# Introduction to Swarm Robotics

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# Summary

- What is a swarm robotic system?
- What can a swarm robotic system do?
- The “control” design problem
- A case study: cooperative transport
- Conclusions

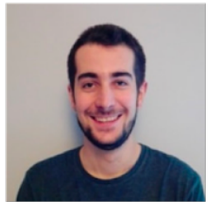
# The Robotics Lab at UNamur


M. Alkilabi


T. Njougou


D. Trendafilov


A. Hubermont

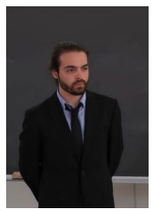

A. Sion


D. Alahvirdi

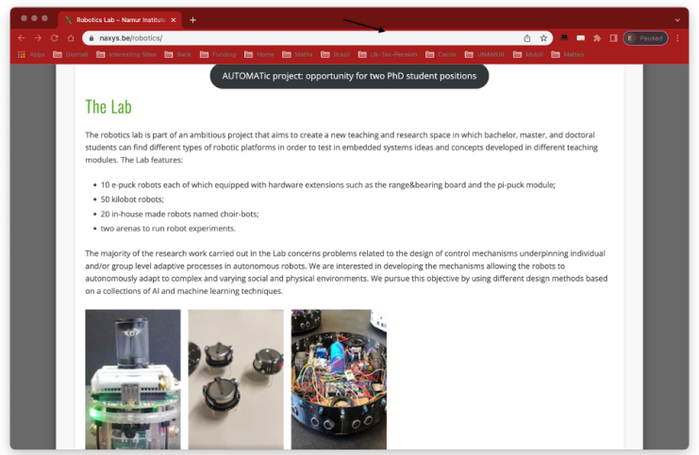

G. Maître


A. Almansoori


A. Vellinger


N. Antonic

(https://www.naxys.be/robotics/)



# Swarm Robotics

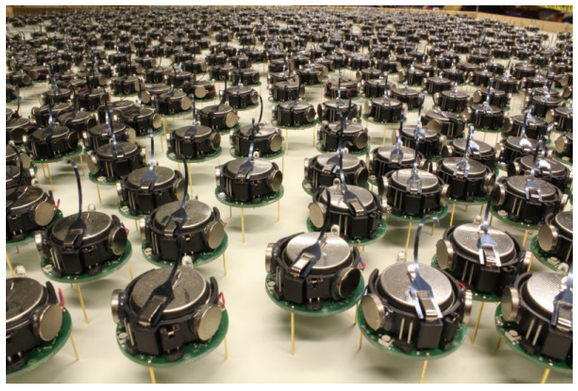
## What is a swarm robotic system?

# Swarm Robotics

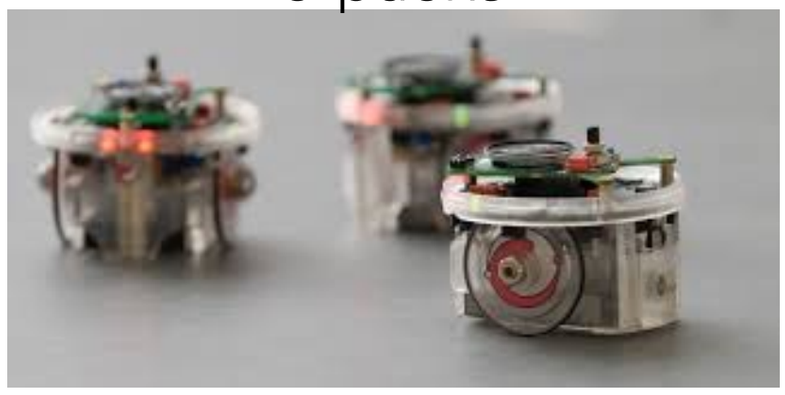
What is a swarm robotic system?

A swarm robotic system is a multi-robot system inspired by the characteristics of social insects (ants, bees)

