Swarm Intelligence and Swarm Robotics: The Swarm-bot experiment

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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

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biologists

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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**

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Technological motivations

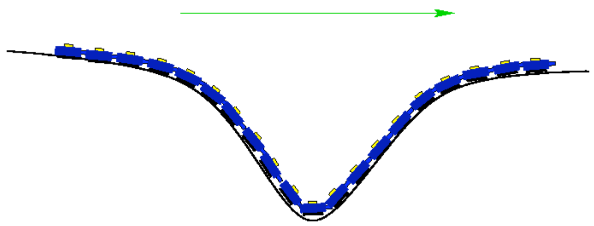
- Parallelism:
  Different robots can perform different task at the same time
- Fault tolerance:
  When a robot breaks down another one can take over. No single point-of-failure
- Cost:
  Simple robots are cheaper to build than complex robots
- Scalability:
  Add more robots, get more work done

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

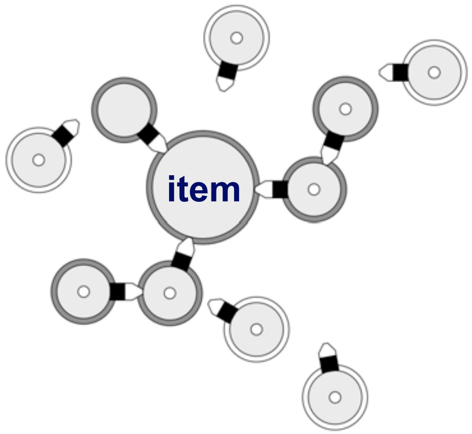
What should a swarm-bot be able to do?

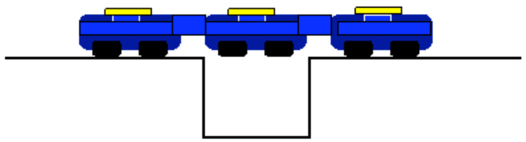


Demonstrate both logical and physical cooperation

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

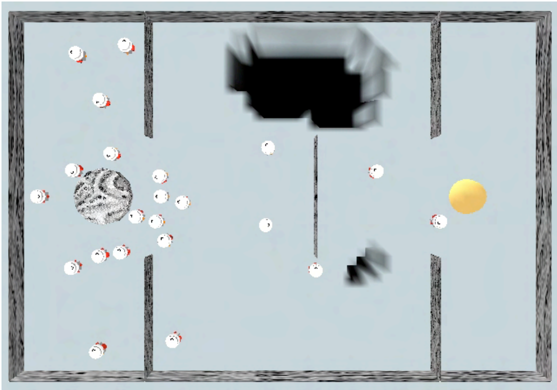




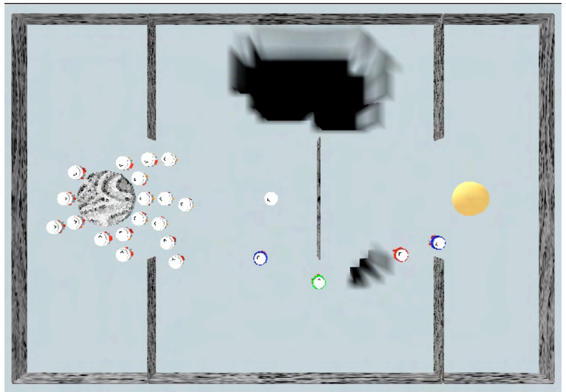
Swarm-bots

Our scenario

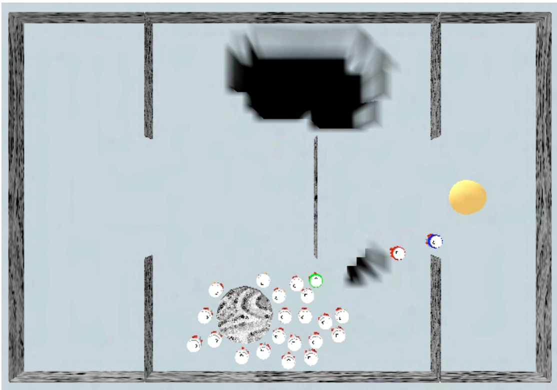
Find object and aggregate around it

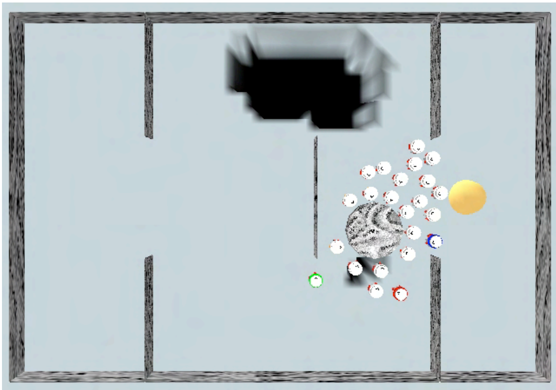


Pull object and search for goal



Change shape and move in a coordinate way avoiding obstacles





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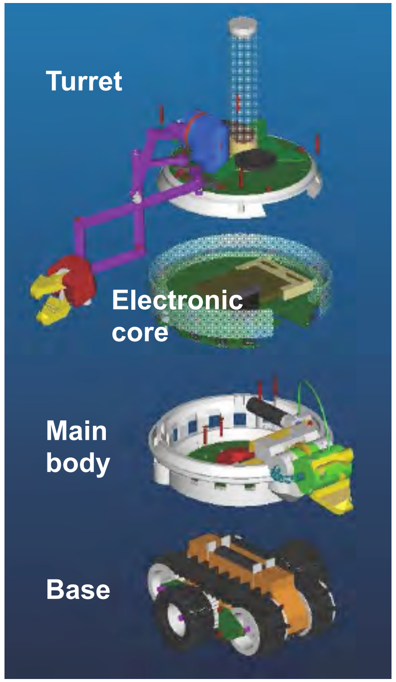
What comes next

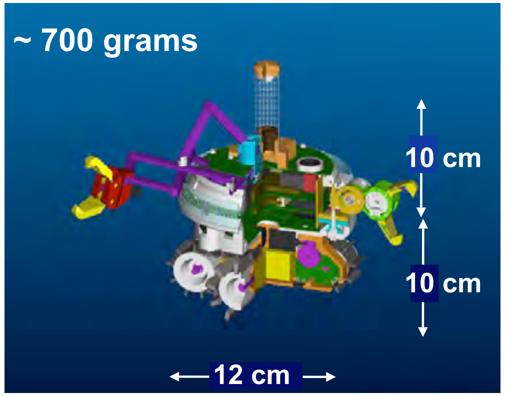
- Brief description of the hardware
- Brief description of the methodology used to develop the controllers
- Results with the real robots
- Ongoing work

