as a source of inspiration for solving a practical problem that has some similarities with the observed social behavior



Research method

- Observe a social behavior
- Build a simple model to explain it
- Use the model of the social behavior as a source of inspiration for solving a practical problem that has some similarities with the observed social behavior

Computer scientists, engineers,
operation researchers, roboticists

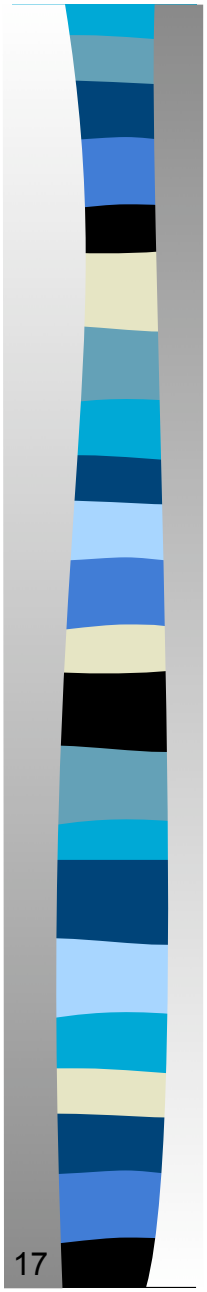


What is swarm robotics?

It is the application of swarm intelligence principles to collective robotics

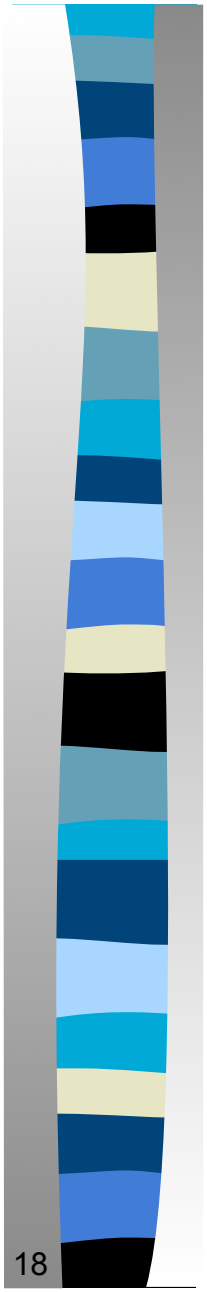
It is research in collective robotics:

- that is relevant for the control and coordination of **large numbers of robots**
- in which robots are **relatively simple and incapable**, so that the tasks they tackle require cooperation
- in which the robots have only **local and limited sensing and communication abilities**



Technological motivations

- Parallelism:
  Different robots can perform different task at the same time
- Fault tolerance:
  When a robot breaks down another one can take over. No single point-of-failure
- Cost:
  Simple robots are cheaper to build than complex robots
- Scalability:
  Add more robots, get more work done

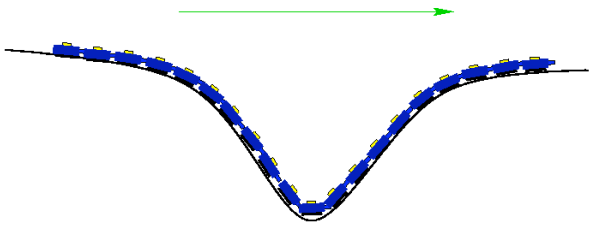


What is a swarm-bot?

The swarm-bot is an experiment in swarm robotics

- A “**swarm-bot**” is an artifact composed of a number of simpler robots, called “**s-bots**”, capable of **self-assembling** and **self-organizing** to adapt to its environment
- S-bots can **connect to and disconnect from** each other to self-assemble and form structures when needed, and disband at will

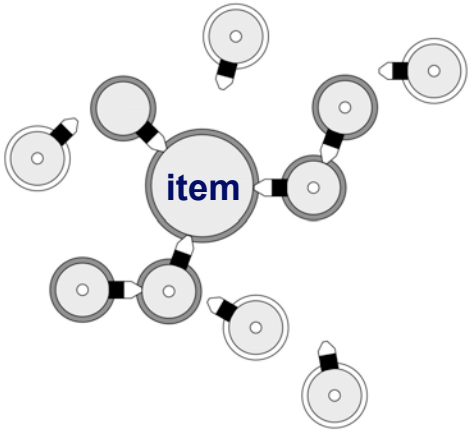
What should a swarm-bot be able to do?

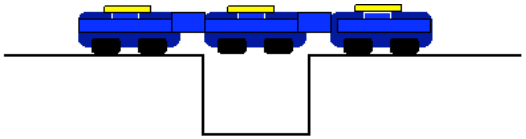


Demonstrate both logical and physical cooperation

For example:

- Move in formation to overcome obstacles that a single s-bot cannot overcome alone
- Retrieve an item that is too heavy for a single s-bot

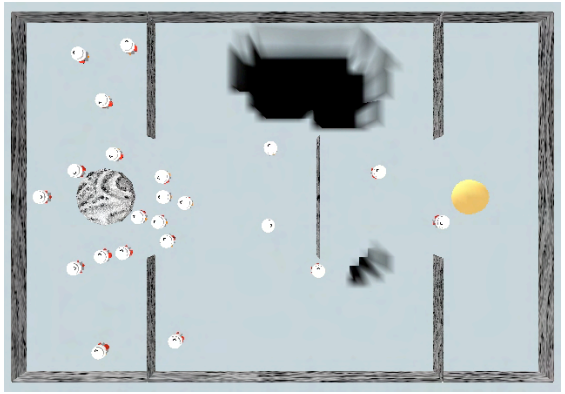




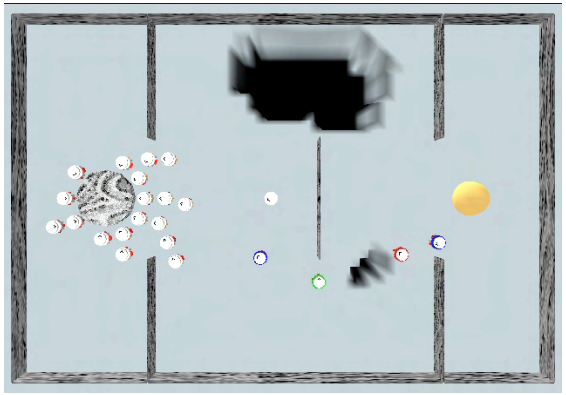
Swarm-bots

Our scenario

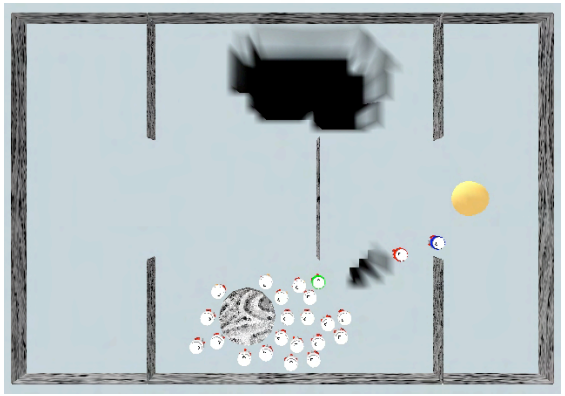
Find object and aggregate around it

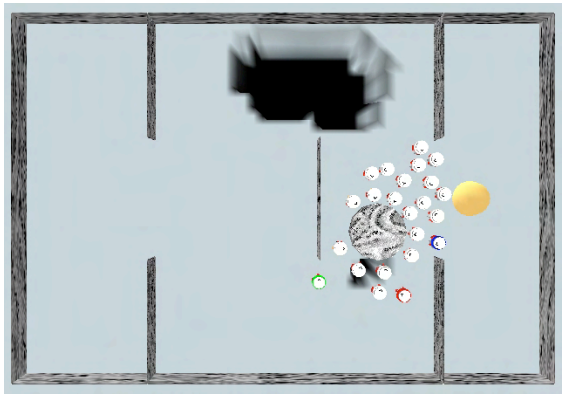


Pull object and search for goal

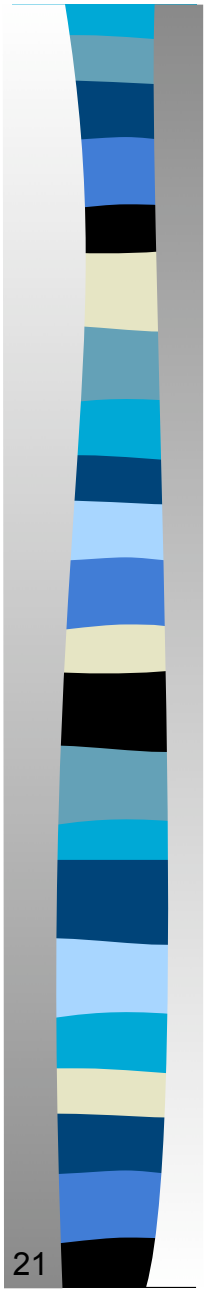


Change shape and move in a coordinate way avoiding obstacles





ULB



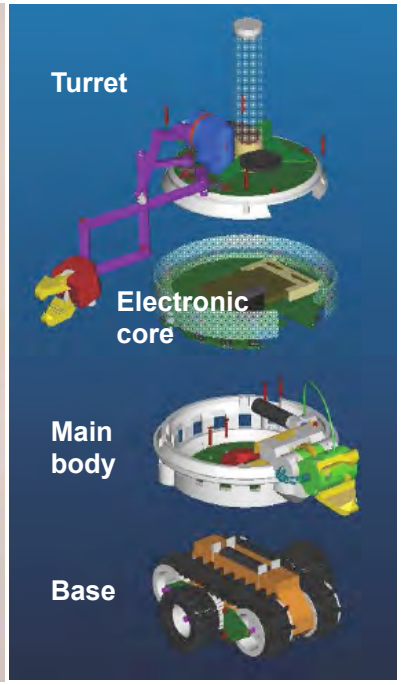
What comes next

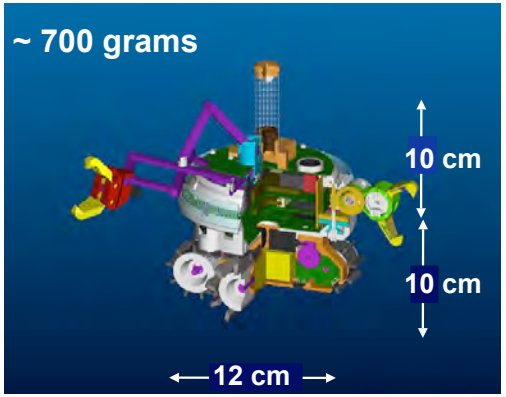
- Brief description of the hardware
- Brief description of the methodology used to develop the controllers
- Results with the real robots
- Ongoing work