kilobots



e-pucks

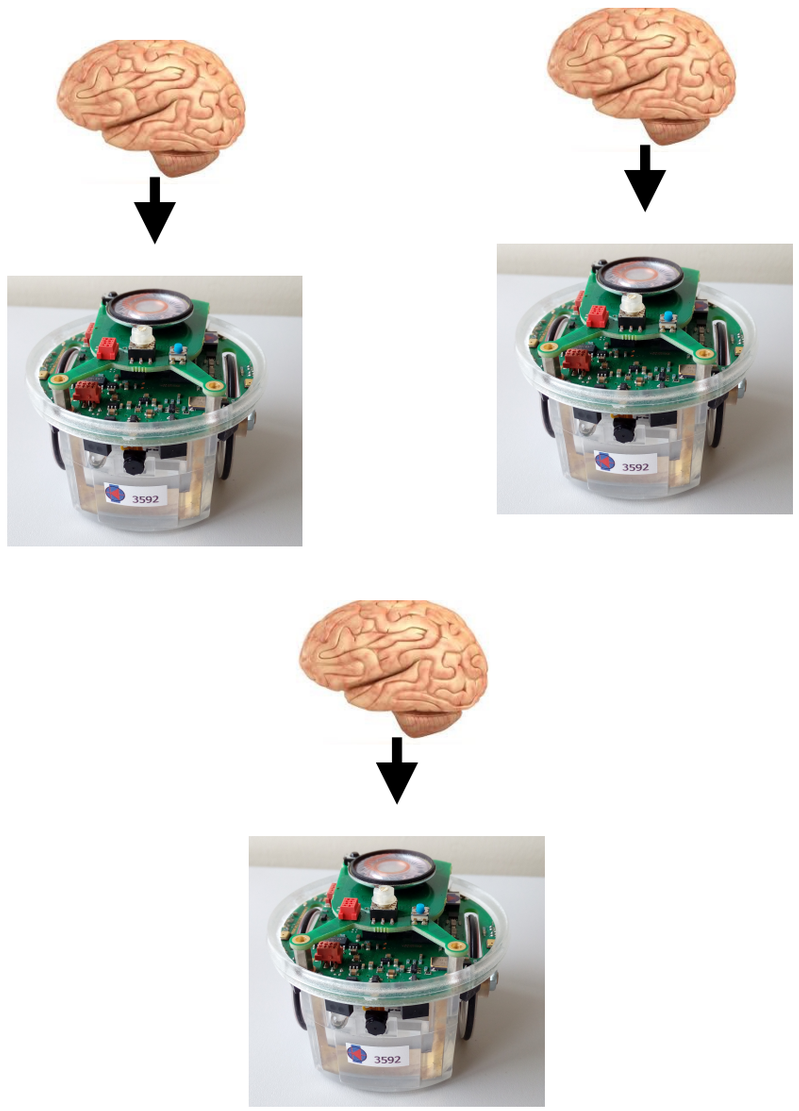


1) Distributed control

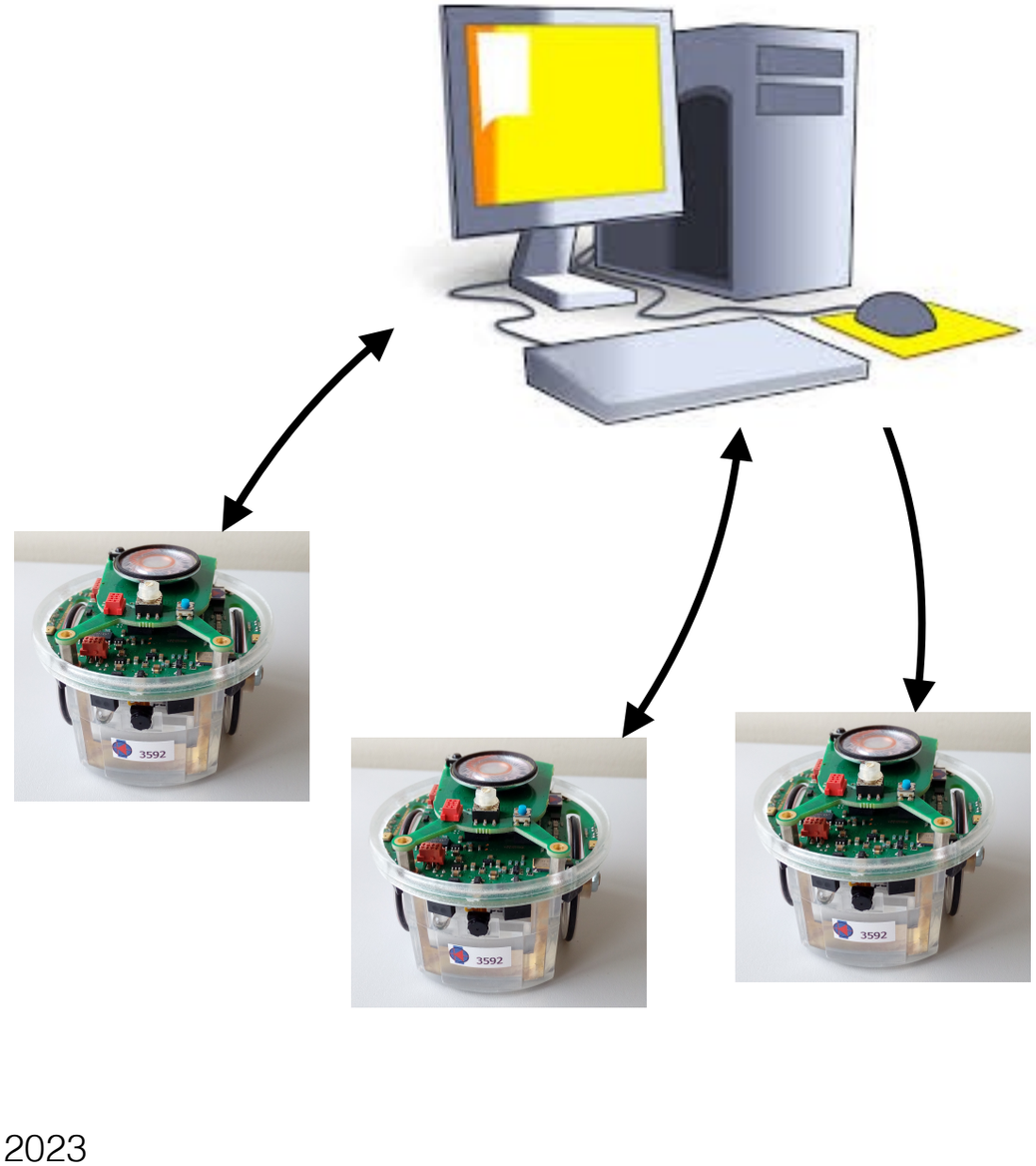
# Swarm Robotics

What is a swarm robotic system?

## Distributed control



## Central control



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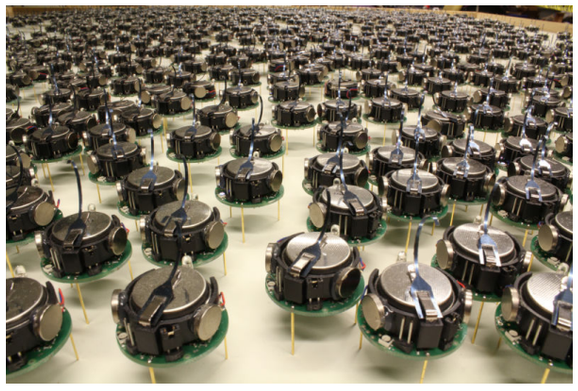

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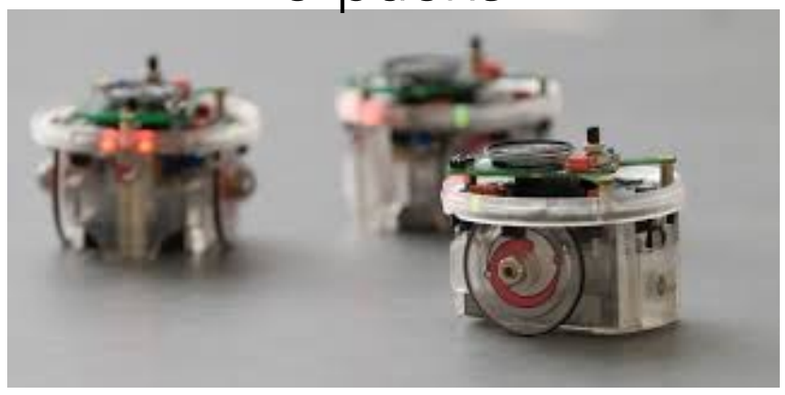