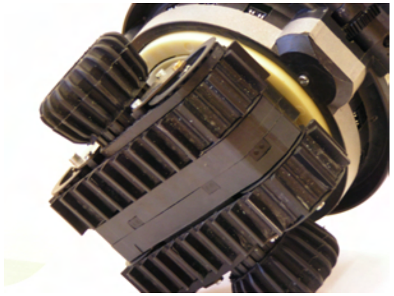
Swarm-bots

Hardware: the s-bot mechanics

Approximately 100 parts

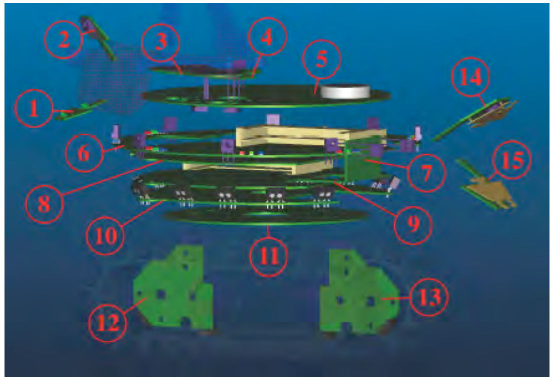


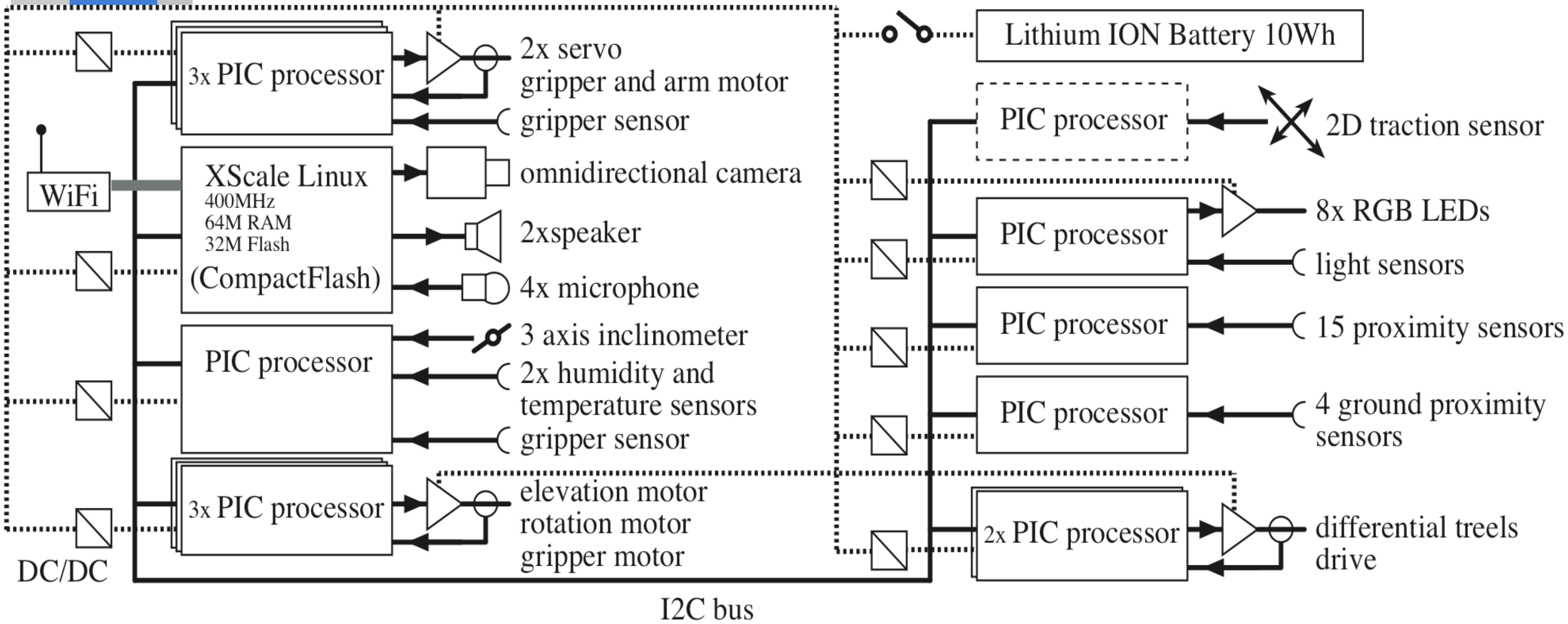




Swarm-bots

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

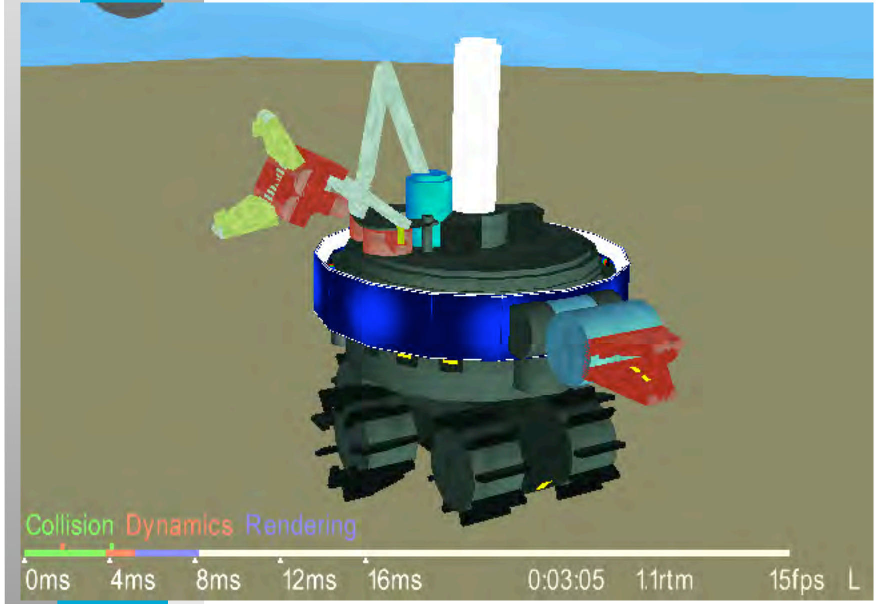
  or

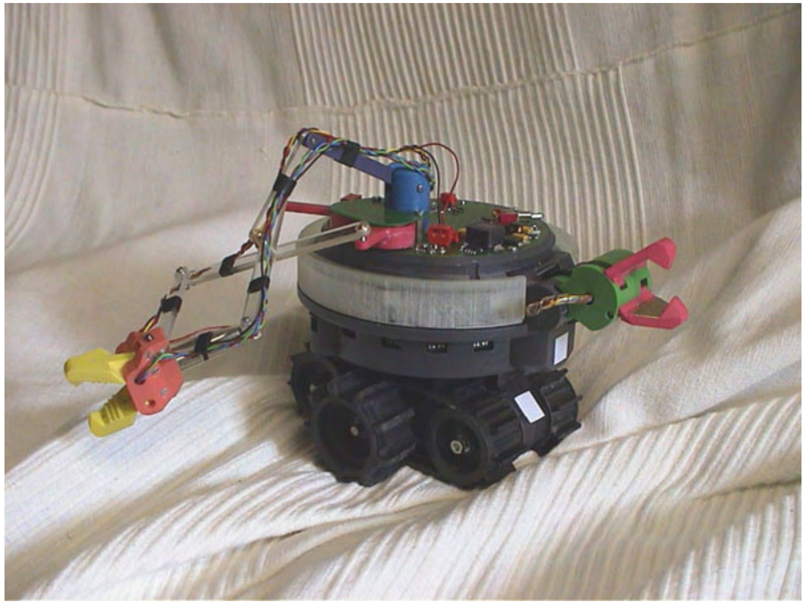
  artificial evolution of neural networks

  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

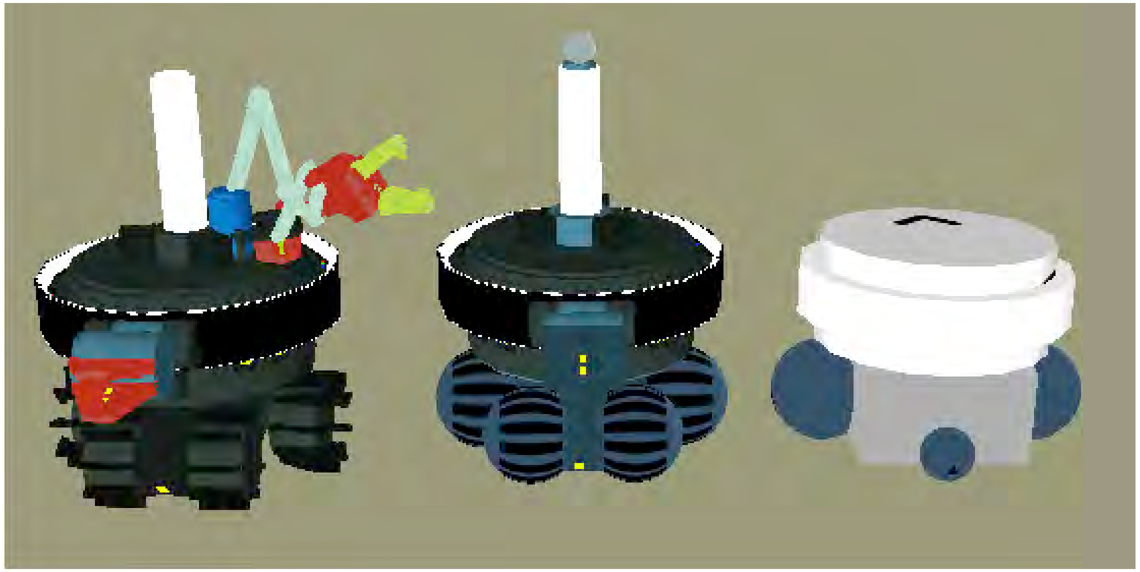
Simulation model





Swarm-bots

Different levels of detail



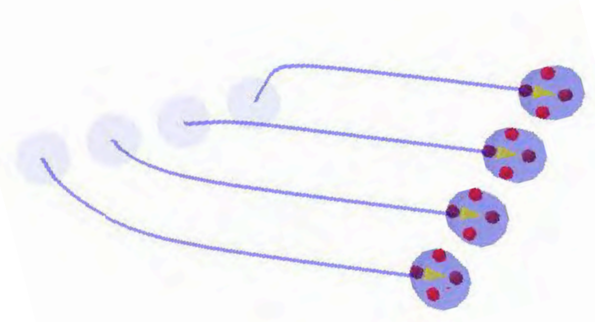
detailed medium simple

Definition of behaviors for the scenario

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

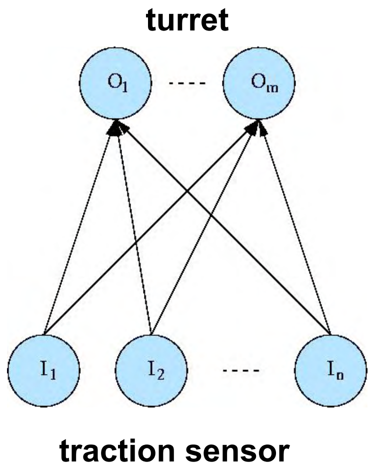
Coordinated motion

- 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



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:

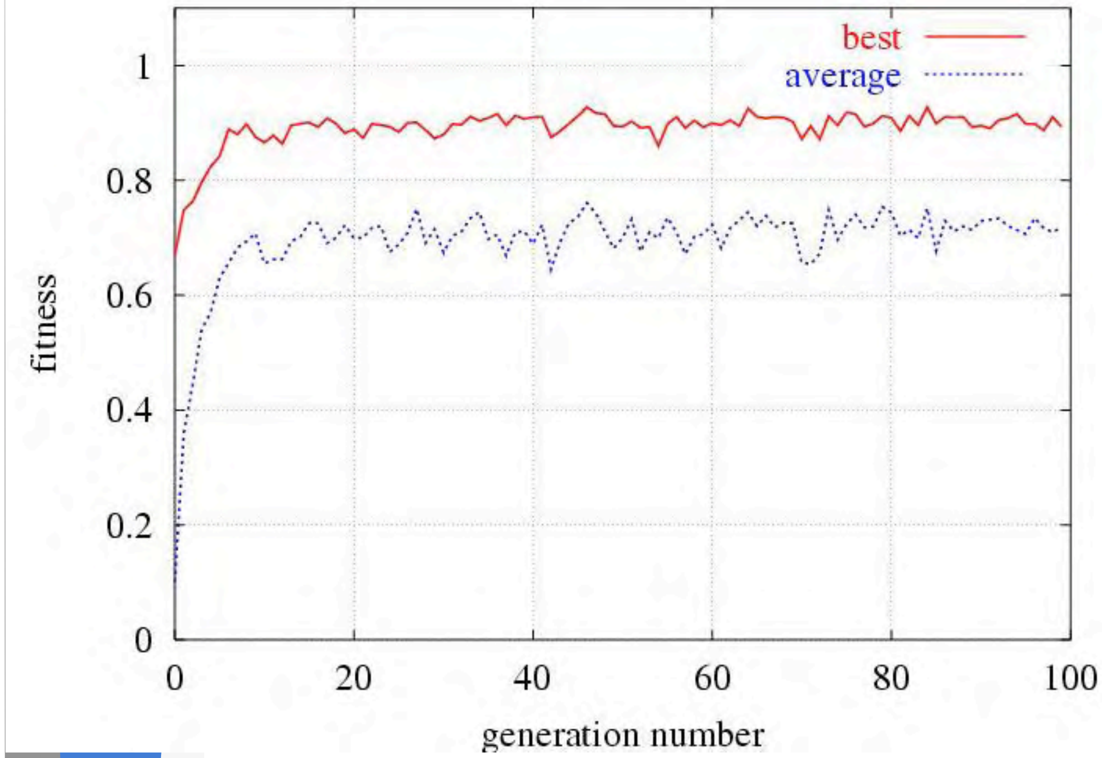
$$F = \frac{\| X(t) - X(0) \|}{D}$$

  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

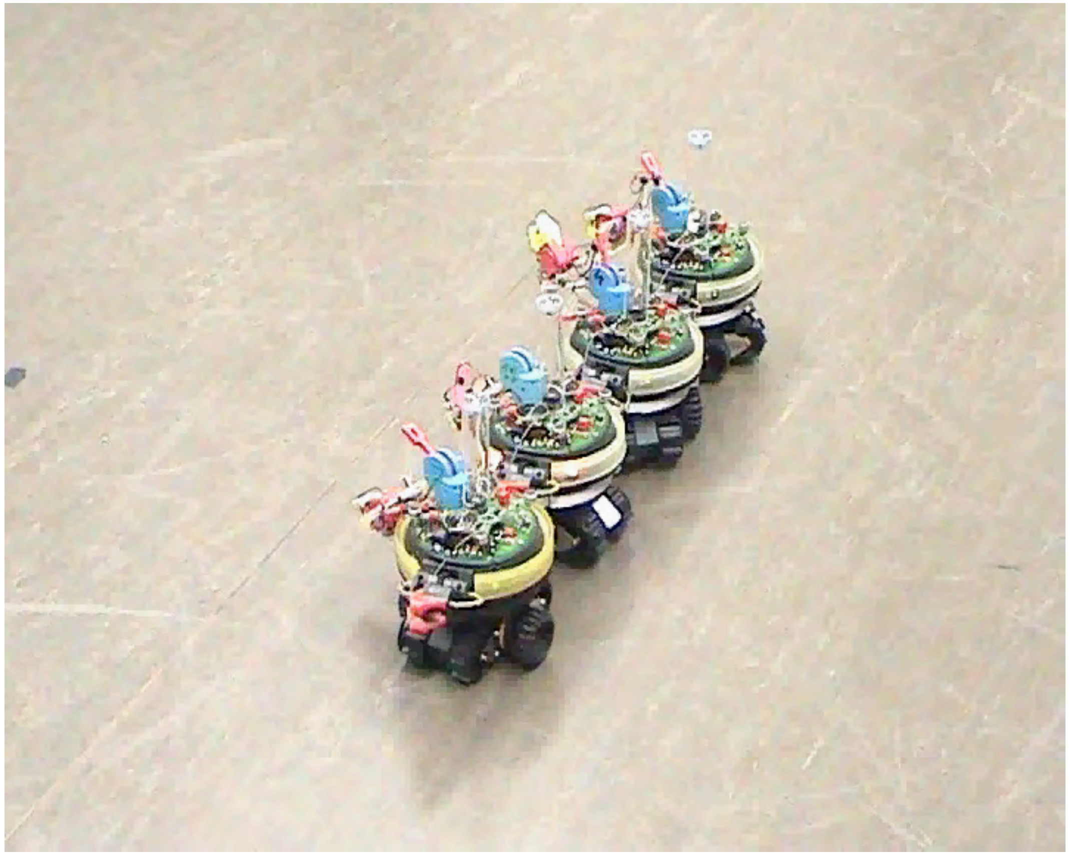
Average fitness



Post-evaluation

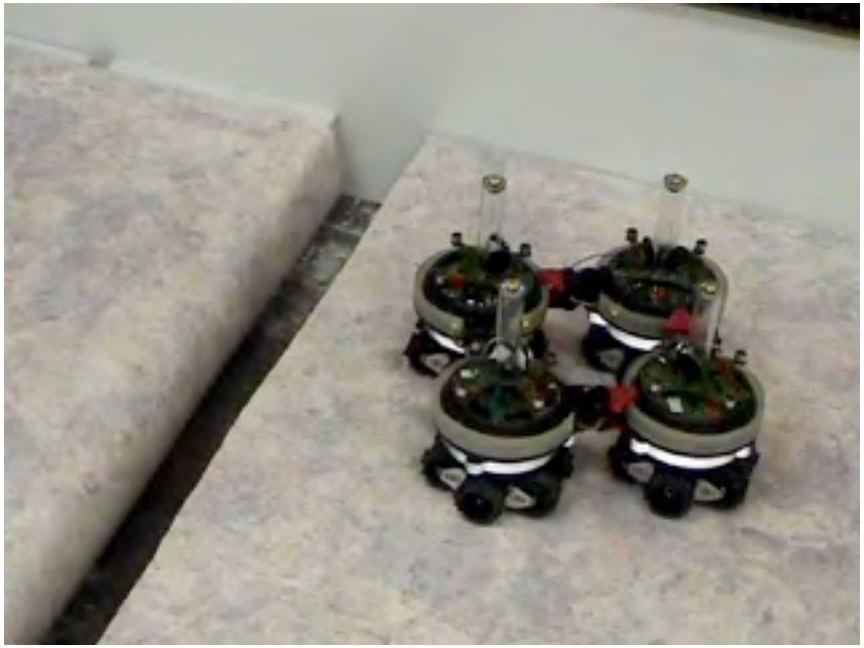
Replication	Performance
1	0.87888
2	0.83959
3	0.88338
4	0.71567
5	0.79573
6	0.75209
7	0.83425
8	0.85848
9	0.87222
10	0.76111