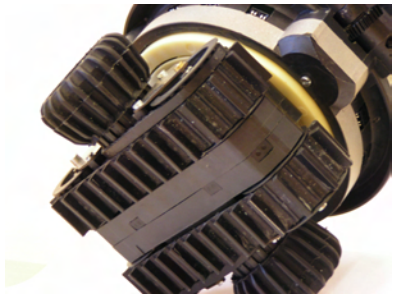
Swarm-bots

Hardware: the s-bot mechanics

Approximately 100 parts

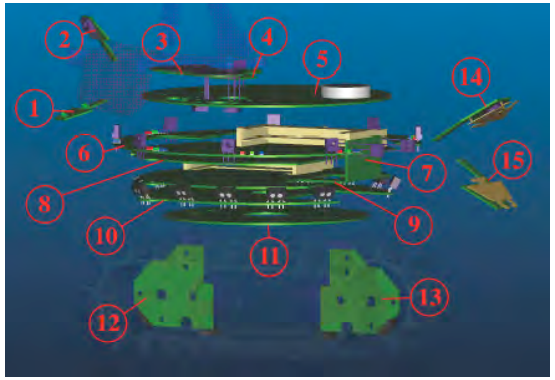


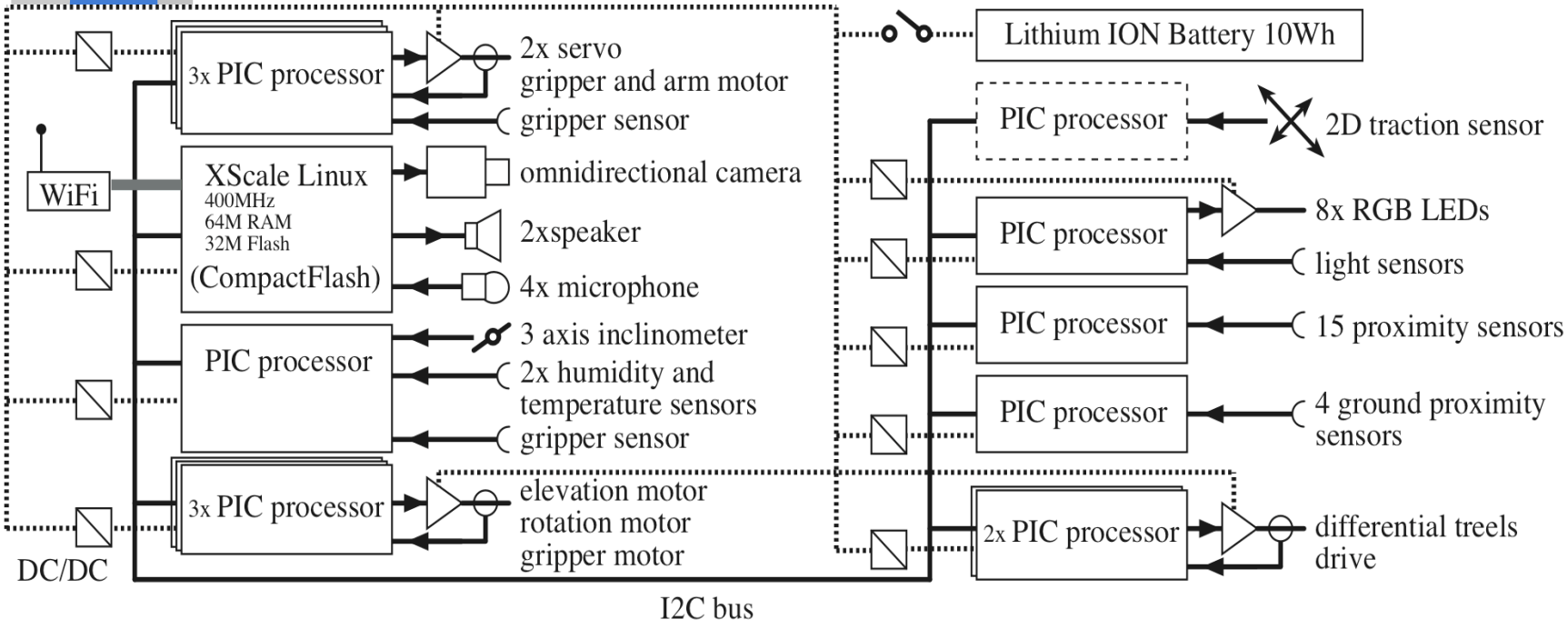


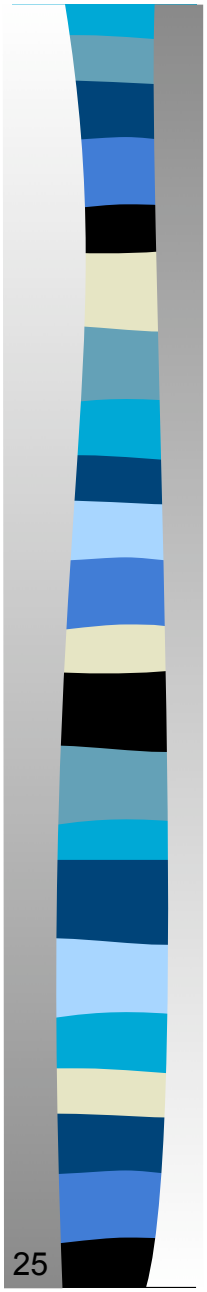


Swarm-bots

Hardware: the s-bot electronics







Controllers development: methodology

- Develop a simulation model of the hardware
- Define the basic behaviors to be developed
- Use either

  hand-coded behavior-based architectures

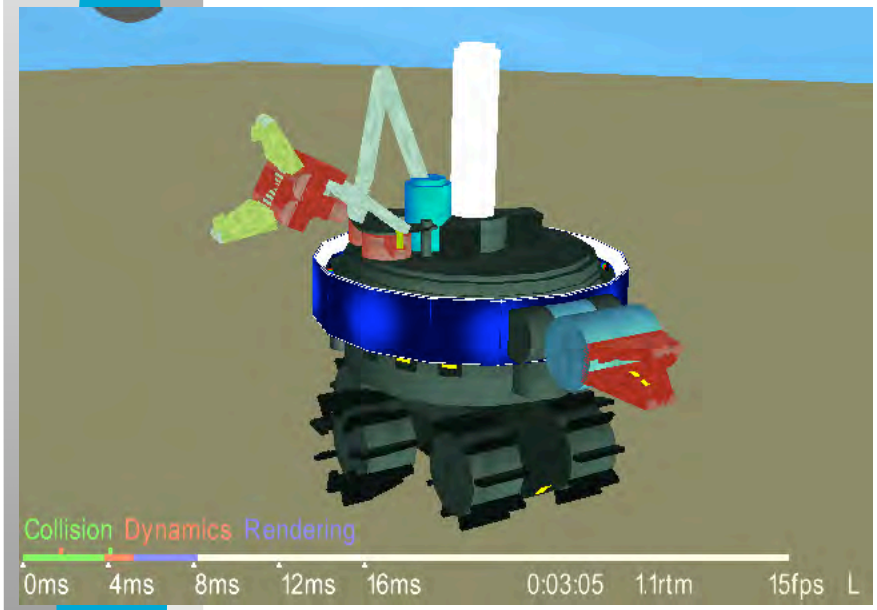
  or

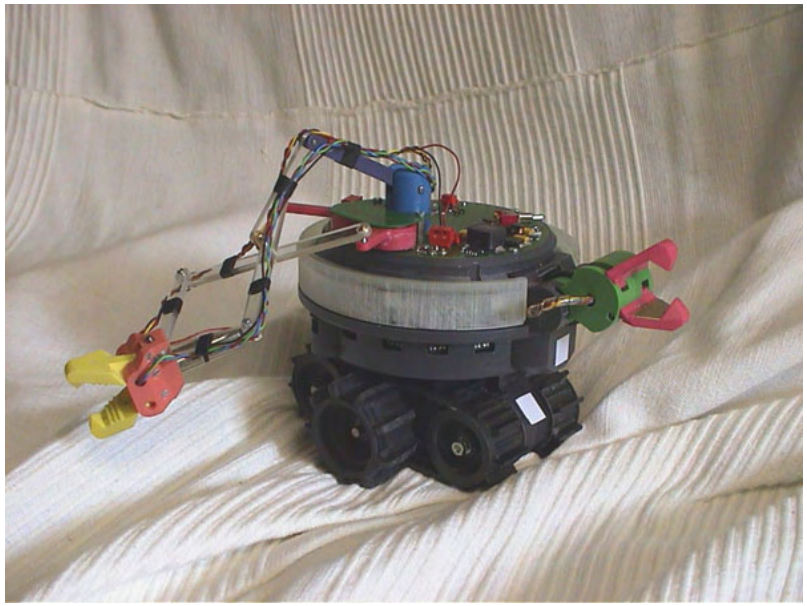
  artificial evolution of neural networks

  to synthesize the basic behaviors in simulation that can be ported to the real *s-bots*
- Download and test the obtained controllers on the real *s-bots*

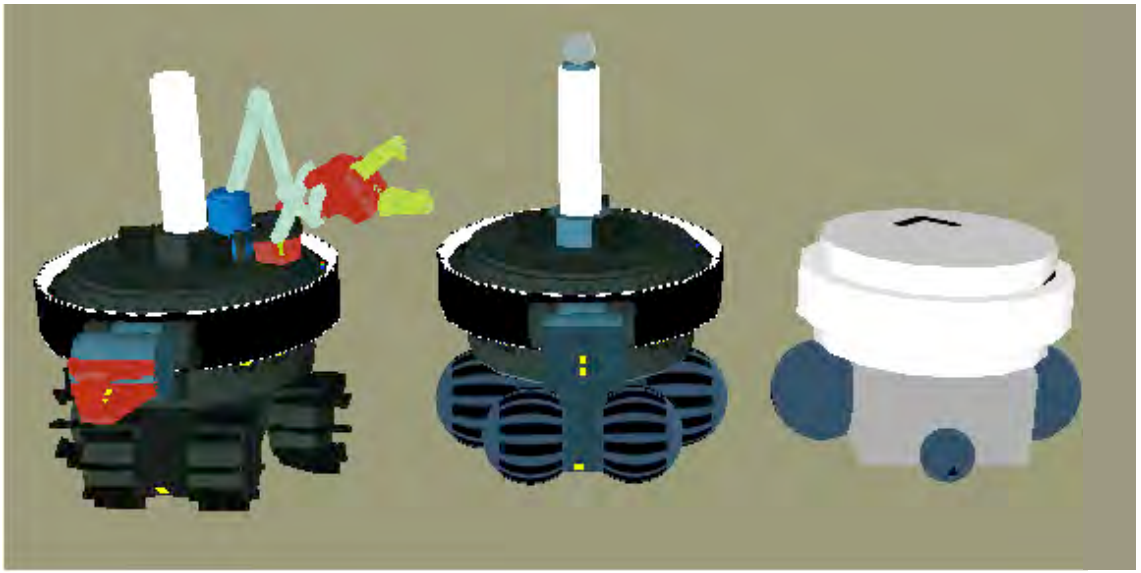
Swarm-bots

Simulation model





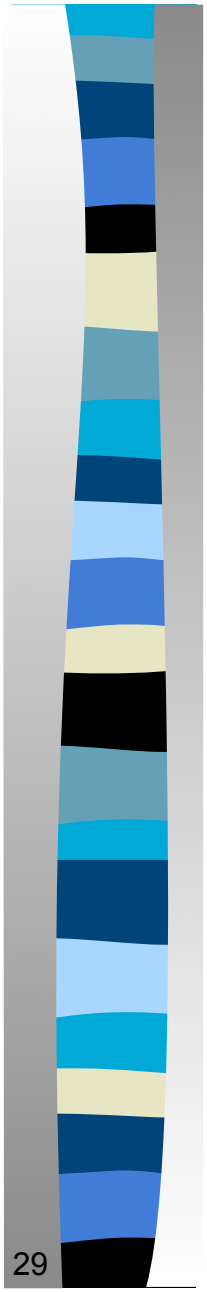
Different levels of detail



detailed medium simple

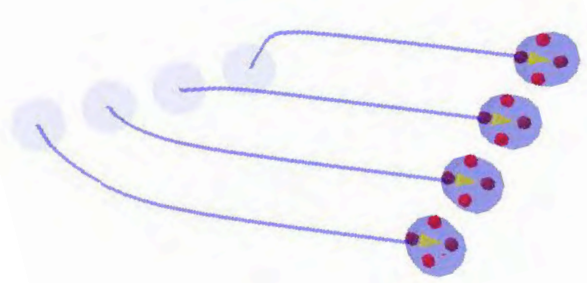
Definition of behaviors for the scenario