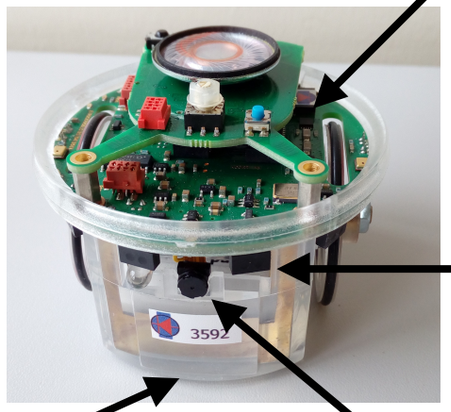
1) Distributed control

2) Local perception

# Swarm Robotics

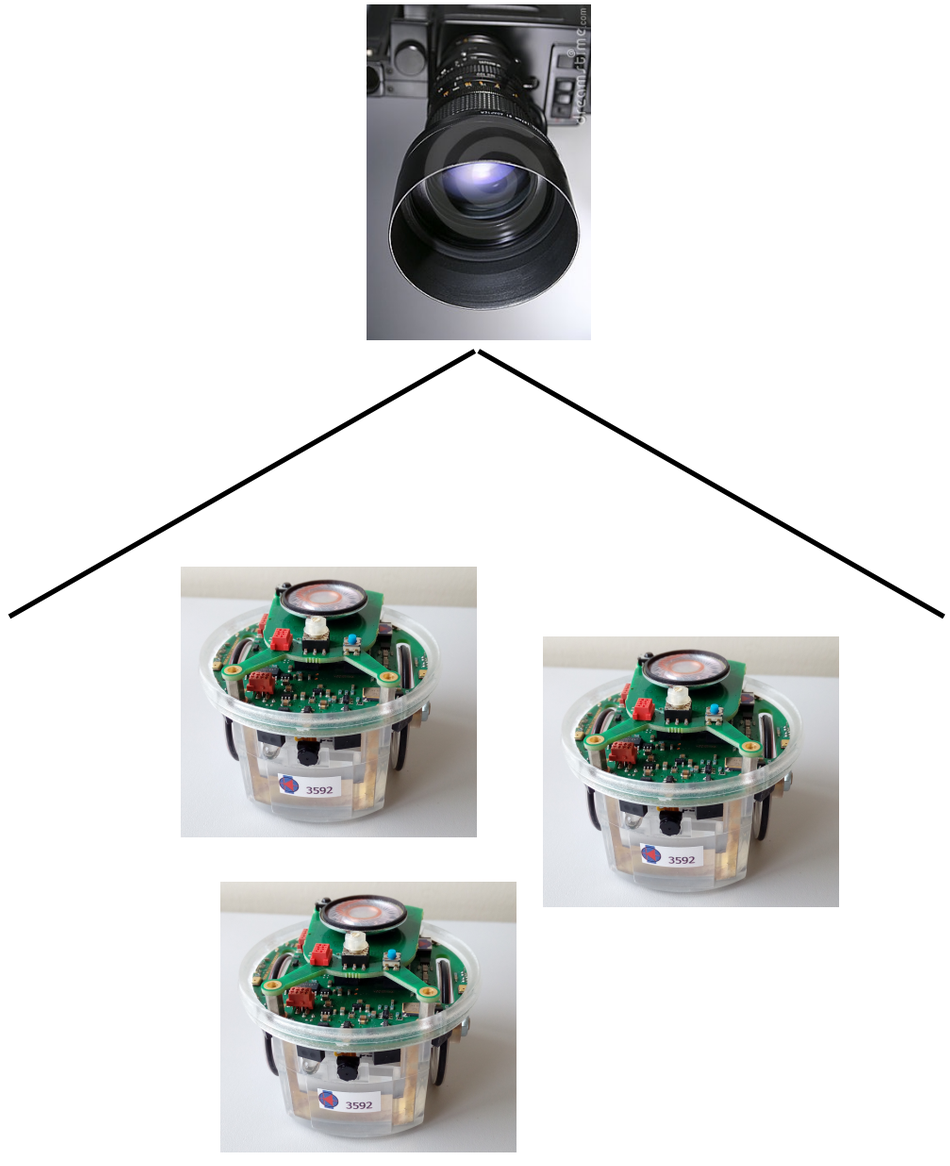
What is a swarm robotic system?

## Local perception




- Sensors are mounted on the robot chassis
- Sensors' activation depends on the robot current position
- Robot's actions are based on its own sensors' readings

## Global perception



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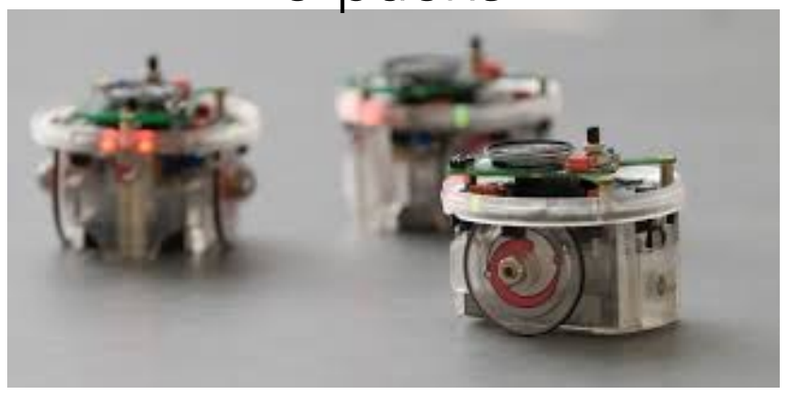