Porting to real s-bots



Swarm-bots: Coordinated motion

Real s-bots



flexibility

Swarm-bots: Coordinated motion

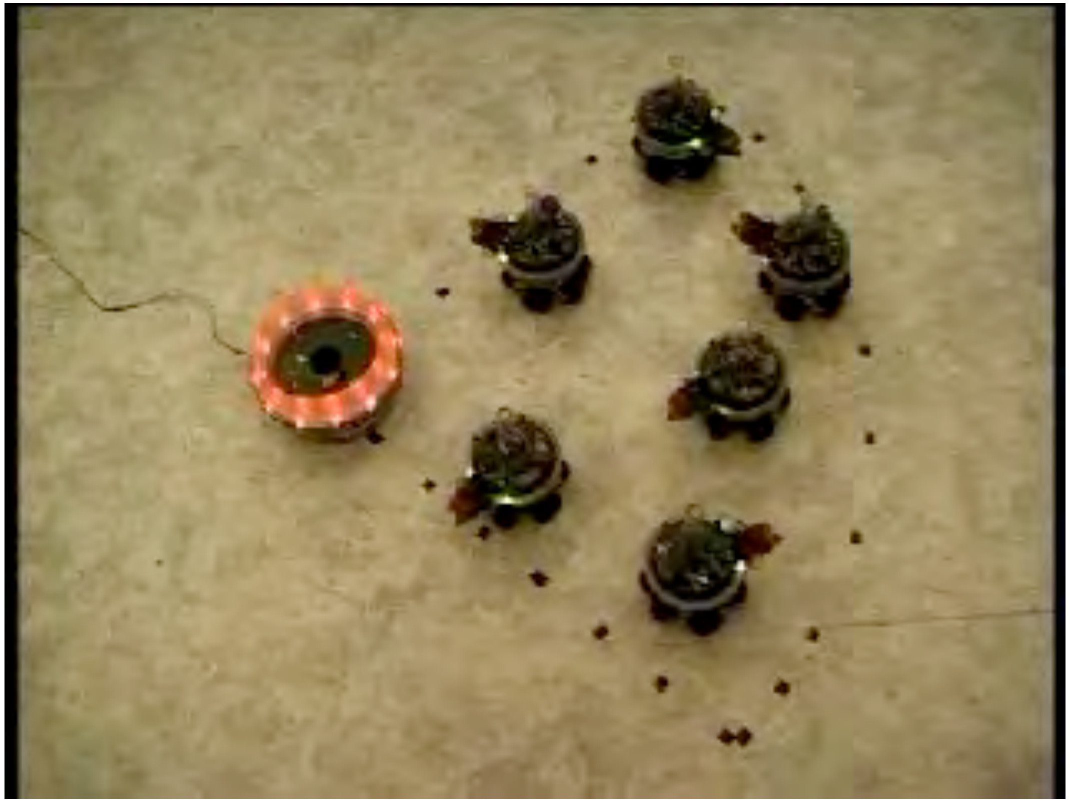
Scalability

scalability

flexibility and scalability

Swarm-bots: Self-assembly

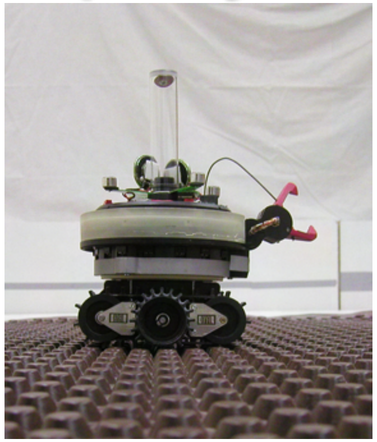
Six s-bots and a prey

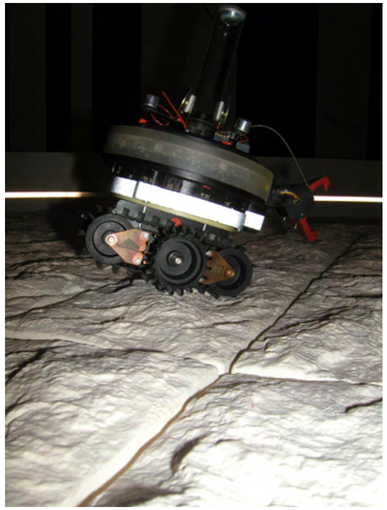


Swarm-bots: Self-assembly

Six s-bots and a prey

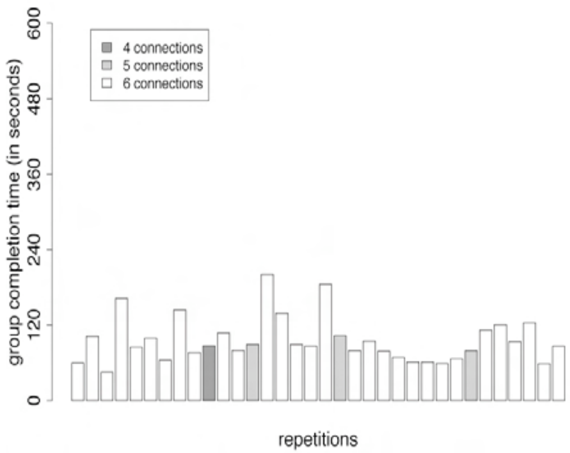
brown rough terrain



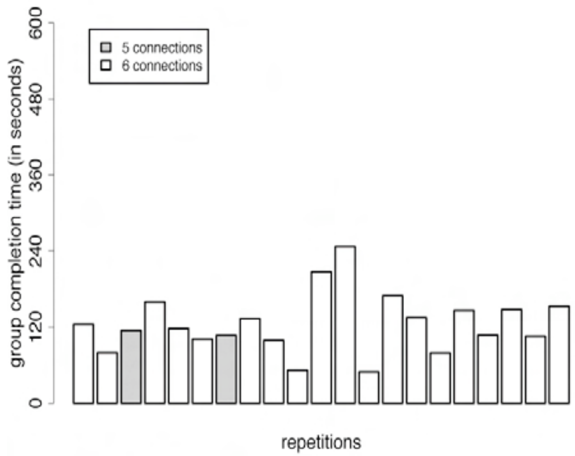


white rough terrain

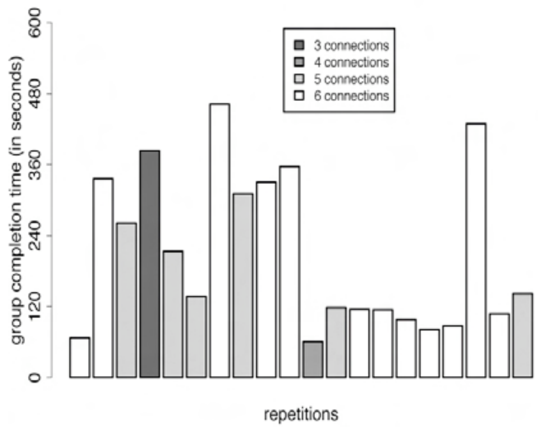
33 repetitions
flat terrain



20 repetitions
brown rough terrain



20 repetitions
white rough terrain



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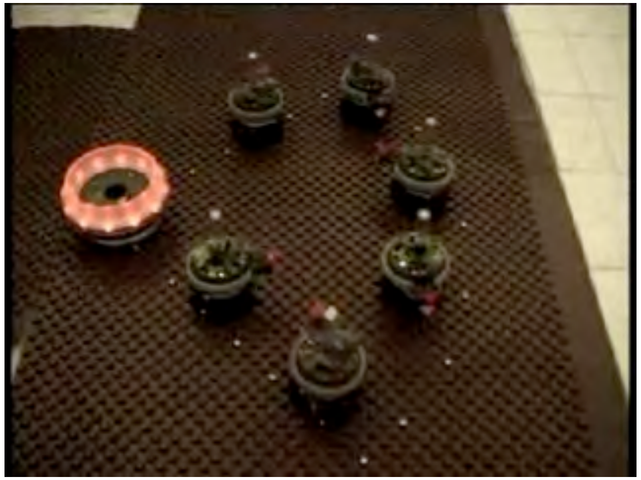
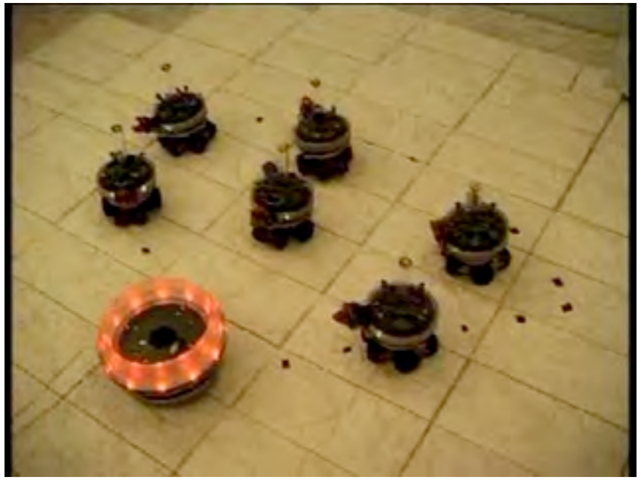