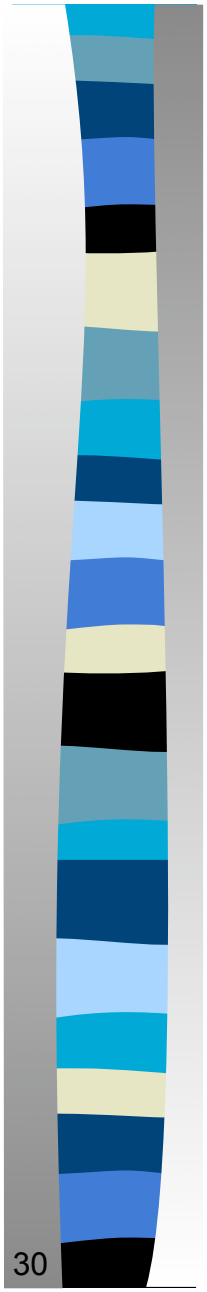
- Coordinated motion
- Self-assembly
- Cooperative transport
- Goal search and path formation



Coordinated motion

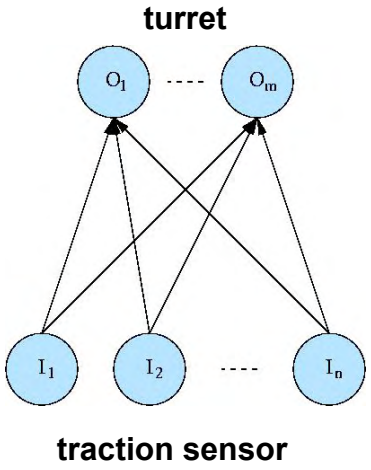
- Four ***s-bots*** are connected in a swarm-bot formation
- Their chassis are randomly oriented
- The ***s-bots*** should be able to
  - collectively choose a direction of motion
  - move as far as possible
- Simple perceptrons are evolved as controllers



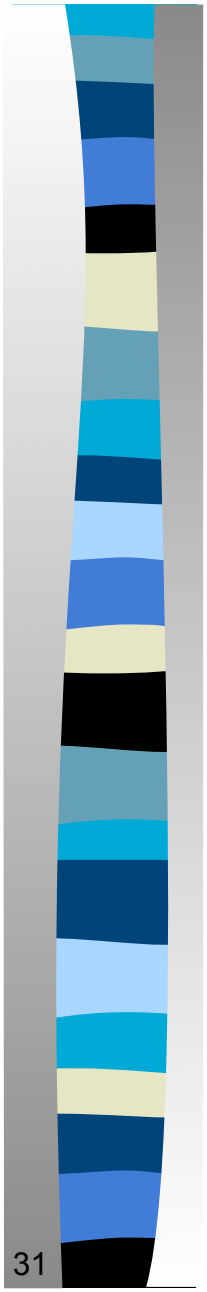


The traction sensor

- Connected ***s-bots*** apply pulling/pushing forces to each other when moving
- Each ***s-bot*** can measure a traction force acting on its turret/chassis connection
- The traction force indicates the mismatch between
  - the average direction of motion of the group
  - the desired direction of motion of the single s-bot

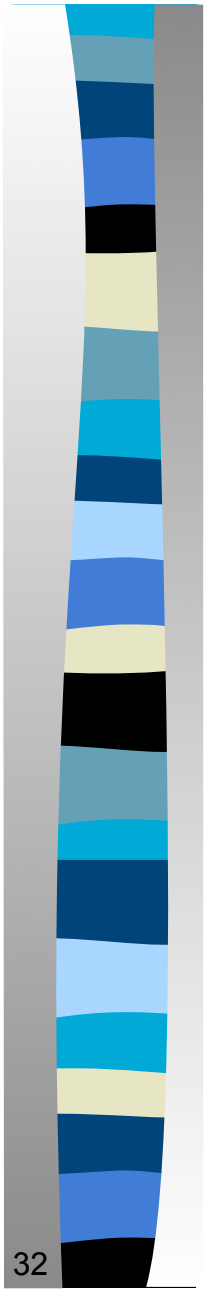


traction sensor



The evolutionary algorithm

- Binary encoded genotype
  - 8 bits per real valued parameter of the neural controllers
- Generational evolutionary algorithm
  - 100 individuals evolved for 100 generations
  - 20 best individuals are allowed to reproduce in each generation
  - Mutation (3% per bit) is applied to the offspring
- The perceptron is cloned and downloaded on each ***s-bot***
- Fitness is evaluated looking at the swarm-bots performance
  - Each individual is evaluated with equal starting conditions



Fitness evaluation

- The fitness F of a genotype is given by the distance covered by the group:

$$F = \frac{\| X(t) - X(0) \|}{D}$$

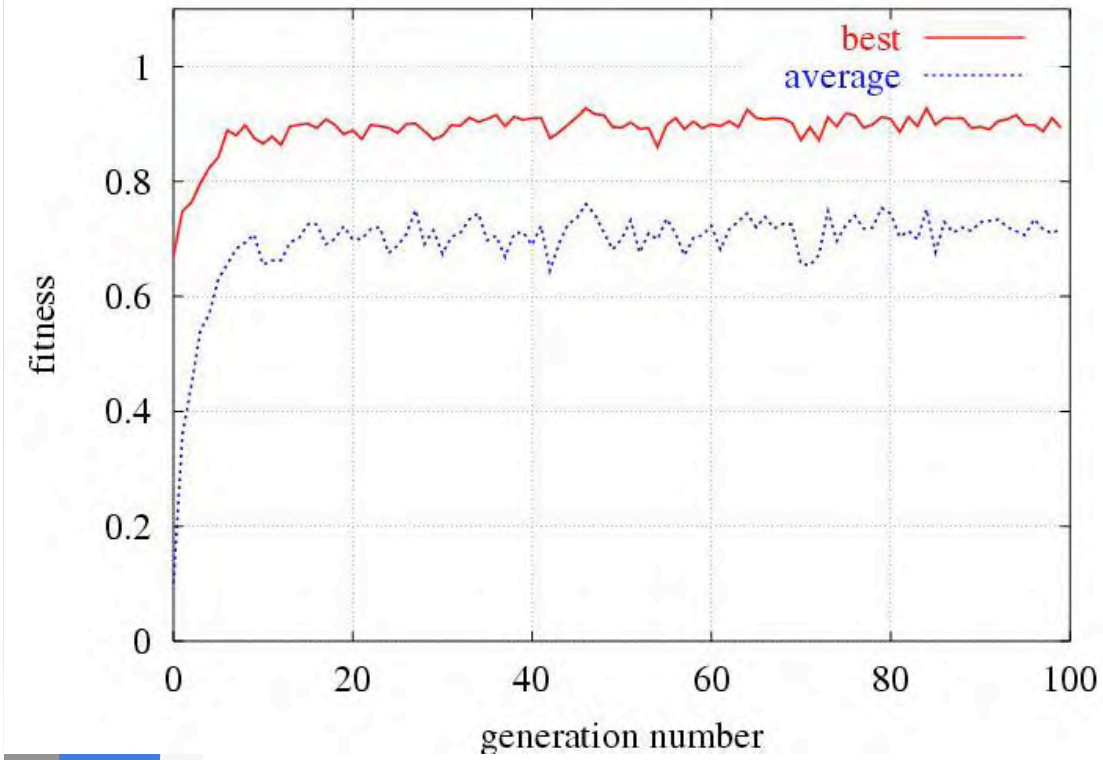
  where $X(t)$ is the coordinate vector of the center of mass at time t, and D is the maximum distance that can be covered in 150 simulation cycles

- Fitness is evaluated 5 times, starting from different random initializations
- The resulting average is assigned to the genotype