1) Distributed control

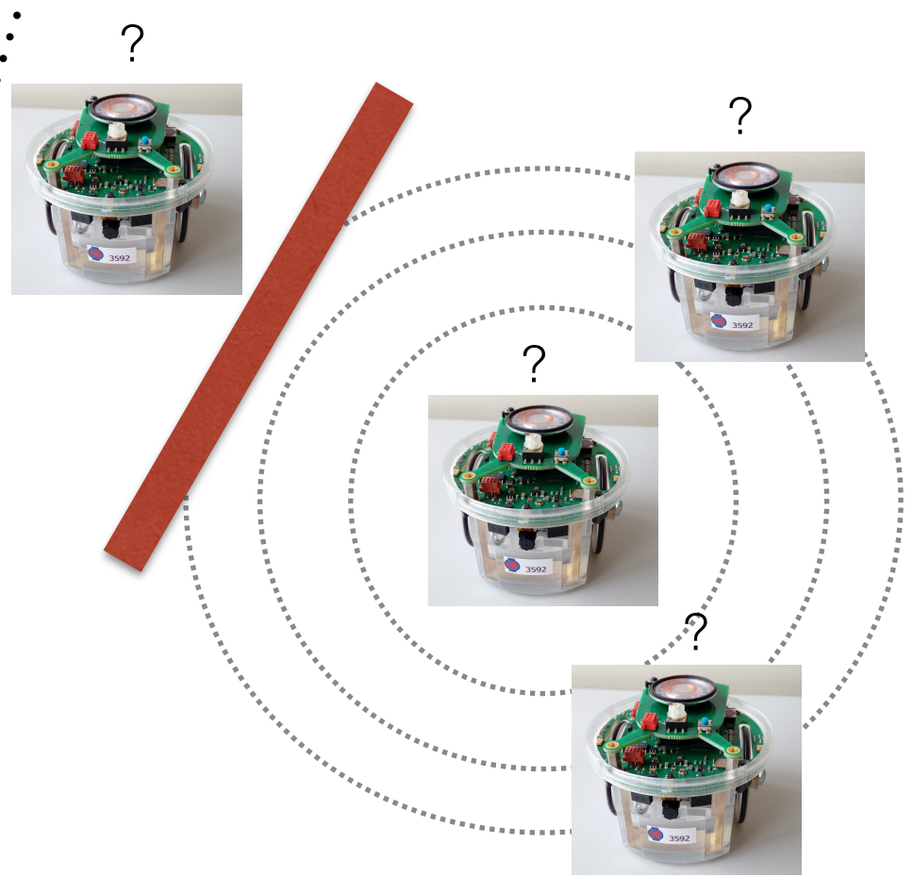
2) Local perception

3) Indirect communication

# Swarm Robotics

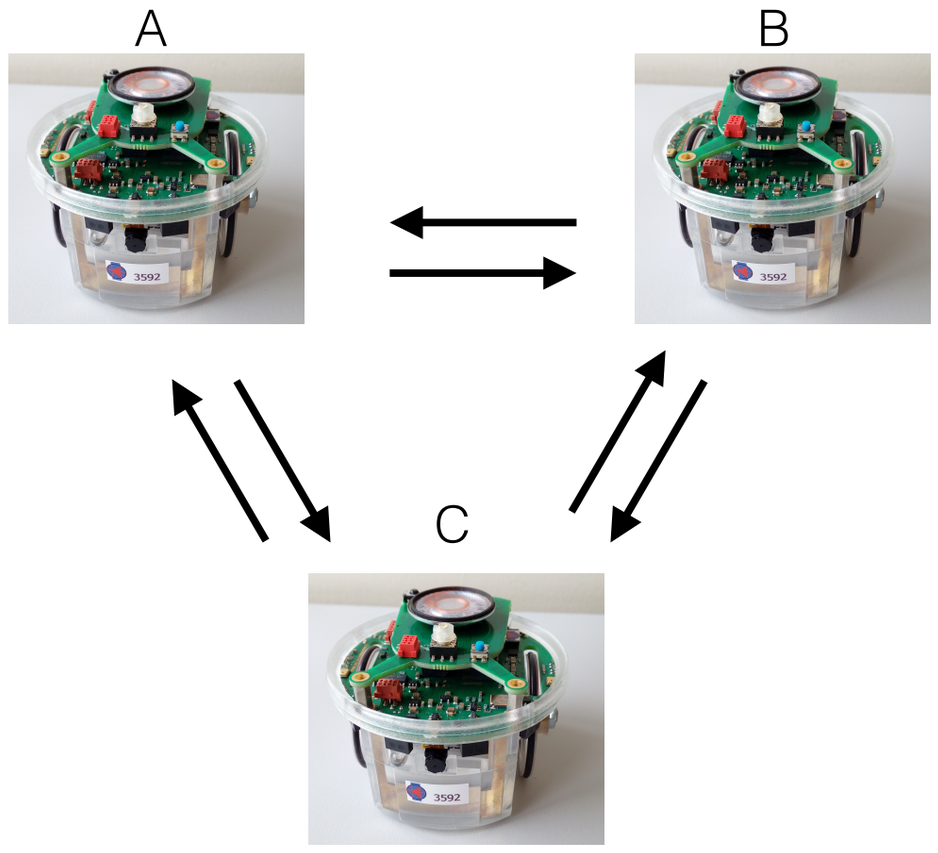
What is a swarm robotic system?

## Indirect communication




- No message are sent directly to a specific robot
- Infra-red, LED, sound, etc
- Stigmergic communication

## Direct communication




- Communication  network
- Robots have a unique identifier
- A can send messages only to B, or only to C or to both of them

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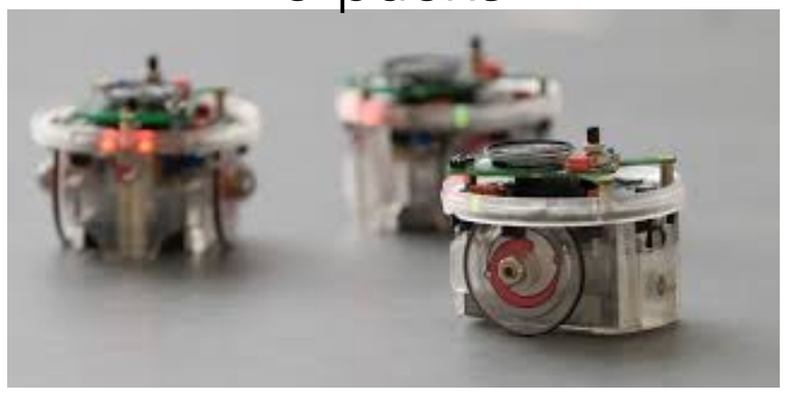


1) Distributed control

2) Local perception

3) Indirect communication

# Swarm Robotics

What is a swarm robotic system?

1) distributed control
2) local perception
3) indirect communication

**1 + 2 + 3 helps to achieve:**

- scalability (easy to remove/add robots)
- fault tolerance (no single point of failure)
- robustness (being able to tolerate local perturbation)

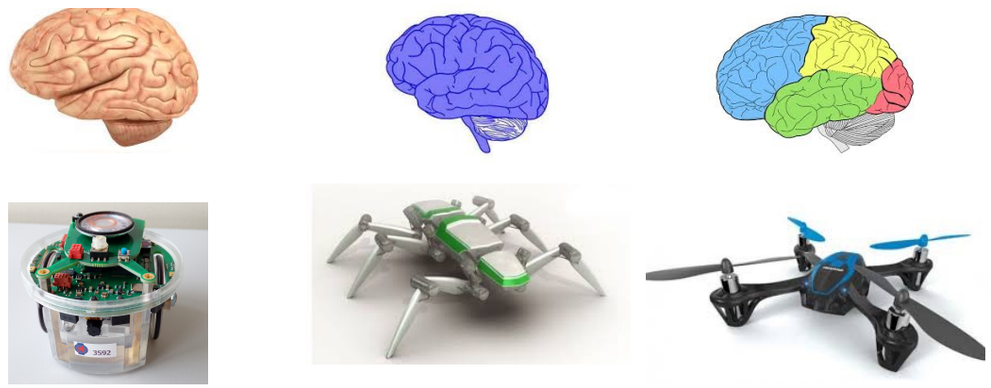
# Swarm Robotics

What is a swarm robotic system?