flexibility



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

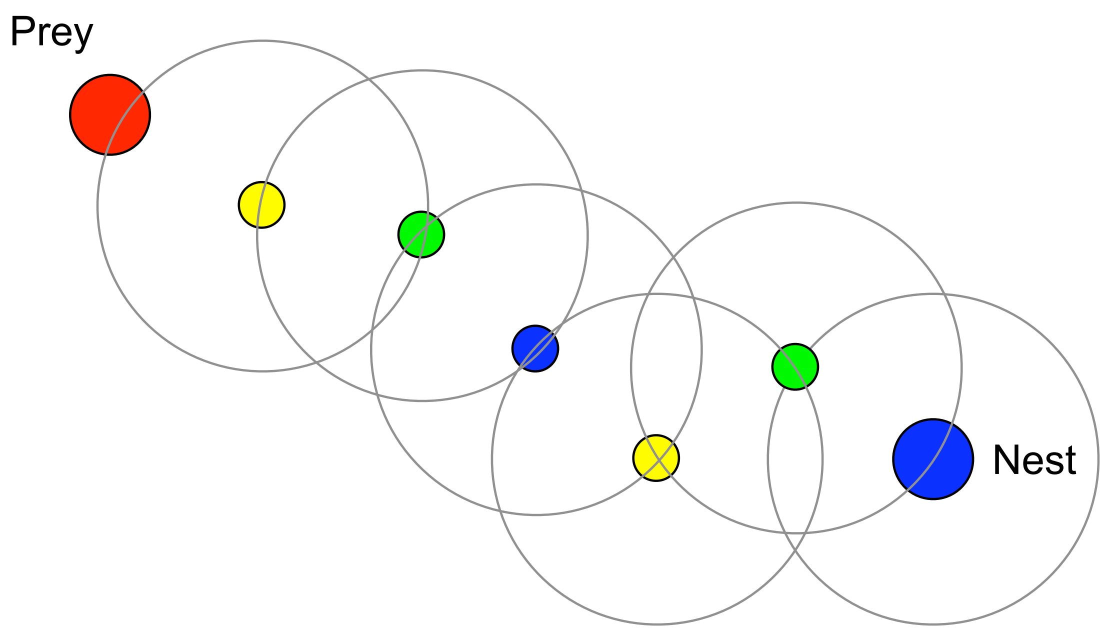
- Swarm-bots composed of 2 to 6 s-bots
- Different types of terrains
- Different weights of the transported object
- Failure during transport
  - One s-bot is blind. Comparisons with:
    - Blind s-bot controlled by learned neural net
    - Blind s-bot replaced by non-blind s-bot
    - Blind s-bot removed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