Swarm-bots: Coordinated motion

Results

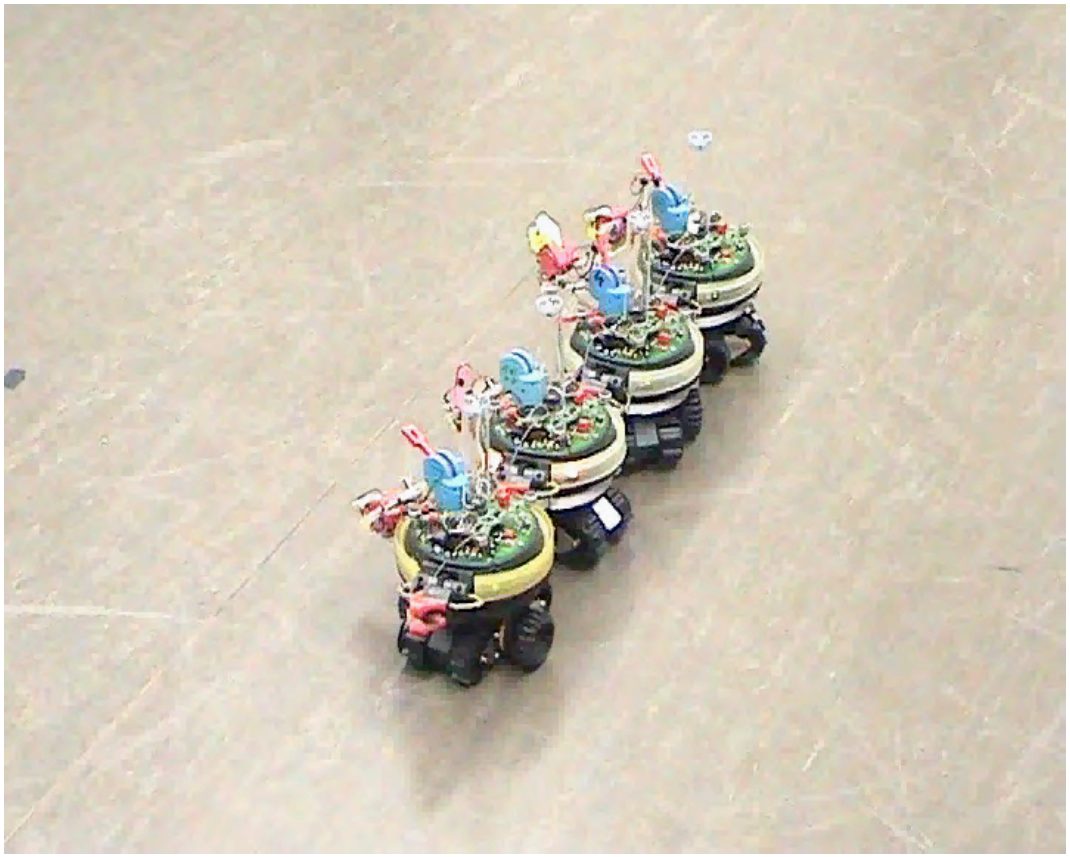
Average fitness



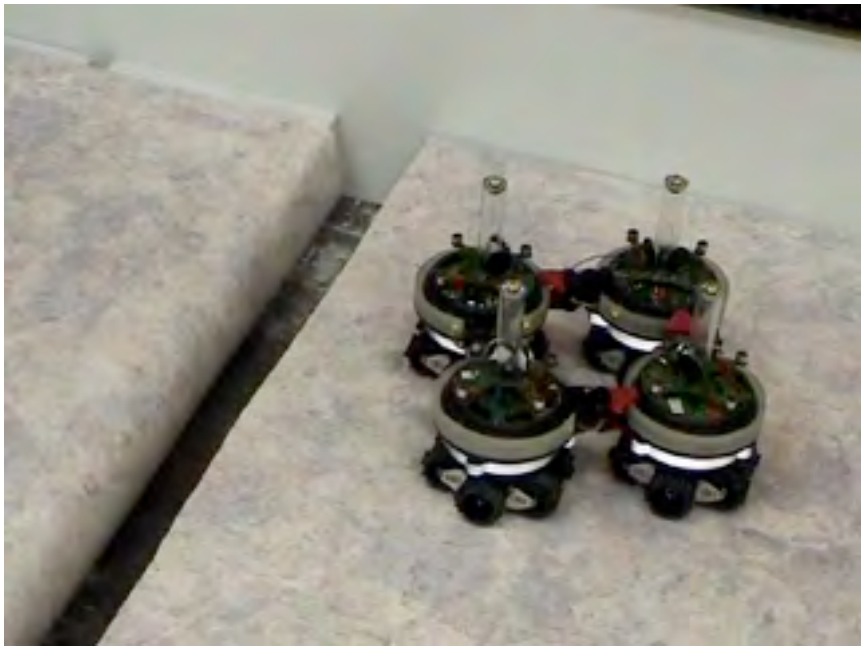
Post-evaluation

Replication	Performance
1	0.87888
2	0.83959
3	0.88338
4	0.71567
5	0.79573
6	0.75209
7	0.83425
8	0.85848
9	0.87222
10	0.76111