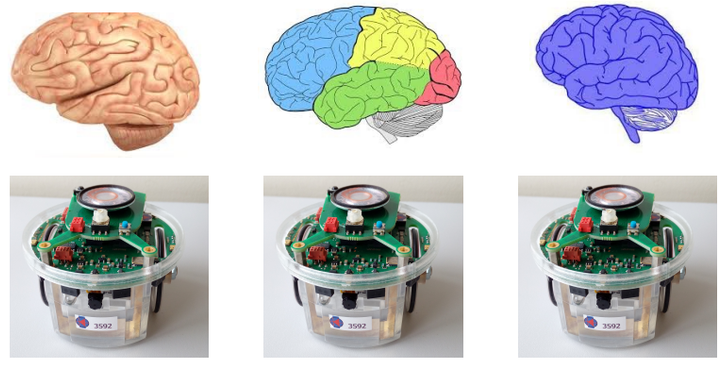
## Homogeneous swarms

Robots are clones : they have same body and same control system

## Heterogeneous swarms



Robots have different body structure and different control system

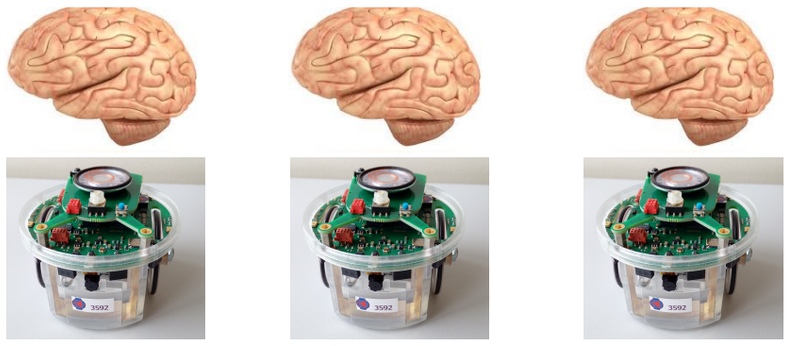


Robots have same body but different control system

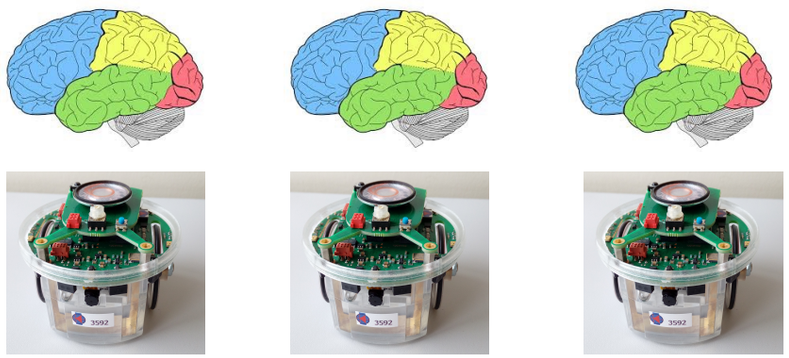
# Swarm Robotics

What is a swarm robotic system?

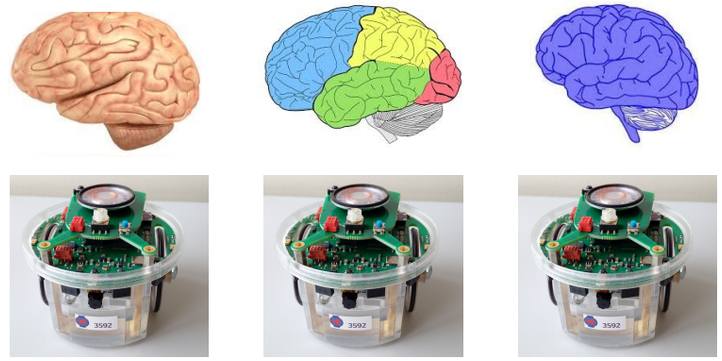
## Homogeneous swarms



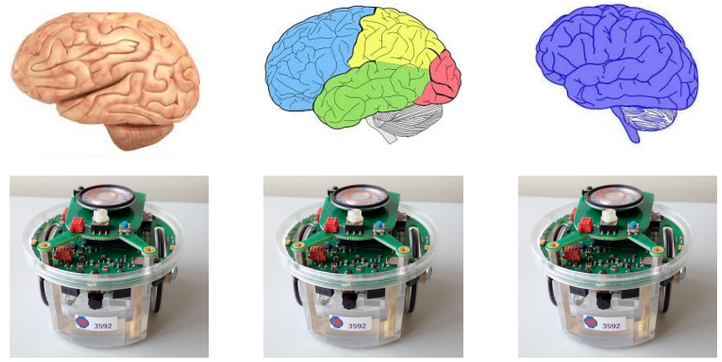
Robots are clones : they have same body and same control system



## Heterogeneous swarms



Robots have same body but different control system



Robots have same body but different control system

# Swarm Robotics

## What can a swarm robotic system do?

# Swarm Robotics

What can a swarm robotic system do?

## Cooperation

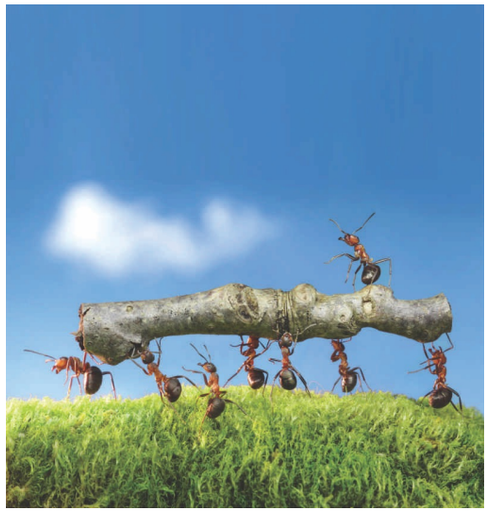
The robots of a swarm work together (cooperate) to do more than what a single agent can do.