Self-assembly and transport

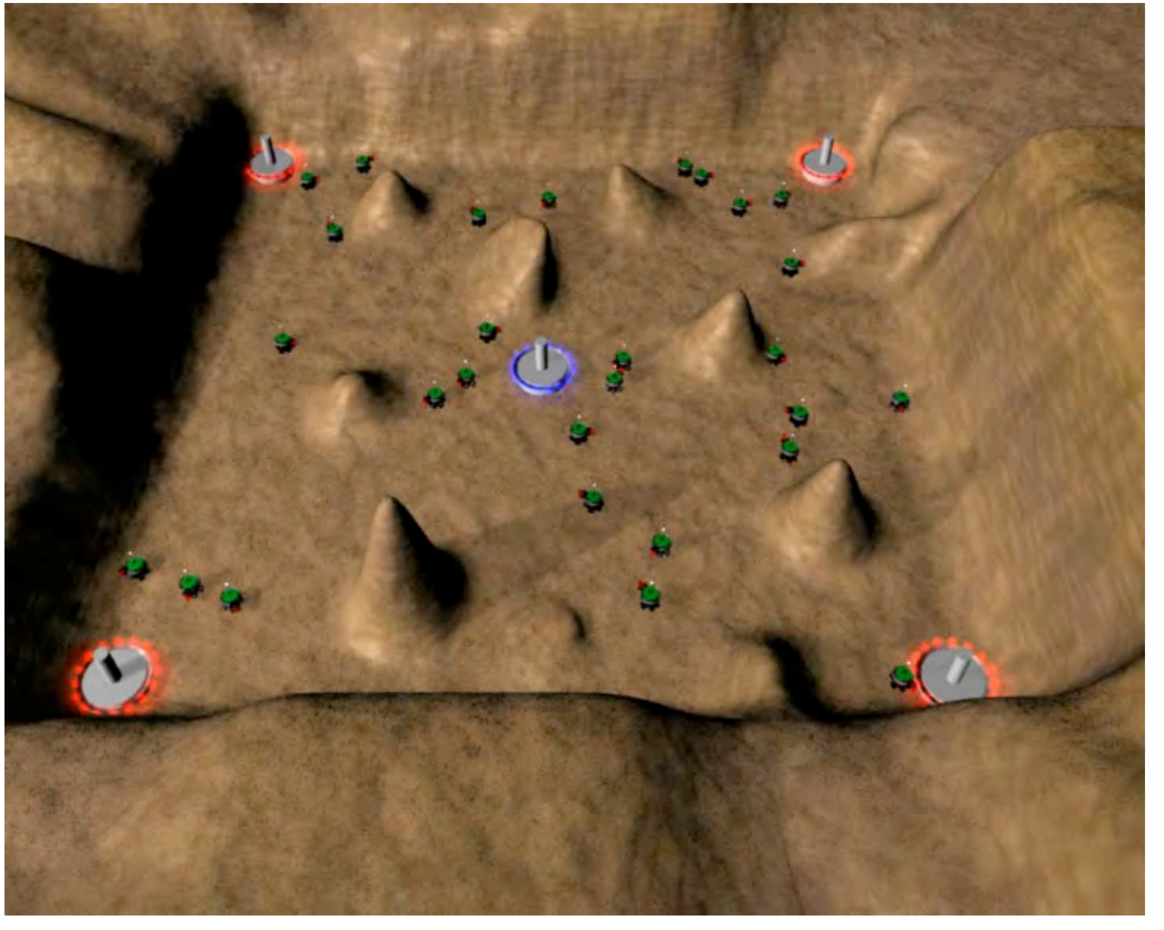
Path formation

- 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

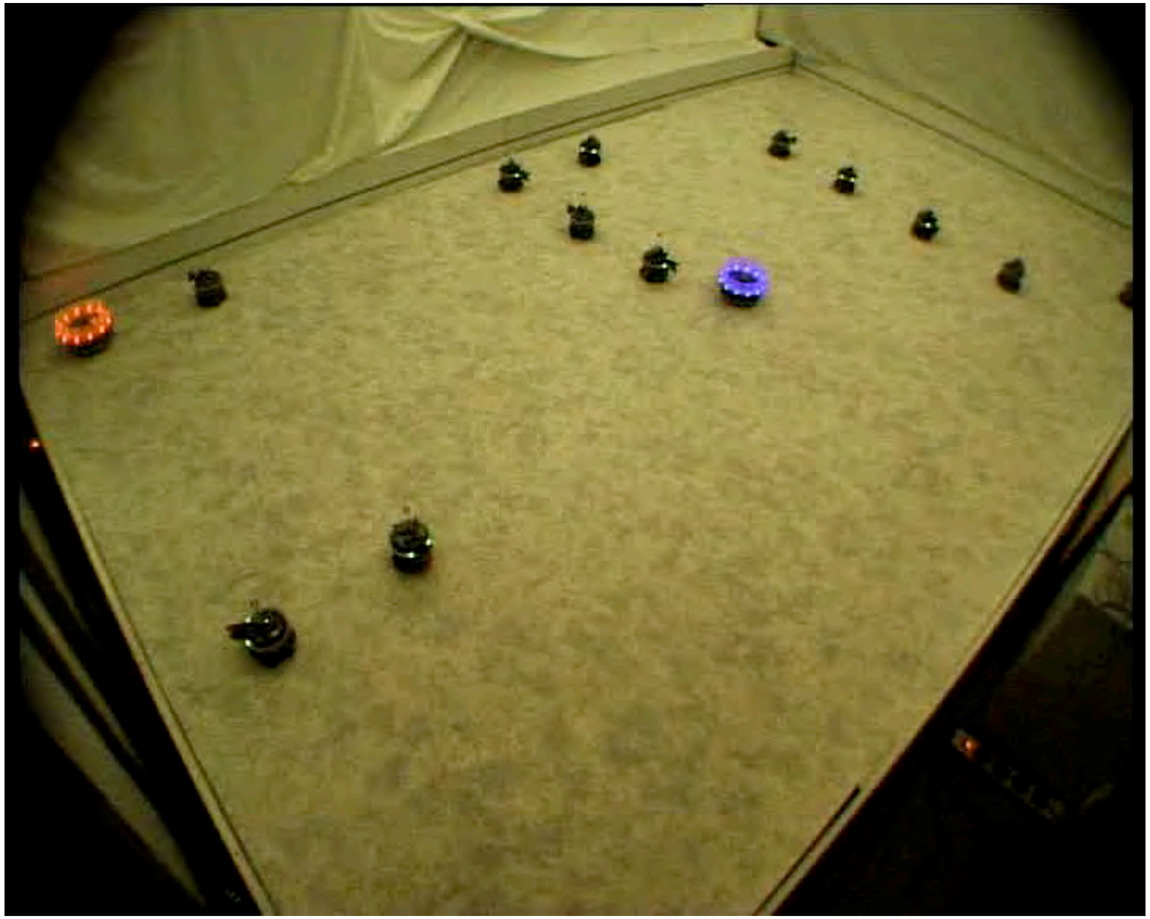
The algorithm



Path formation and retrieval



Path formation and retrieval



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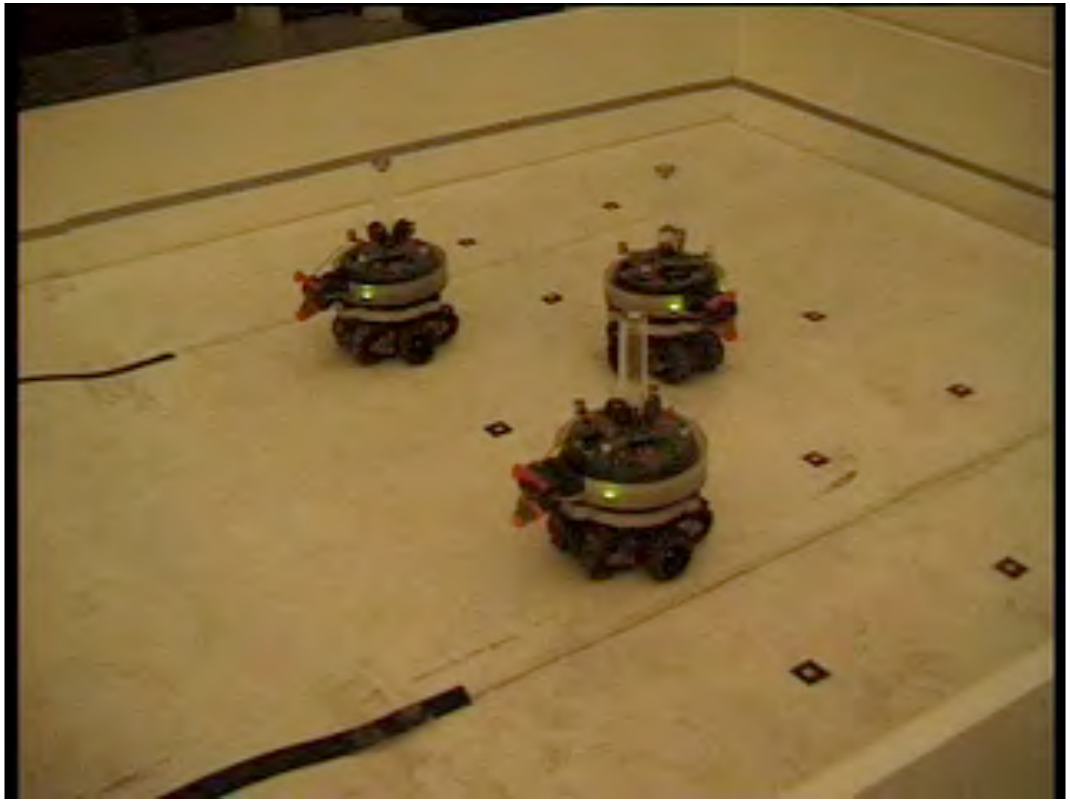
Swarm-bots: Ongoing work