Porting to real s-bots



Real s-bots



flexibility

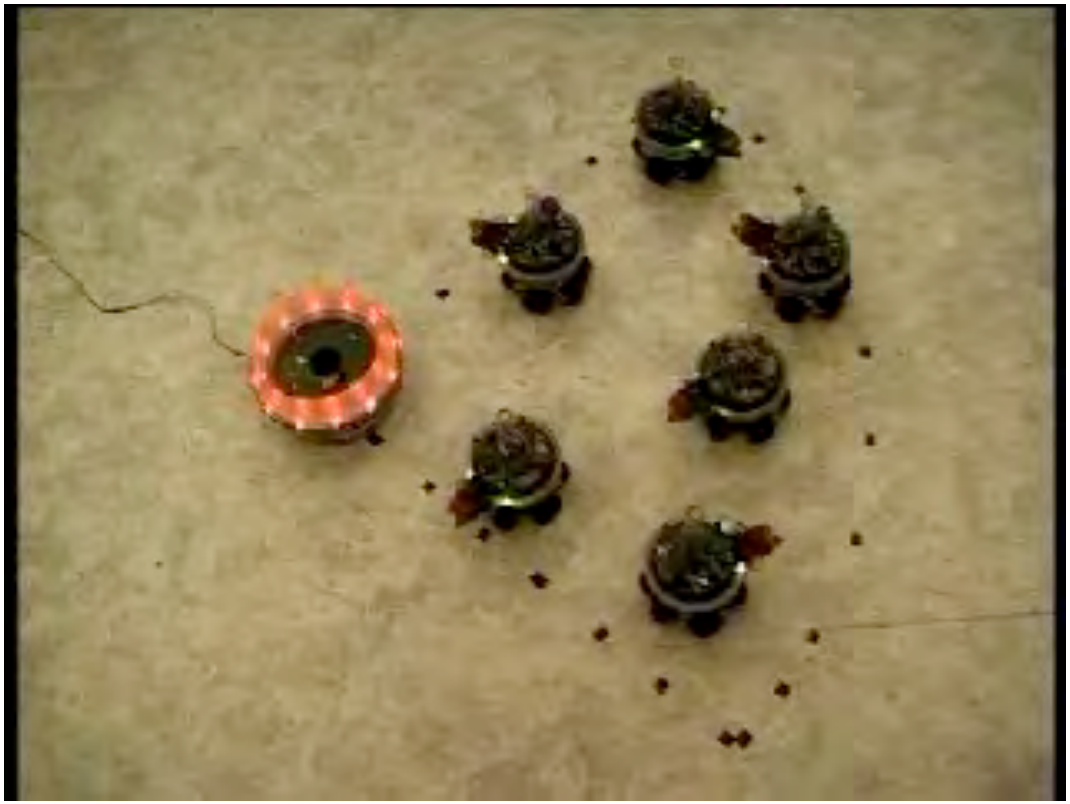
Swarm-bots: Coordinated motion

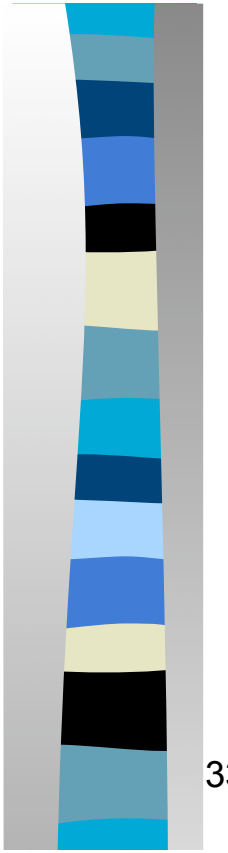
Scalability

scalability

flexibility and scalability

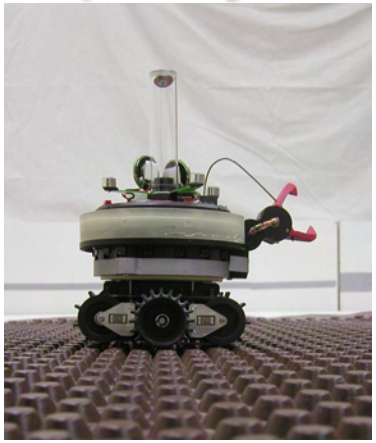
Six s-bots and a prey



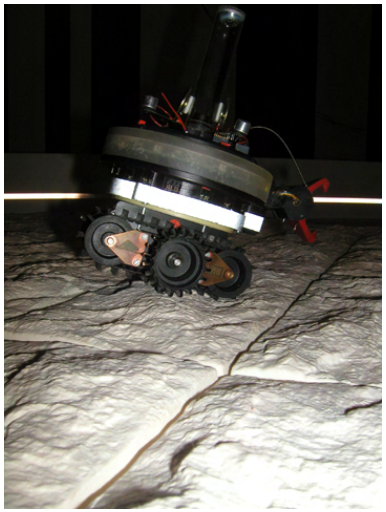


Swarm-bots: Self-assembly

Six s-bots and a prey

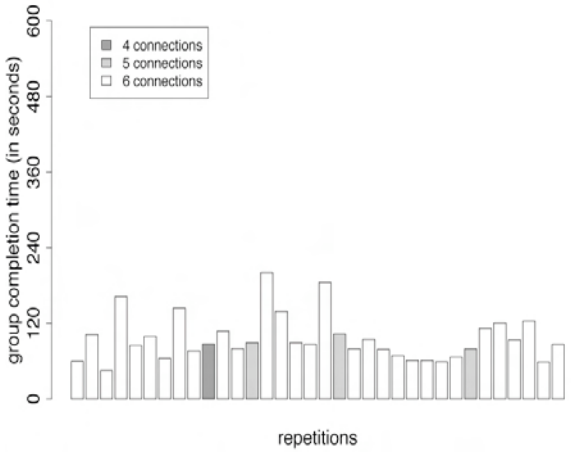


brown rough terrain

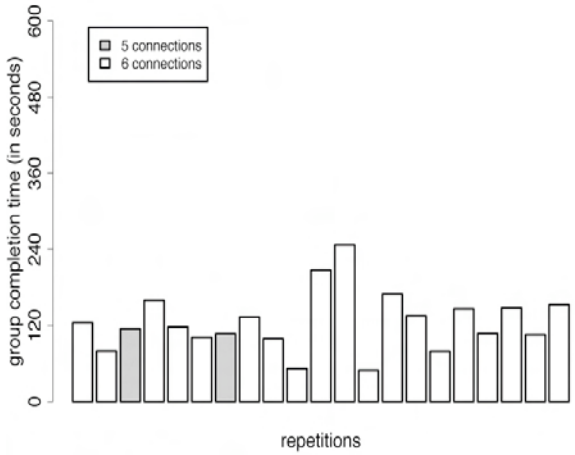


white rough terrain

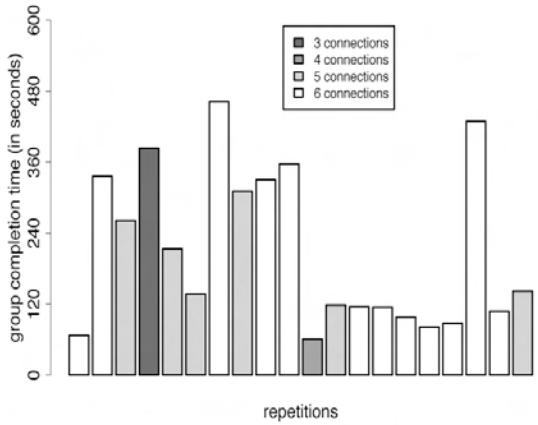
33 repetitions
flat terrain



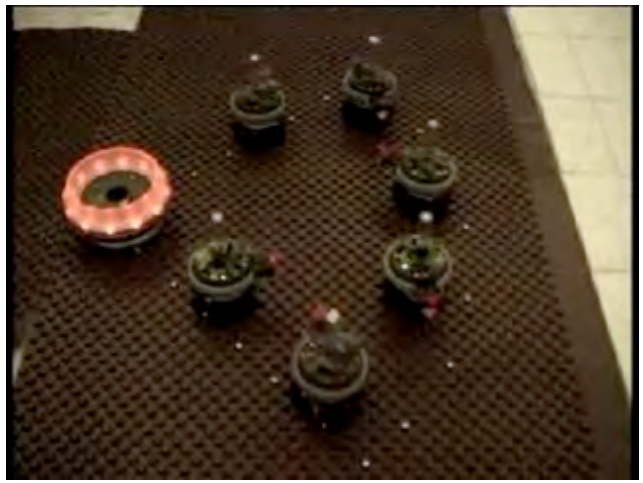
20 repetitions
brown rough terrain



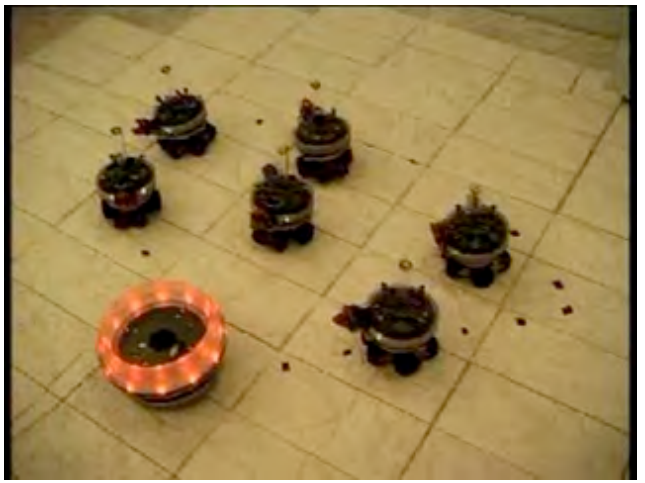
20 repetitions
white rough terrain



Six s-bots and a prey

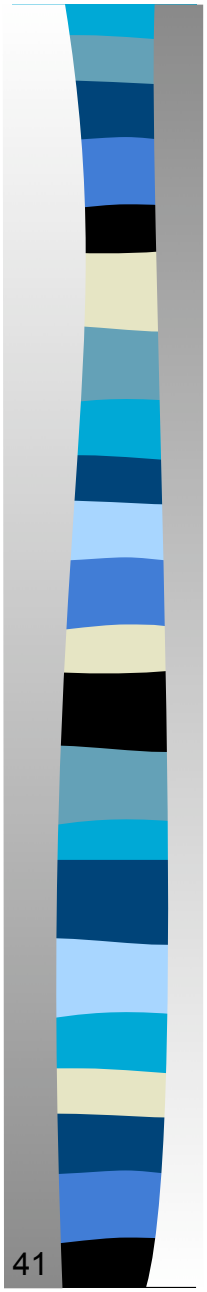


flexibility



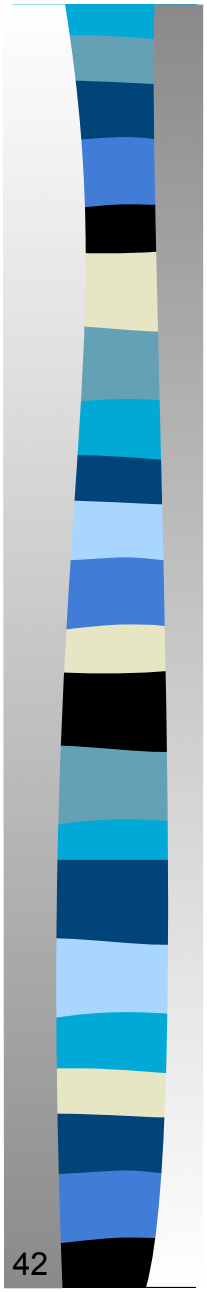
flexibility

scalability



Cooperative transport

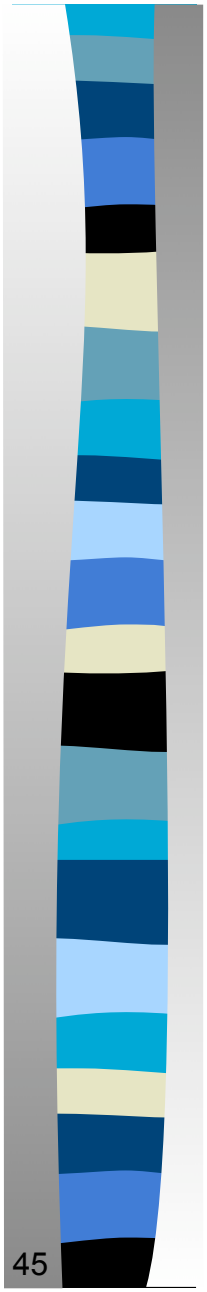
- **Goal:**
  - **Let a swarm-bot transport an object to a goal location**
- **Control**
  - **Designed phototaxis behavior**
  - **Neural net for blind s-bots**



Experiments

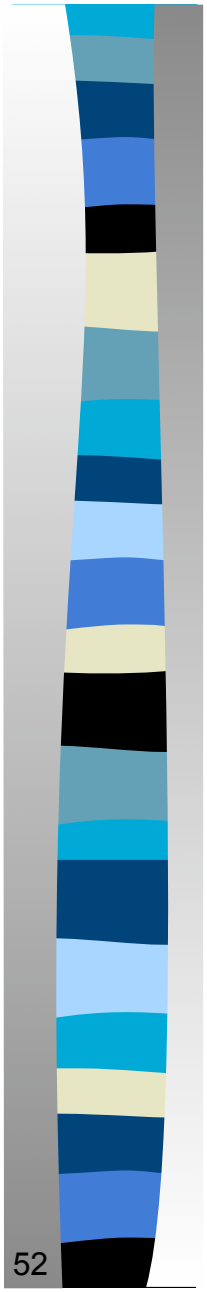
- Swarm-bots composed of 2 to 6 s-bots
- Different types of terrains
- Different weights of the transported object
- Failure during transport
  - One s-bot is blind. Comparisons with:
    - Blind s-bot controlled by learned neural net
    - Blind s-bot replaced by non-blind s-bot
    - Blind s-bot removed
- Failure during transport
  - One s-bot is not operational
- Integration with self-assembly

Self-assembly and transport

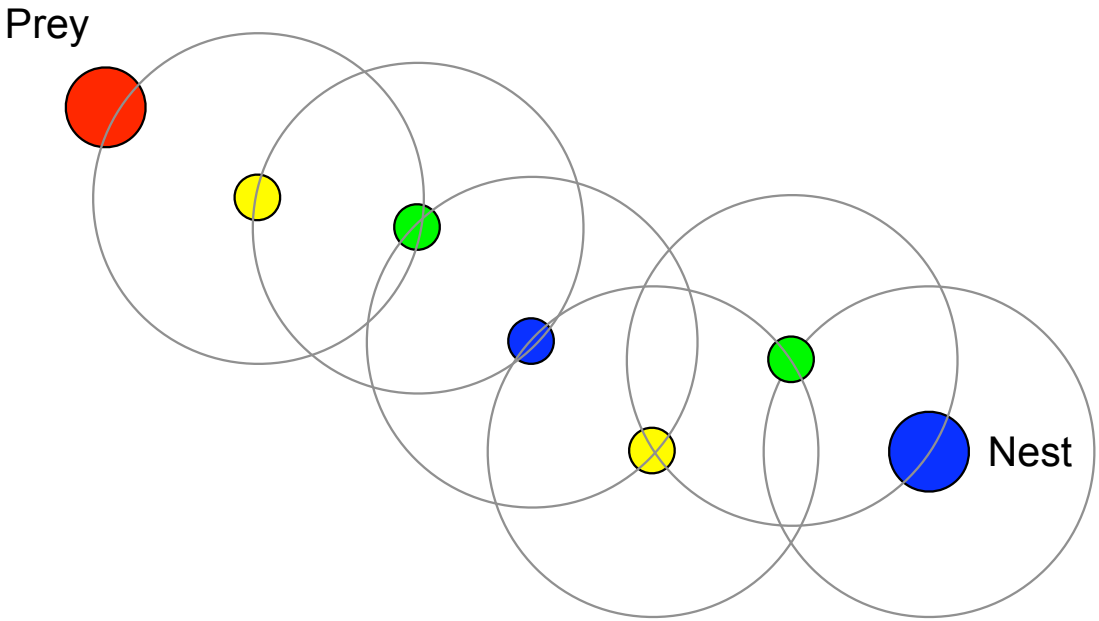


Path formation

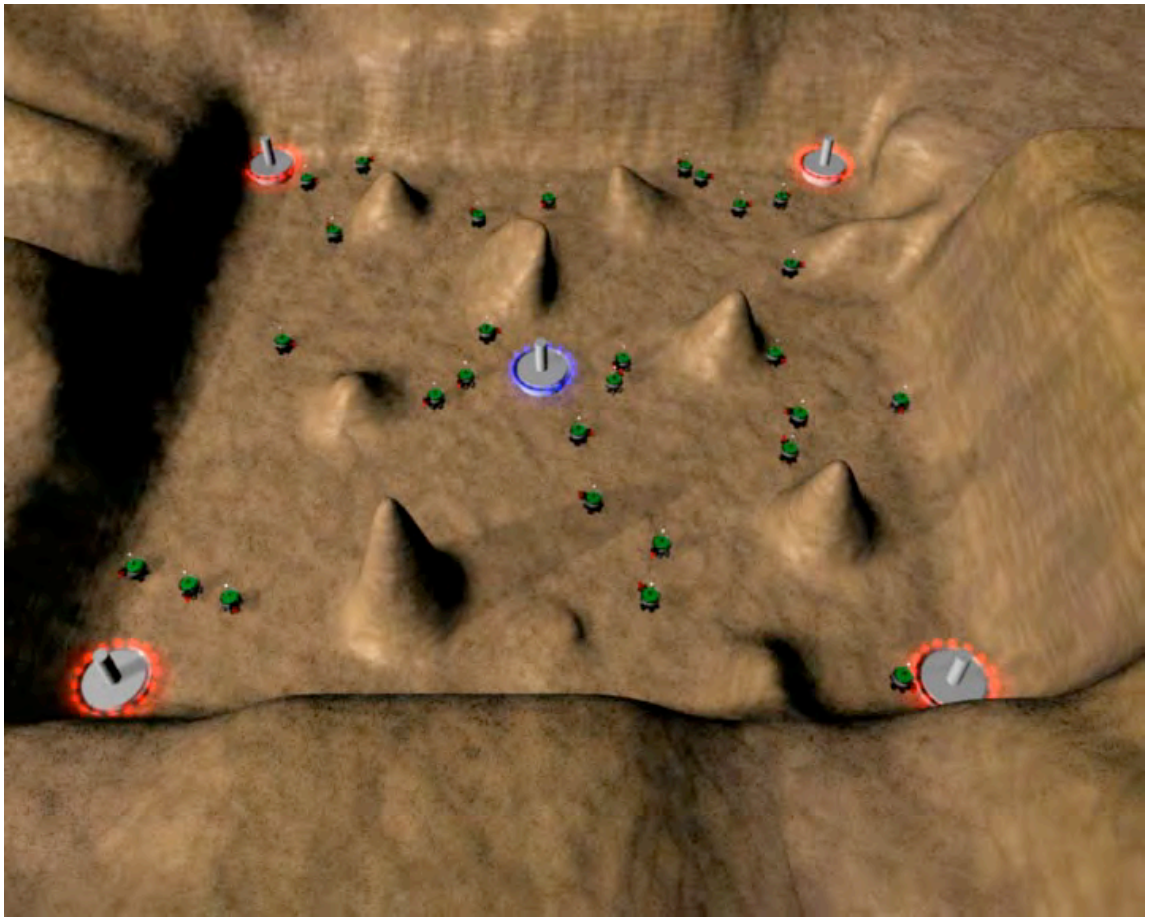
- Our robots have limited sensing capabilities:
  - Can distinguish 3 colors (approx up to 30 cm away)
  - Can say which color is closer
- We want to mimic ants trail formation, but ***s-bots*** cannot lay pheromones
- We use ***s-bots*** instead of pheromones