# Swarm Robotics

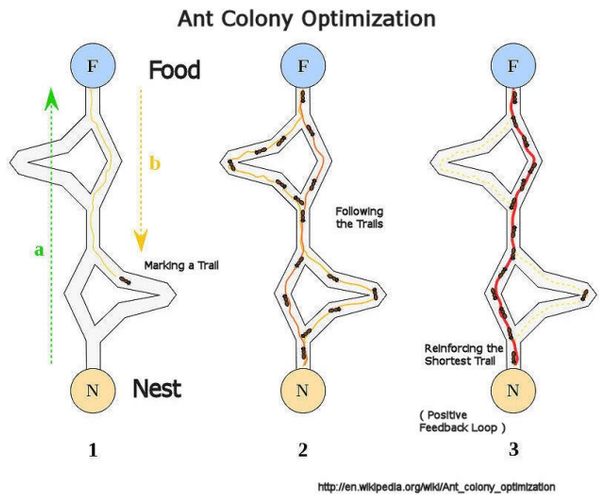
## What can a swarm robotic system do?

### bridging gaps

### object transport



### find shortest path




# Swarm Robotics

What can a swarm robotic system do?

Swarms of robots are designed to perform cooperative tasks that:

- are spatially distributed
  surveillance
- can be parallelised
  objects retrieval (e.g., hazardous waste removal/disposal)
- require competencies that can be hardly implemented in a single robot
  e.g., to fly and to swim

# Swarm Robotics

## The “control” design problem

# Swarm Robotics

The “control” design problem

The designer’s goal is the **group response (what the group does)**

A swarm of robots is a self-organising system

The group response emerges from the interactions of the system’s components through a process of self-organisation

**No central control, no group plan**

# Swarm Robotics

## The “control” design problem

The designer’s → // → **group response**

self-organisation

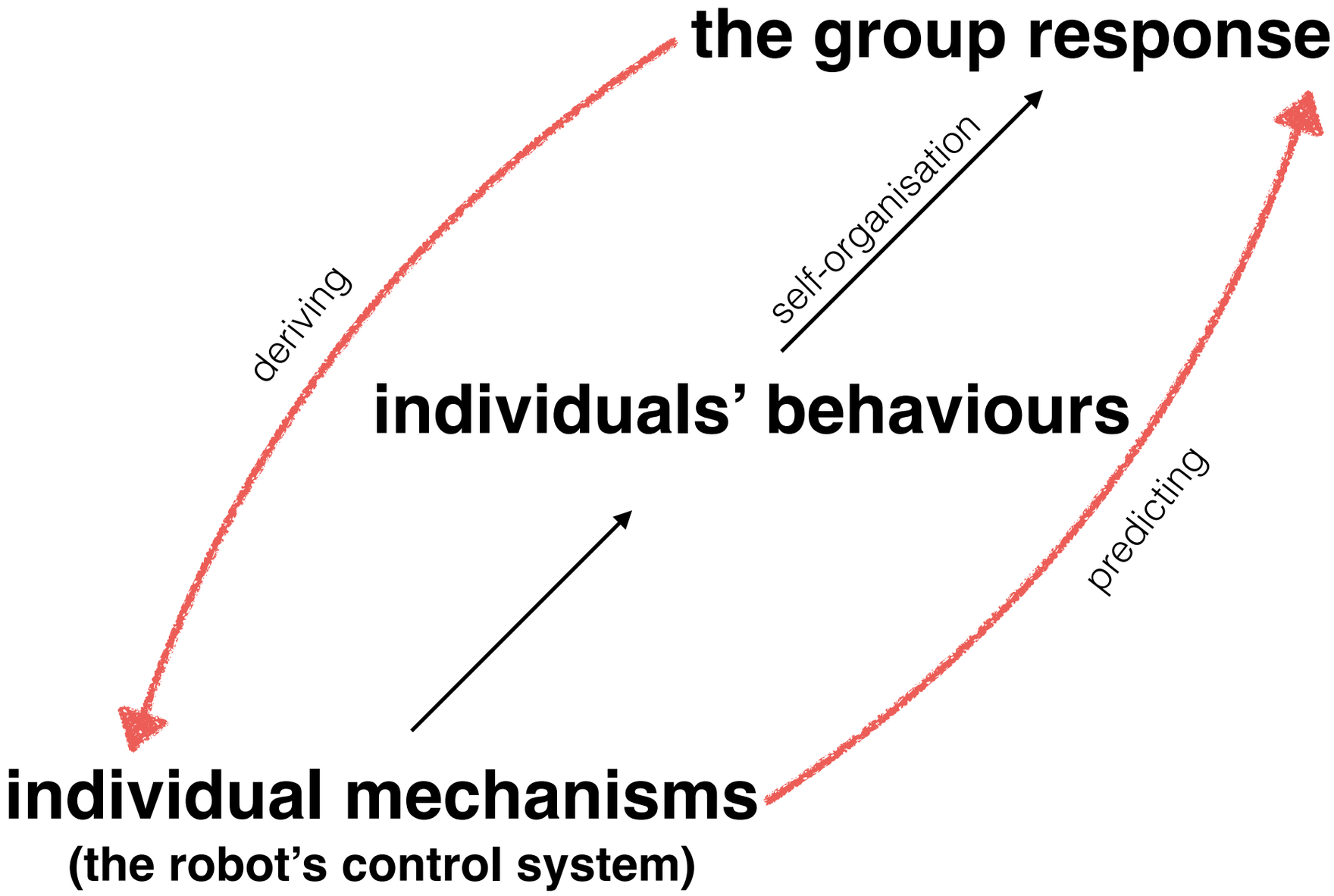
**individuals’ behaviour**

**individual mechanisms**

**(the robot’s control system)**

# Swarm Robotics

## The design problem



# Swarm Robotics

The “control” design problem

Complex group level responses can be generated by the interactions of individuals controlled by simple mechanisms