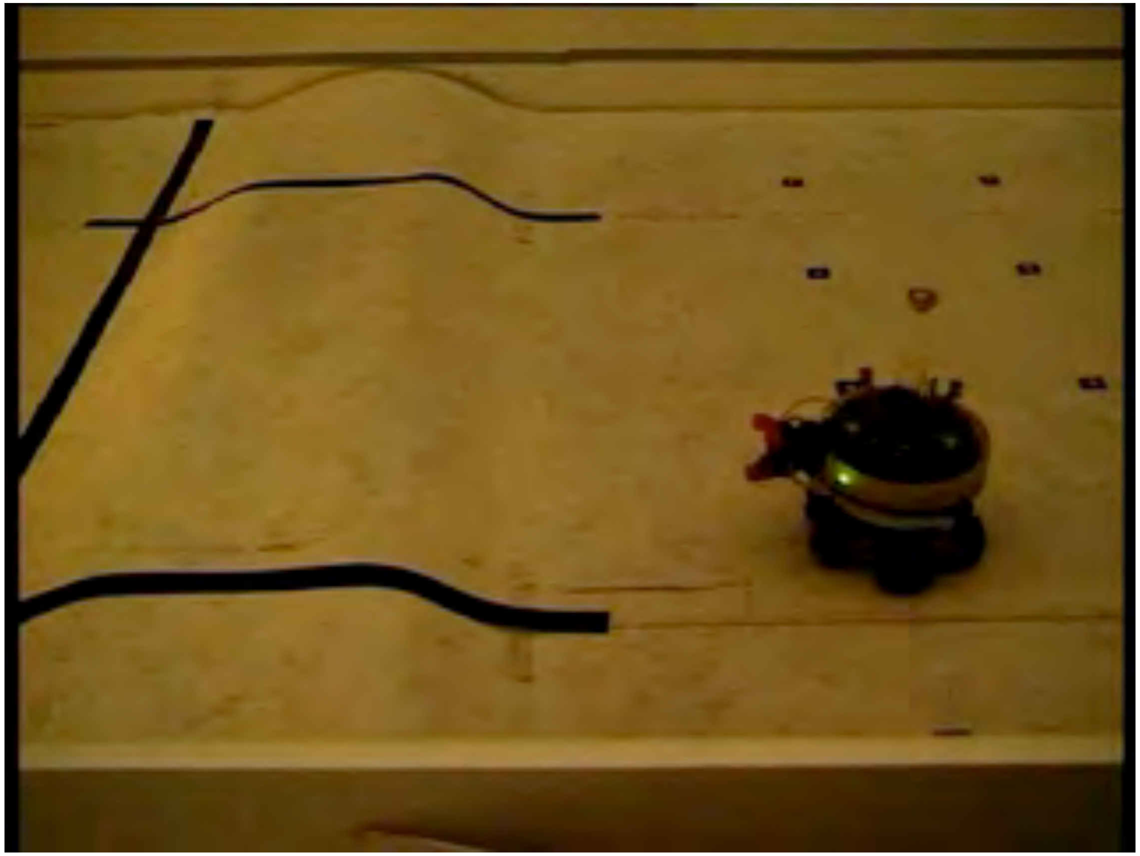
Functional self-assembly

Functional self-assembly



S-bots can pass a low hill

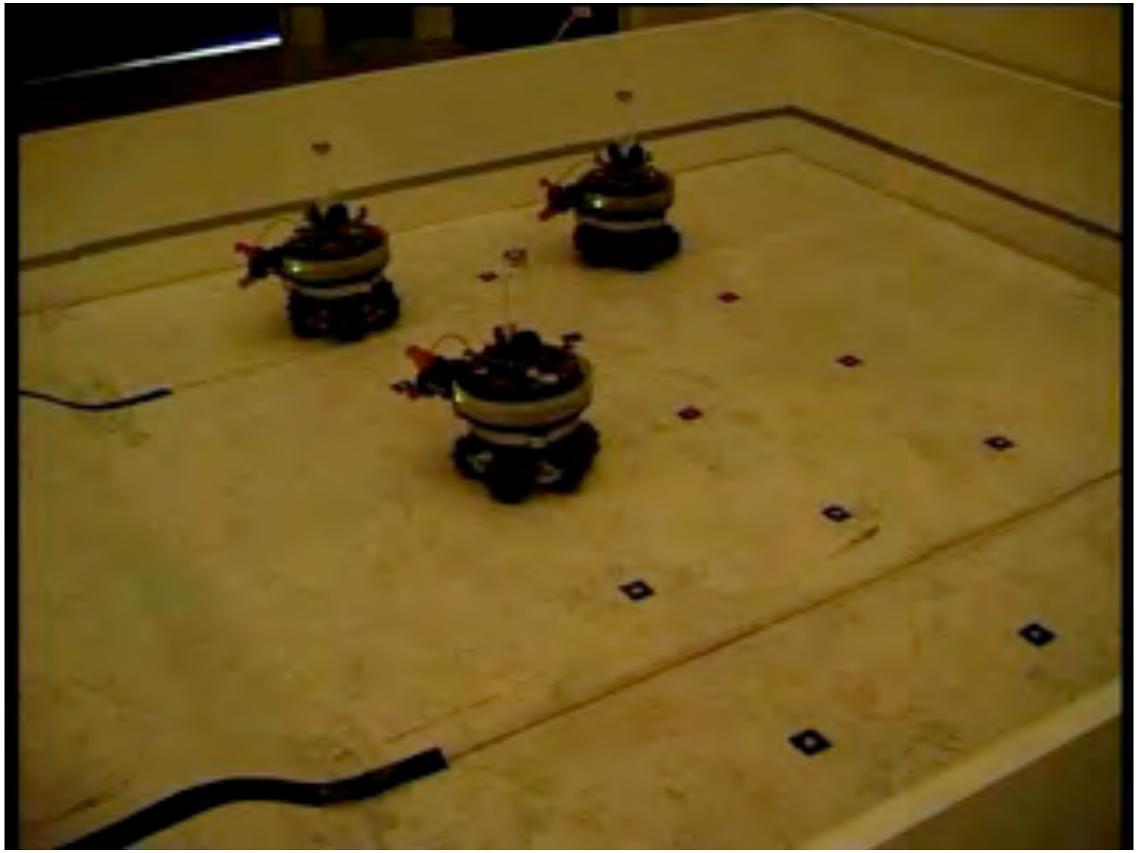
Functional self-assembly



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

Swarm-bots: Ongoing work

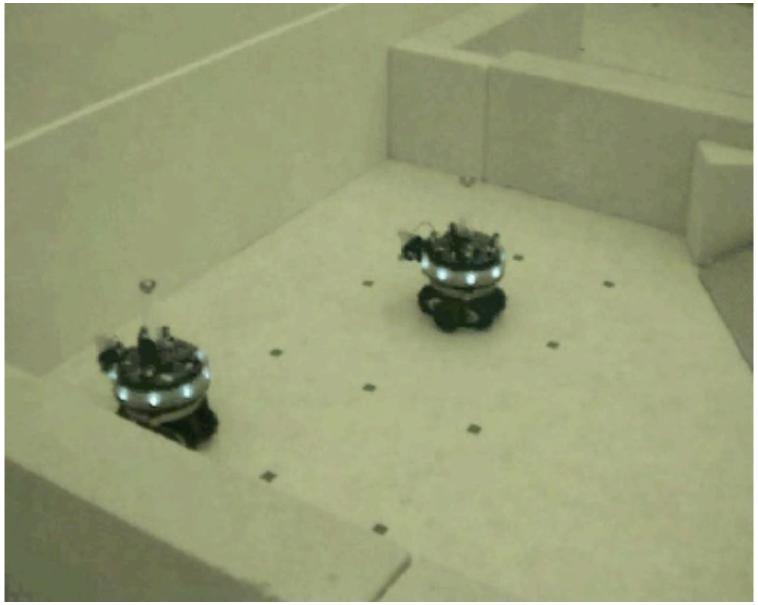
Functional self-assembly

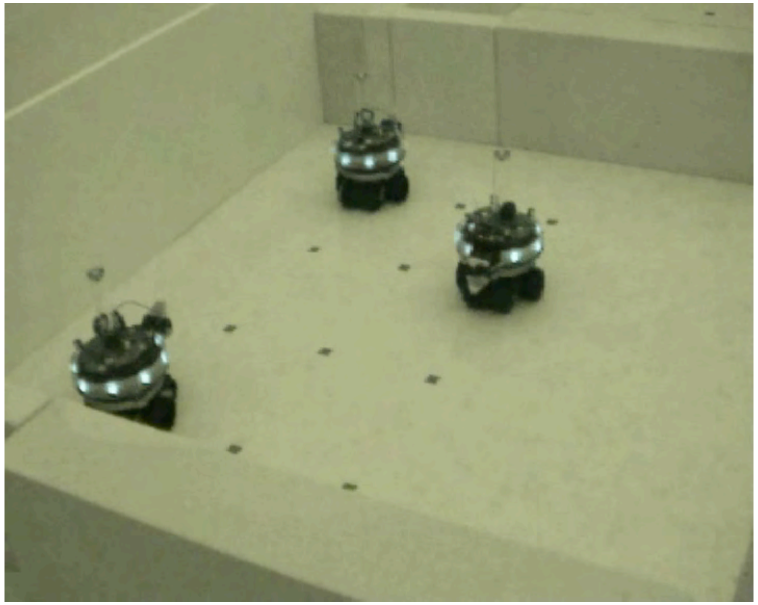


A *swarm-bot* composed of 3 *s-bots* can

Swarm-bots: Ongoing work

Functional self-assembly

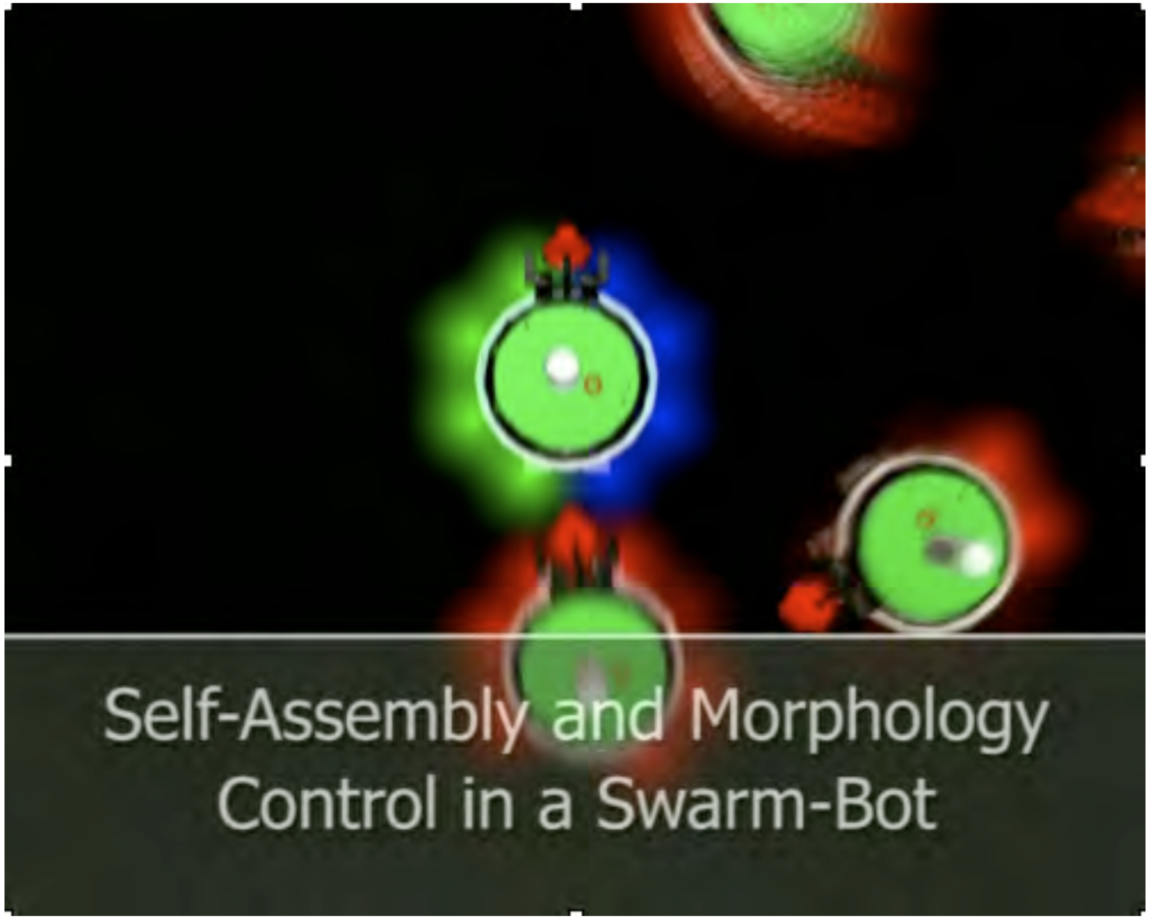




Adaptive rotation

Swarm-bots: Ongoing work