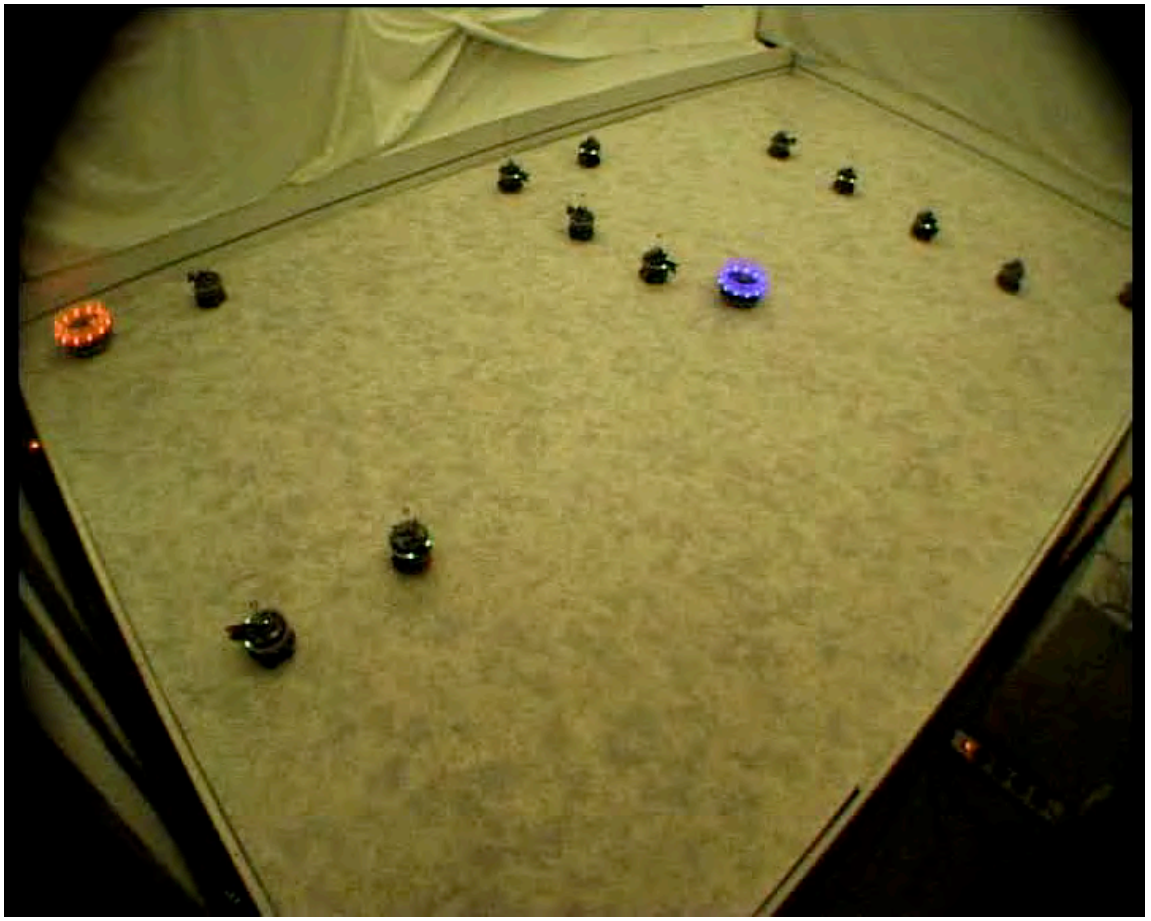
The algorithm



Path formation and retrieval

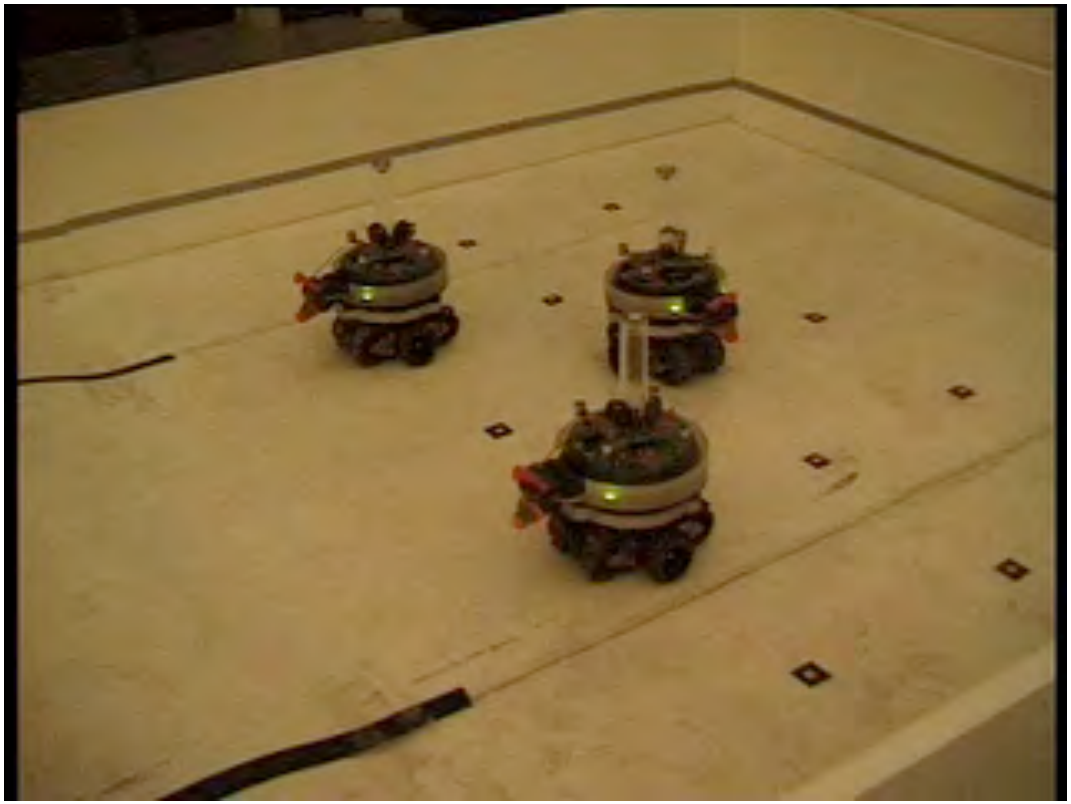


Path formation and retrieval



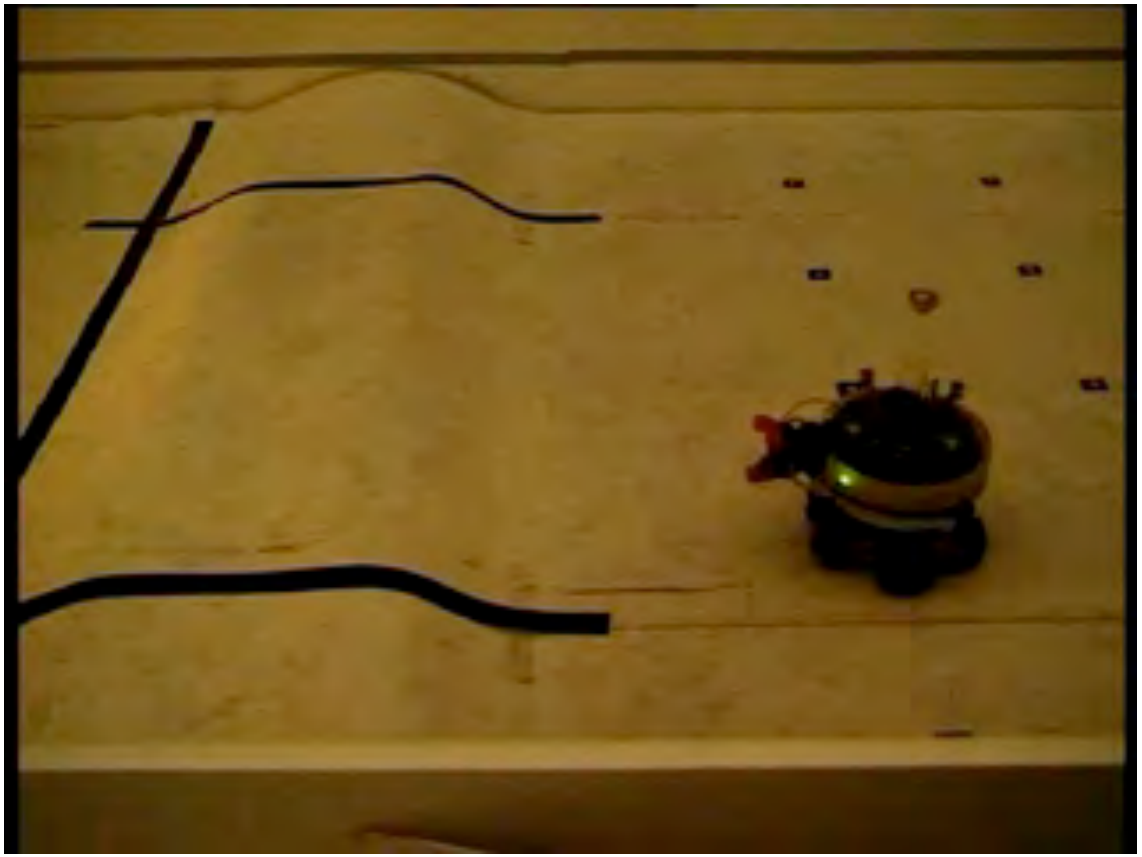
Functional self-assembly

Functional self-assembly



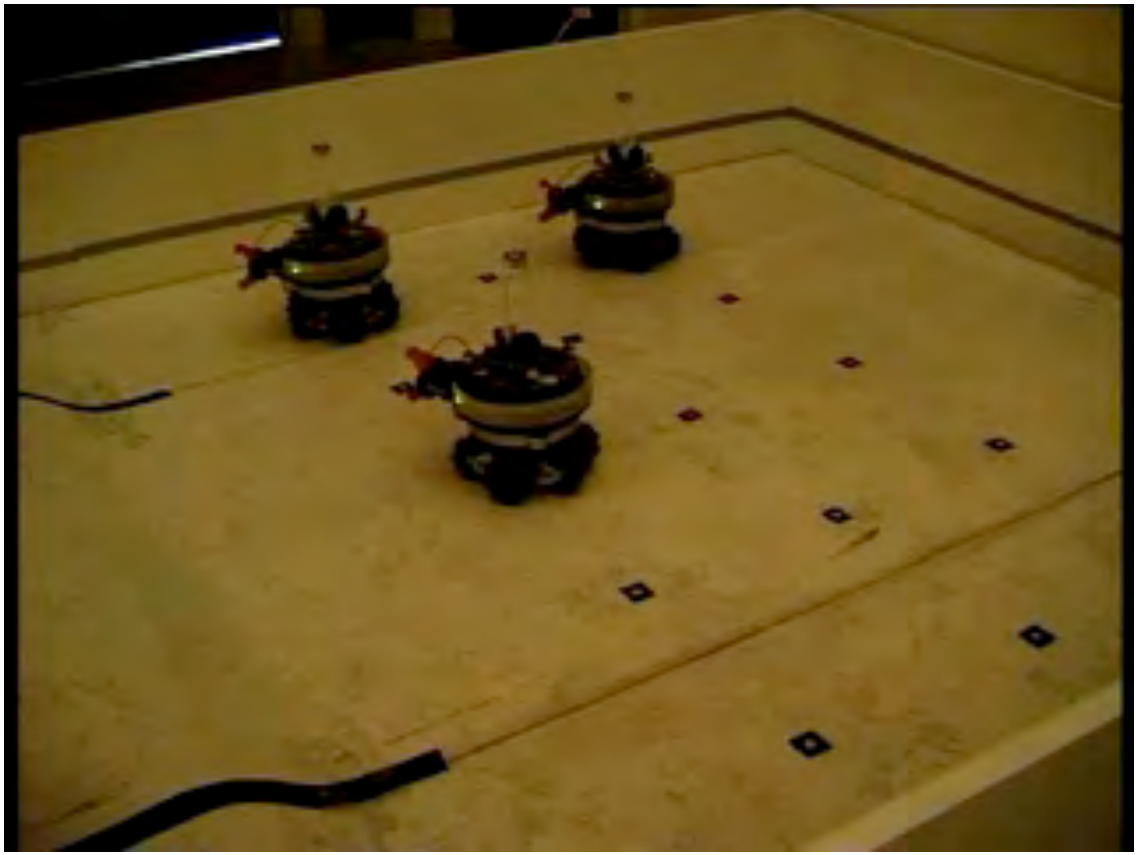
S-bots can pass a low hill

Functional self-assembly



A single *s-bot* cannot pass a high hill

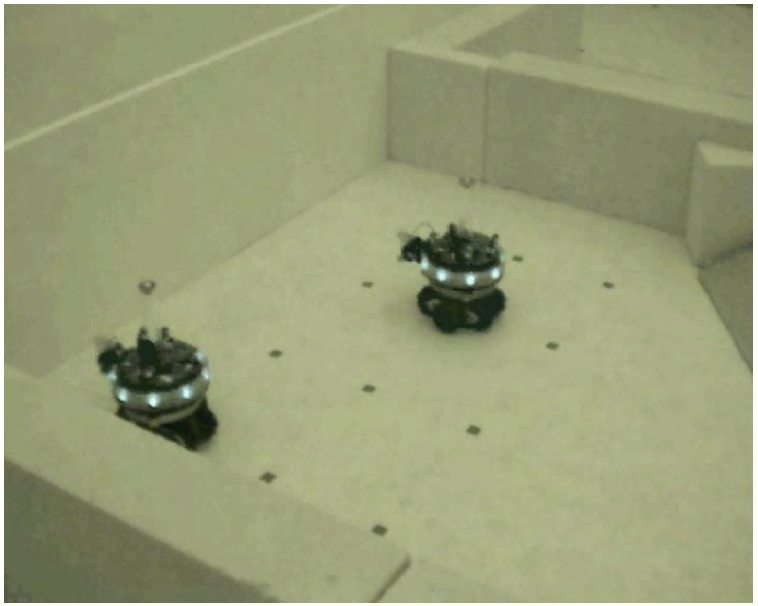
Functional self-assembly

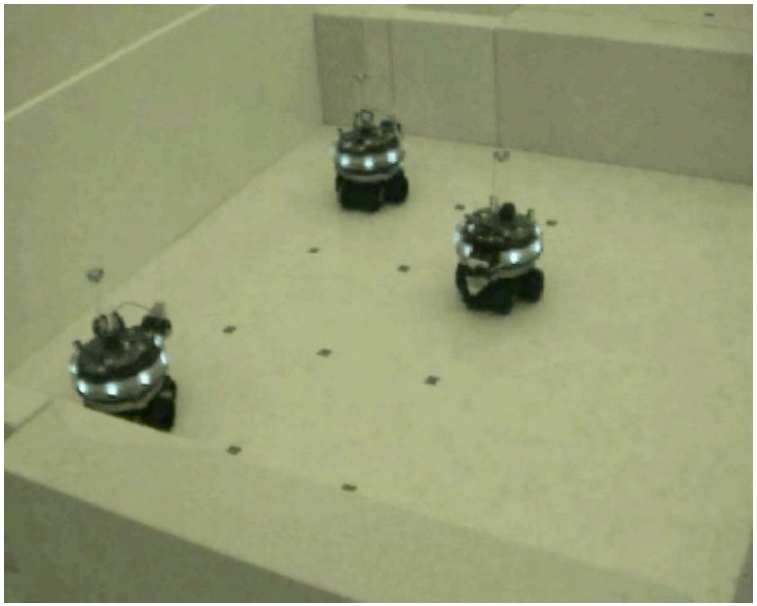


A *swarm-bot* composed of 3 *s-bots* can

Swarm-bots: Ongoing work

Functional self-assembly

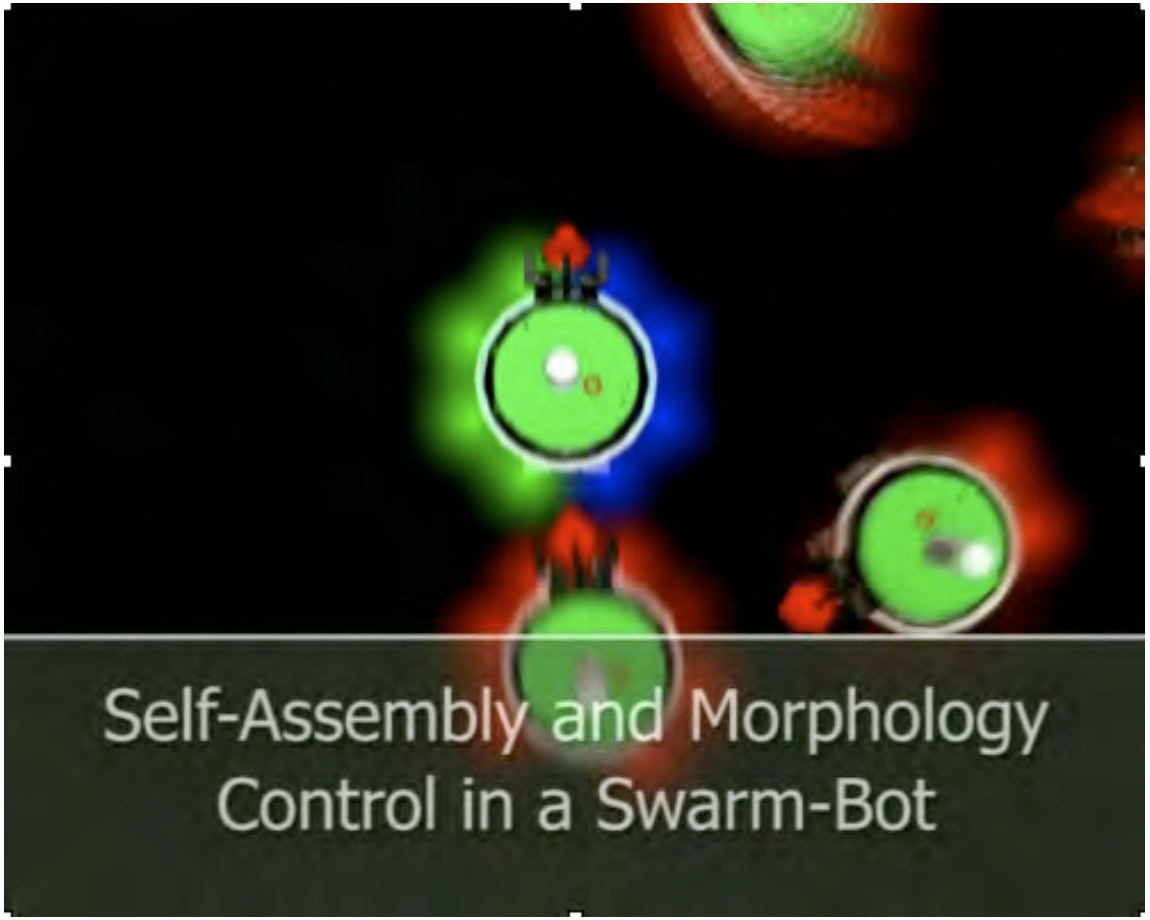


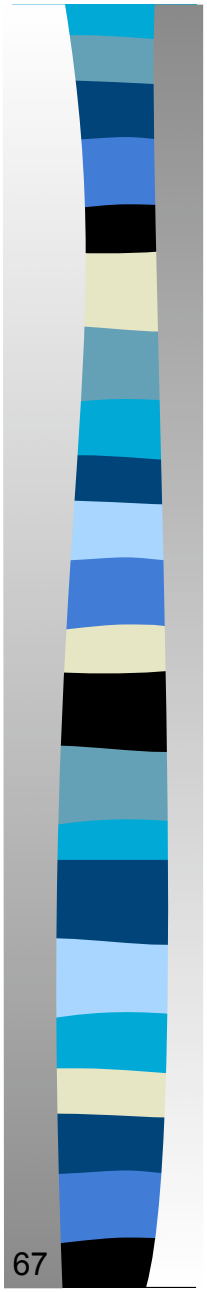


Swarm-bots: Ongoing work

Adaptive rotation

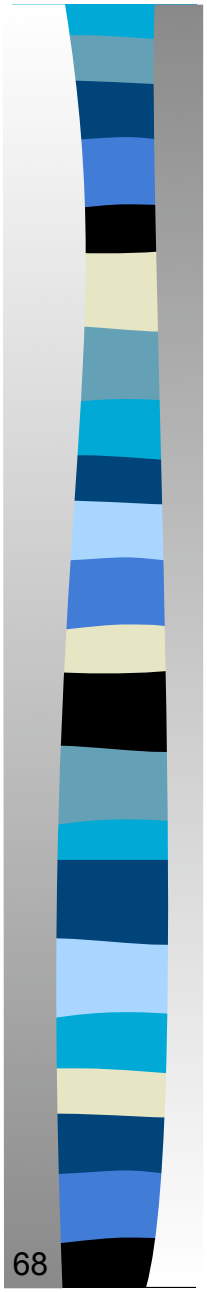
Morphology control





Swarm-bot partners