Cohesion, Separation, Alignment

# Swarm Robotics

## The design problem : a solution

**Artificial evolution**

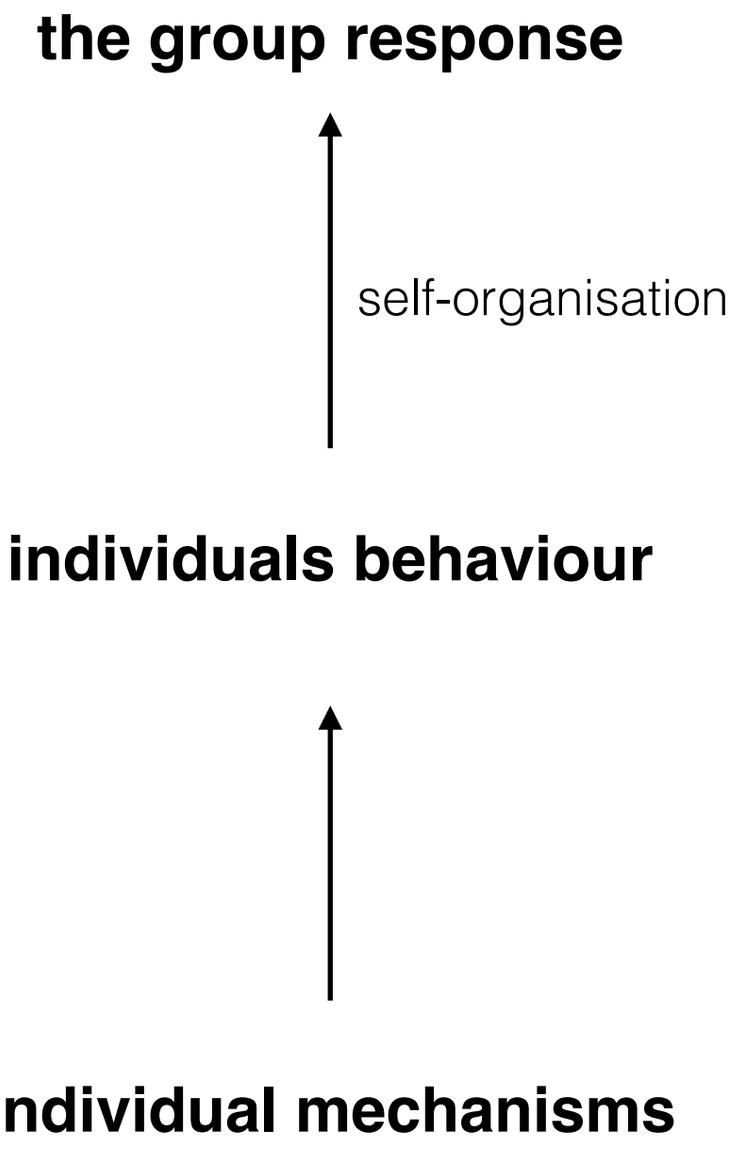
**+**

**Swarm robotics**

**=**

**Evolutionary swarm robotics**

A methods to design individual mechanisms
using **Artificial Evolution**
(genetic inheritance, selection, random variation)



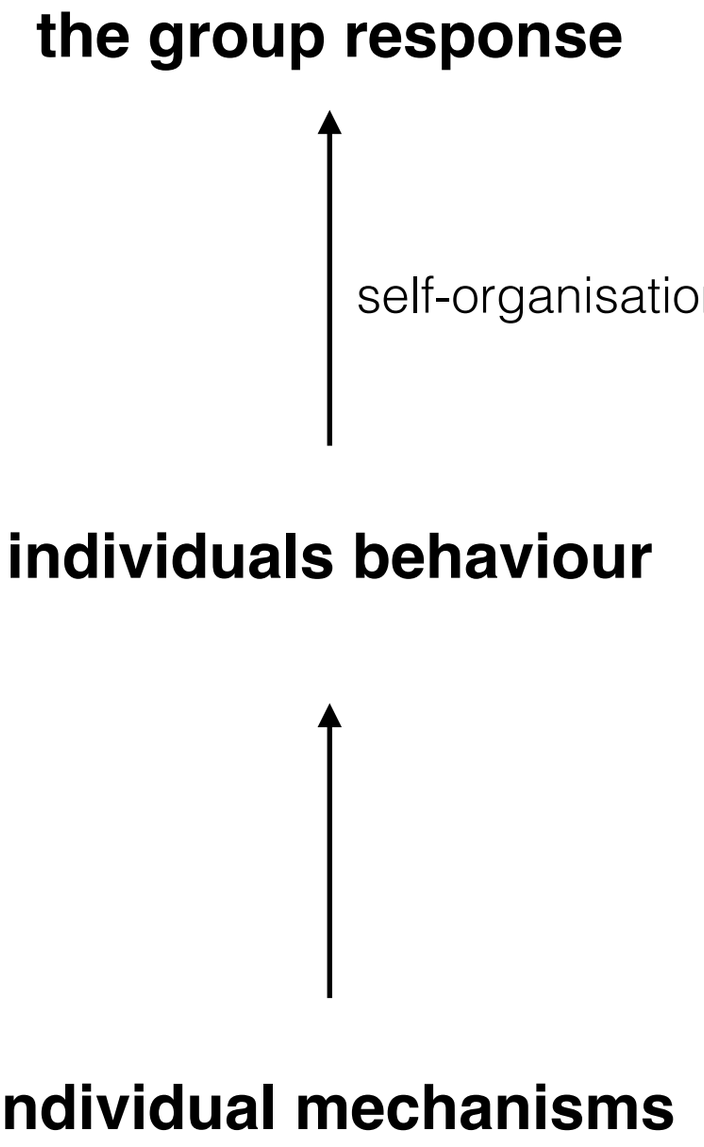
# Swarm Robotics

## The design problem : Evolutionary Swarm Robotics

The designer provides evolution with basic building blocks
(components of the robot's controller, etc.)

Press "Start"

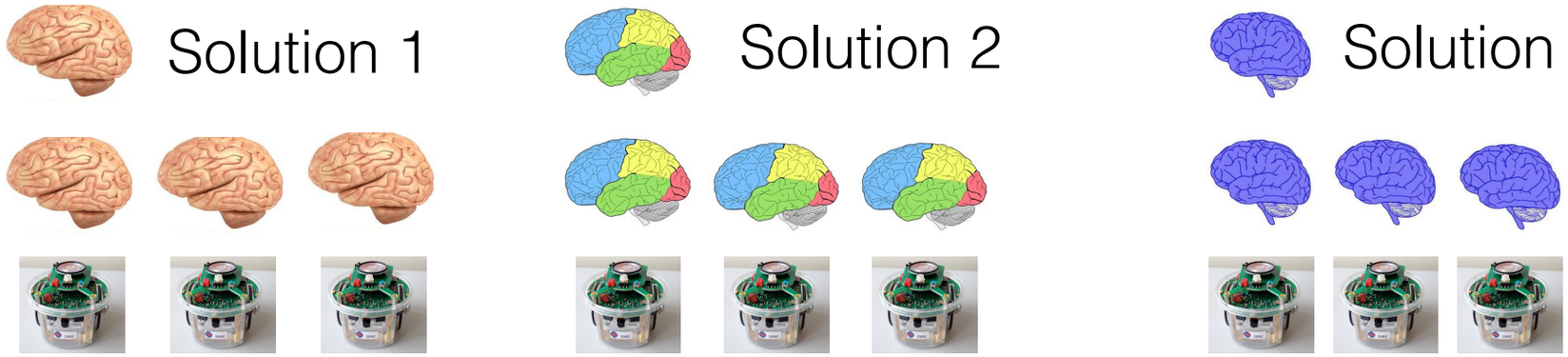
After *n* generations evolution finds



# Swarm Robotics

## The design problem : Evolutionary Swarm Robotics

### 1) Generate a population of random solutions




Evaluate

Select the best

Create a new population

with random variation

# Swarm Robotics

## A case study: cooperative object transport

Muhanad Alkilabi

Cooperative object transport with a swarm of e-puck robots: robustness and scalability of evolved collective strategies Muhanad H. Mohammed Alkilabi, Aparajit Narayan, Elio Tuci, Swarm Intelligence Journal, 2017, https://doi.org/10.1007/s11721-017-0135-8