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

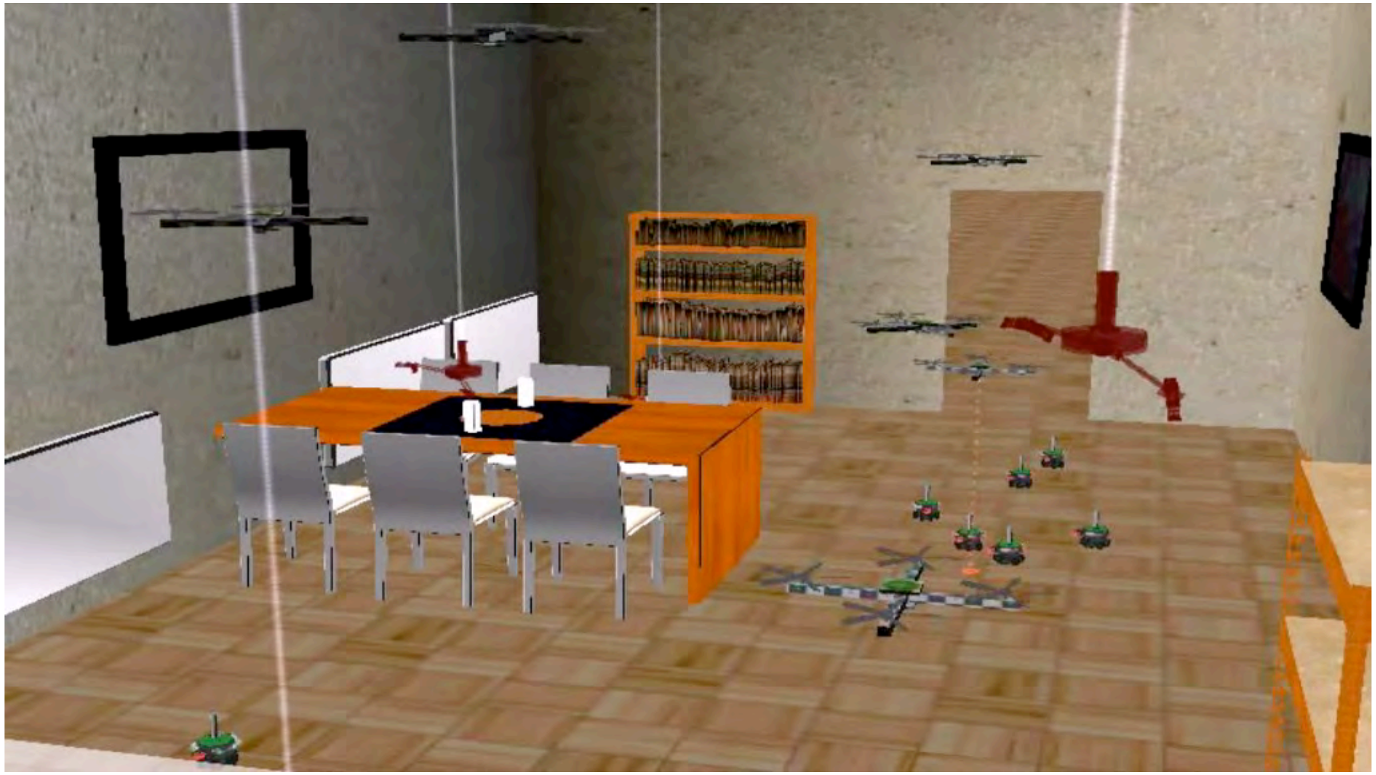
New work

Swarmanoid

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

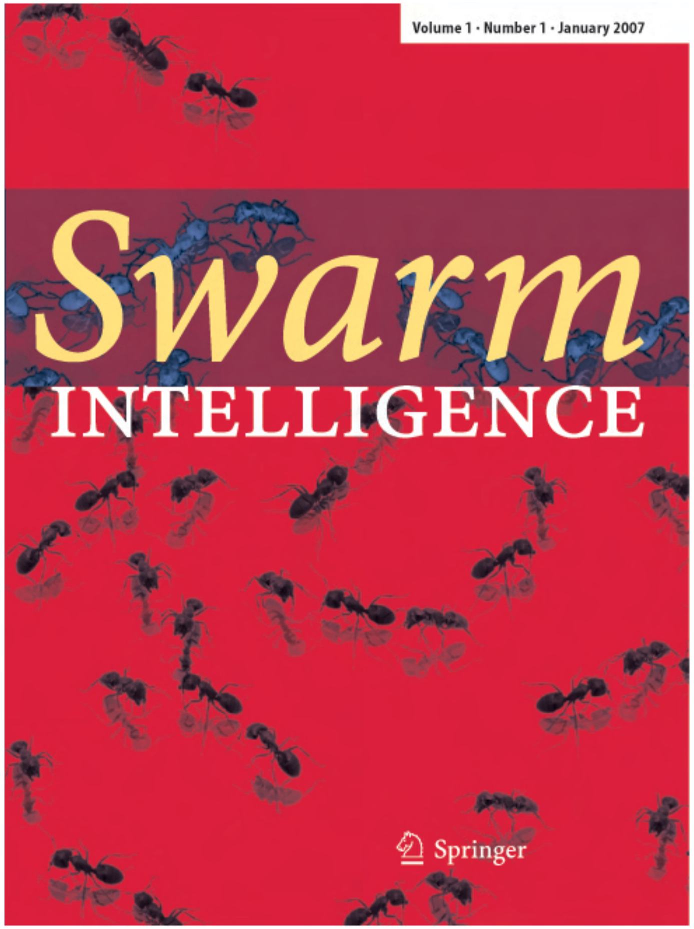
New work

Swarmanoid



Swarm intelligence

A new journal



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

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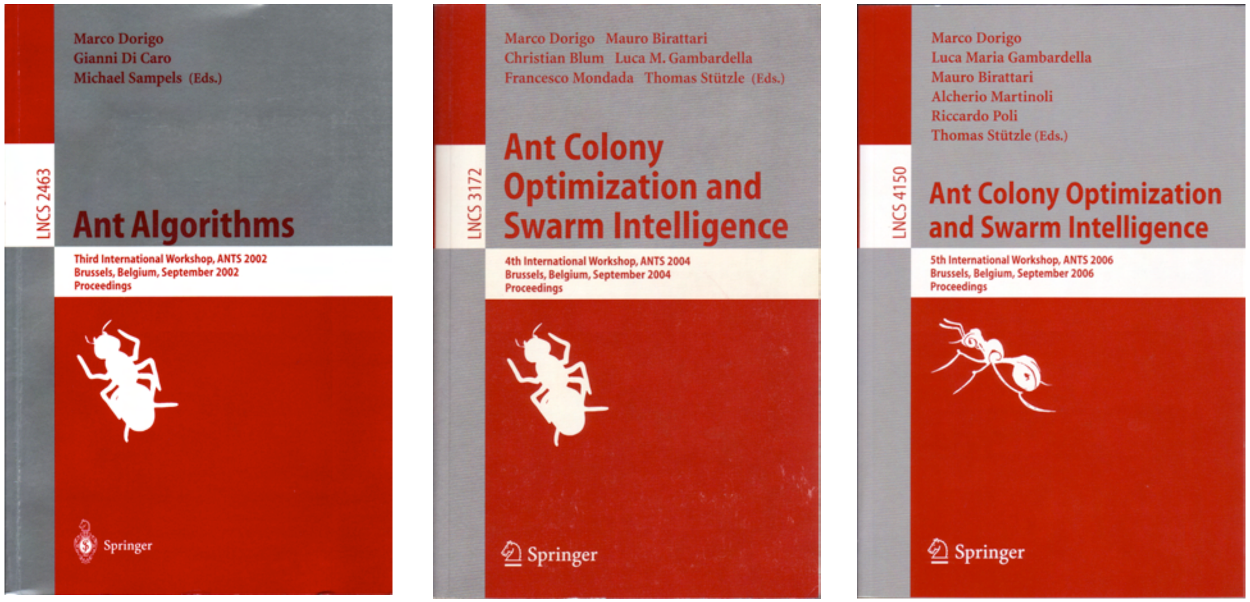
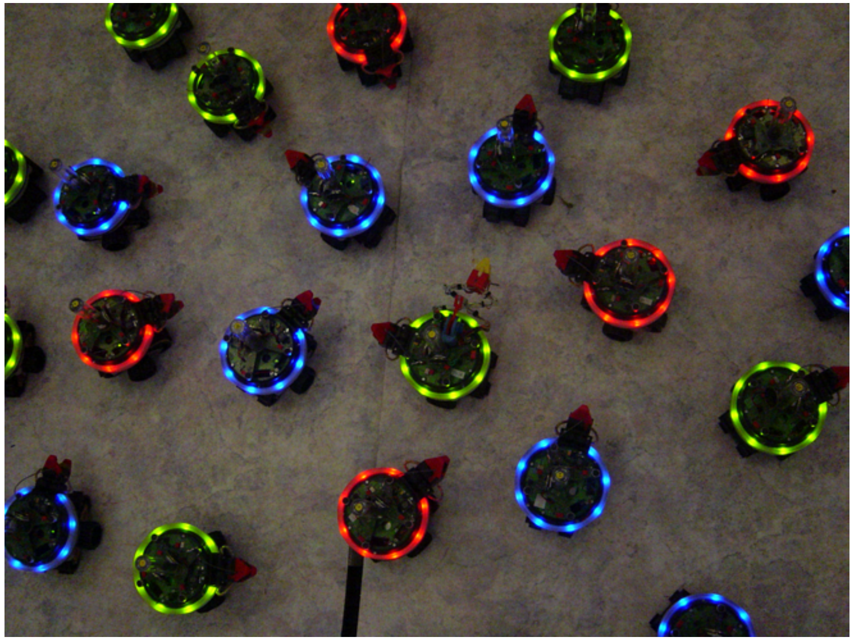
ANTS Conferences

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

September 22–24, 2008, Brussels



The end



www.swarm-bots.org