- More than 20 people for a duration of 42 months
- 2 Millions Euros funding
- Four labs involved:
  - IRIDIA-ULB (Belgium: Dorigo and Deneubourg):
    - Coordinator
    - Main expertise: swarm intelligence
  - EPFL (Switzerland: Floreano & Mondada):
    - Main expertise: hardware and evolutionary robotics (Khepera people)
  - IDSIA (Switzerland: Gambardella):
    - Main expertise: simulation
  - CNR (Italy: Nolfi):
    - Main expertise: evolutionary robotics
- One subcontractor:
  - METU, Ankara (Turkey: Sahin)
    - Collaborated to the development of a parallel environment for simulations



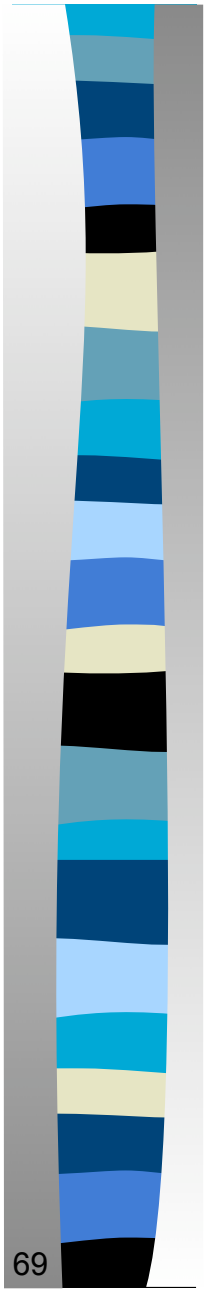
New work

Swarmanoid

Swarmanoid is a new project:

- Started on October 1st, 2006
- Funded with 2.5 Millions EUR

  (European Union – Future and Emerging Technologies program)
- Same partners as Swarm-bots



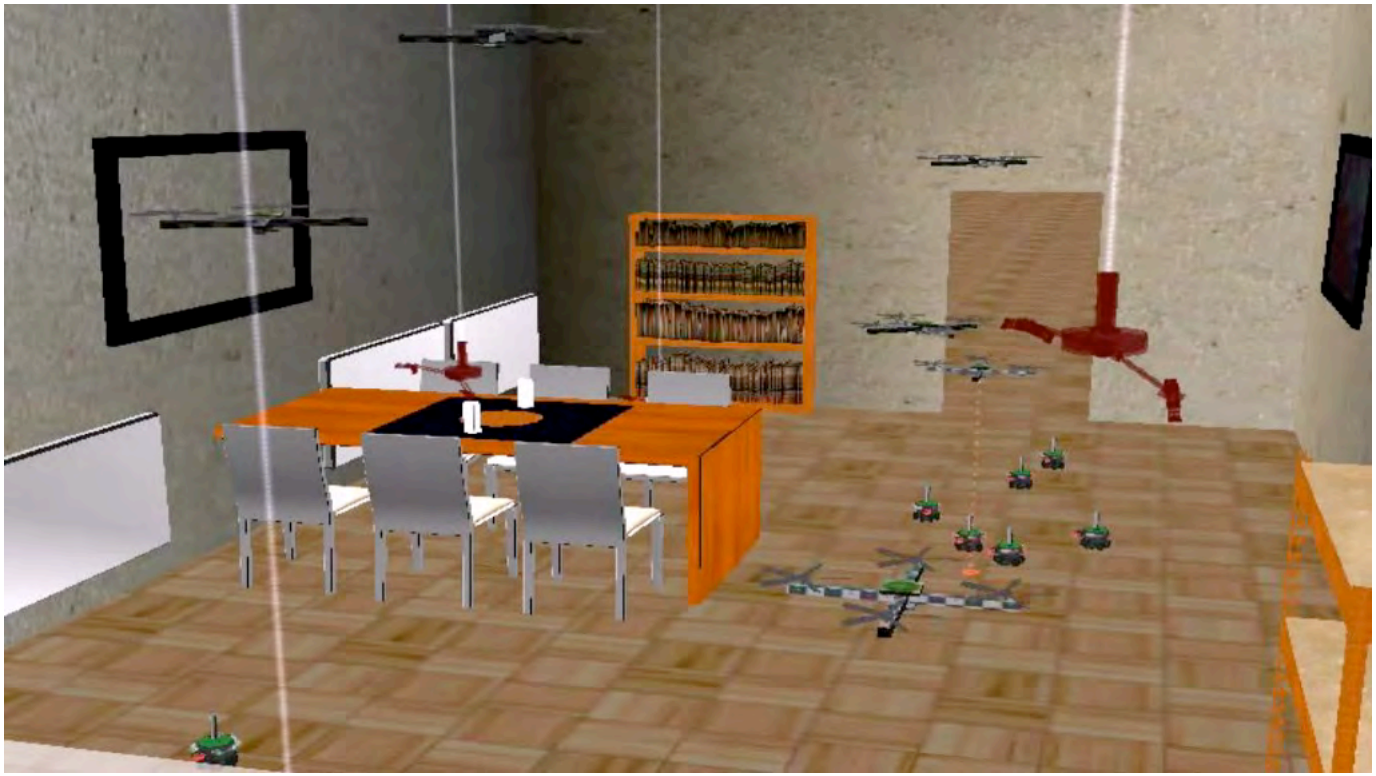
New work

Swarmanoid

- A swarmanoid is composed of:
  - Eye-bots
  - Hand-bots
  - Foot-bots
- Goal: build heterogeneous swarms that act in 3D space

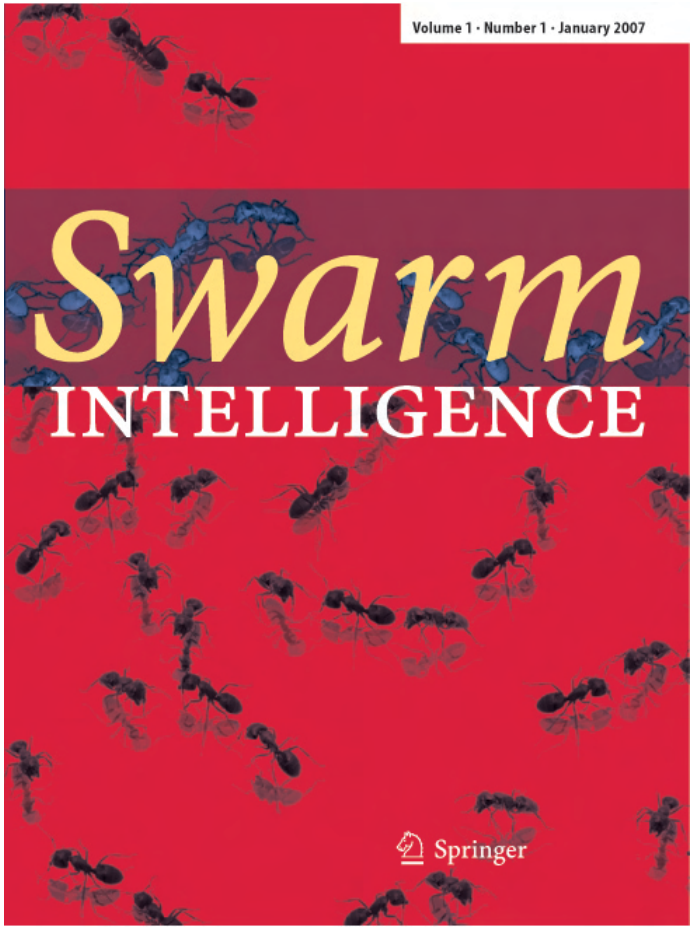
New work

Swarmanoid



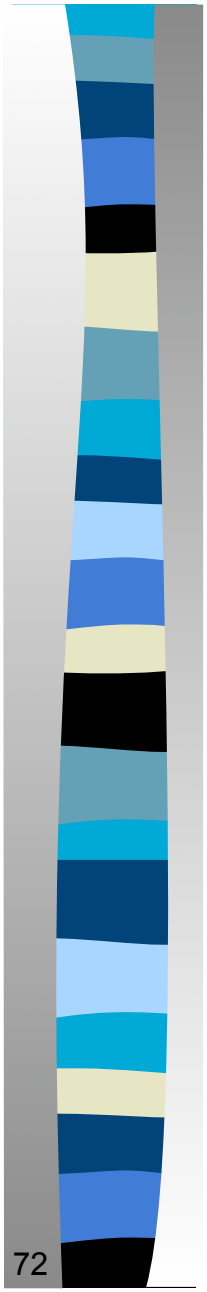
Swarm intelligence

A new journal



- Swarm Intelligence publishes four issues per year
- Editor-in-Chief: Marco Dorigo
- Publisher: Springer

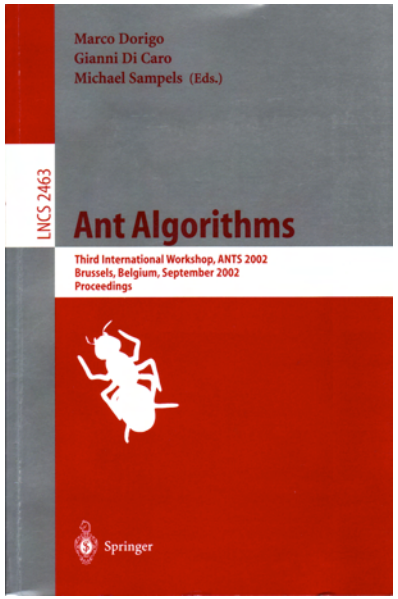
ULB

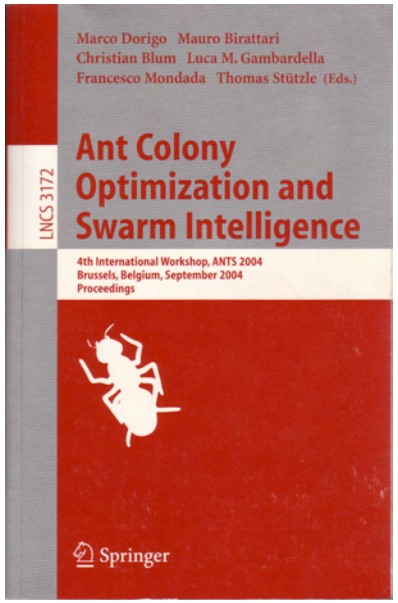


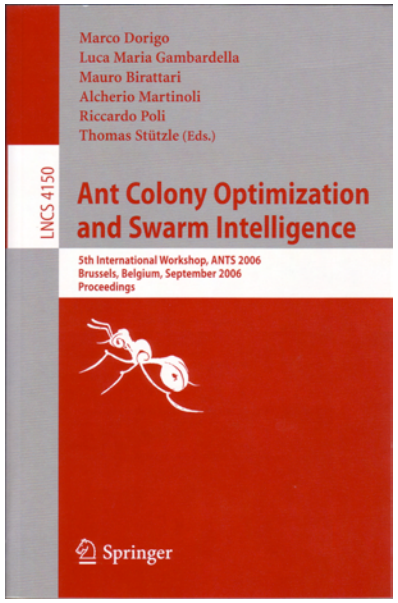
ANTS Conferences

ANTS 2008, 6th International Conference on
Ant Colony Optimization and Swarm Intelligence

September 22–24, 2008, Brussels







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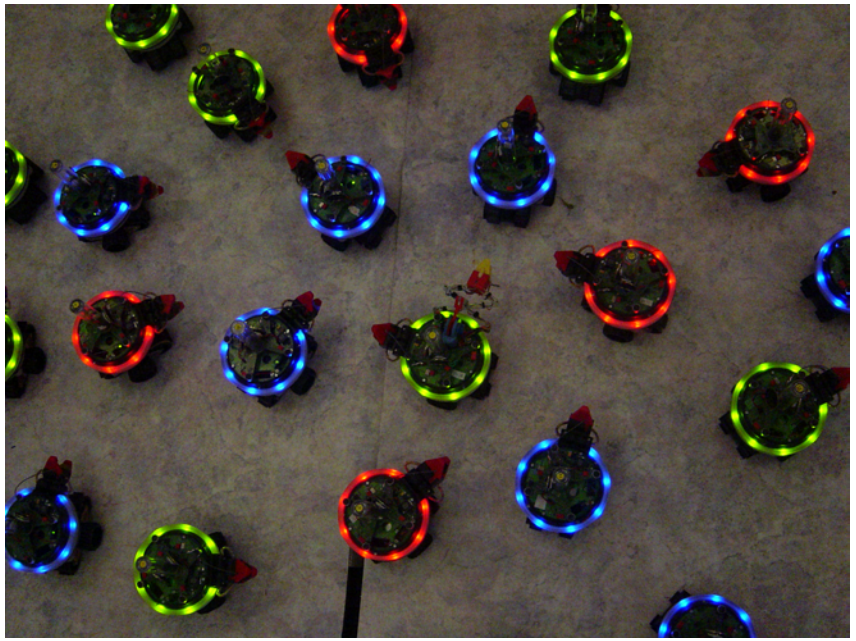
The end



www.swarm-bots.org