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Namur Institute
for Complex Systems

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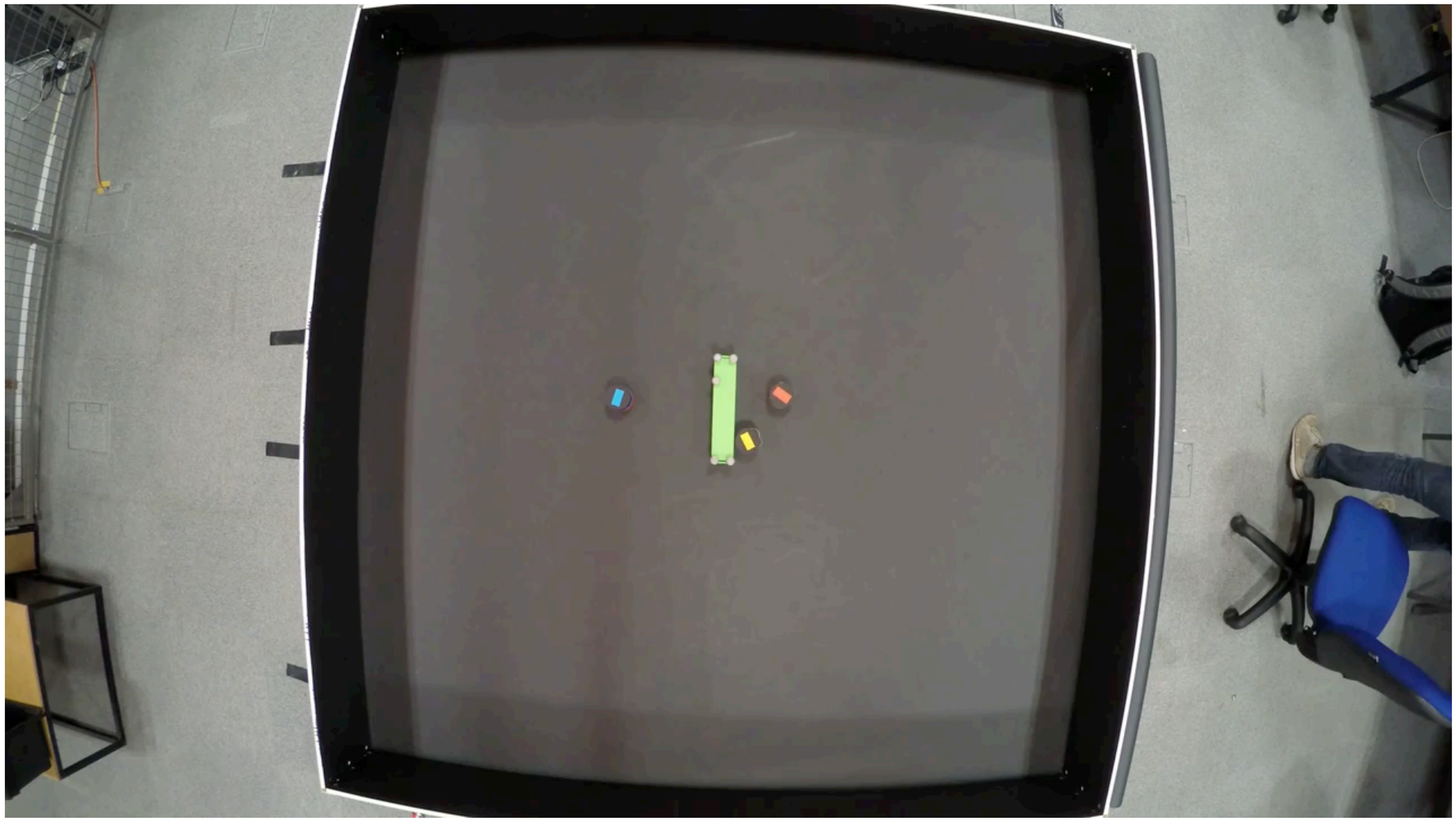
DE NAMUR

# Swarm Robotics

## A case study: cooperative object transport



# Swarm Robotics

## A case study: cooperative object transport

Objectives of our study:

to demonstrate that with evolutionary swarm robotics is possible to get scalable and robust solutions to variability in object's size/mass

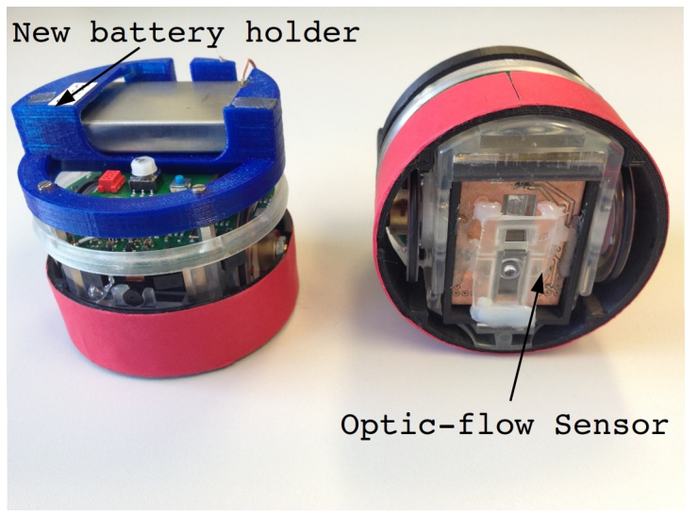
to demonstrate that alignment and coordination of actions during transport can be achieved without perceiving forces

# Swarm Robotics

## A case study: cooperative object transport

Homogeneous groups (4 robots)

Modified e-puck robots with optic-flow sensors



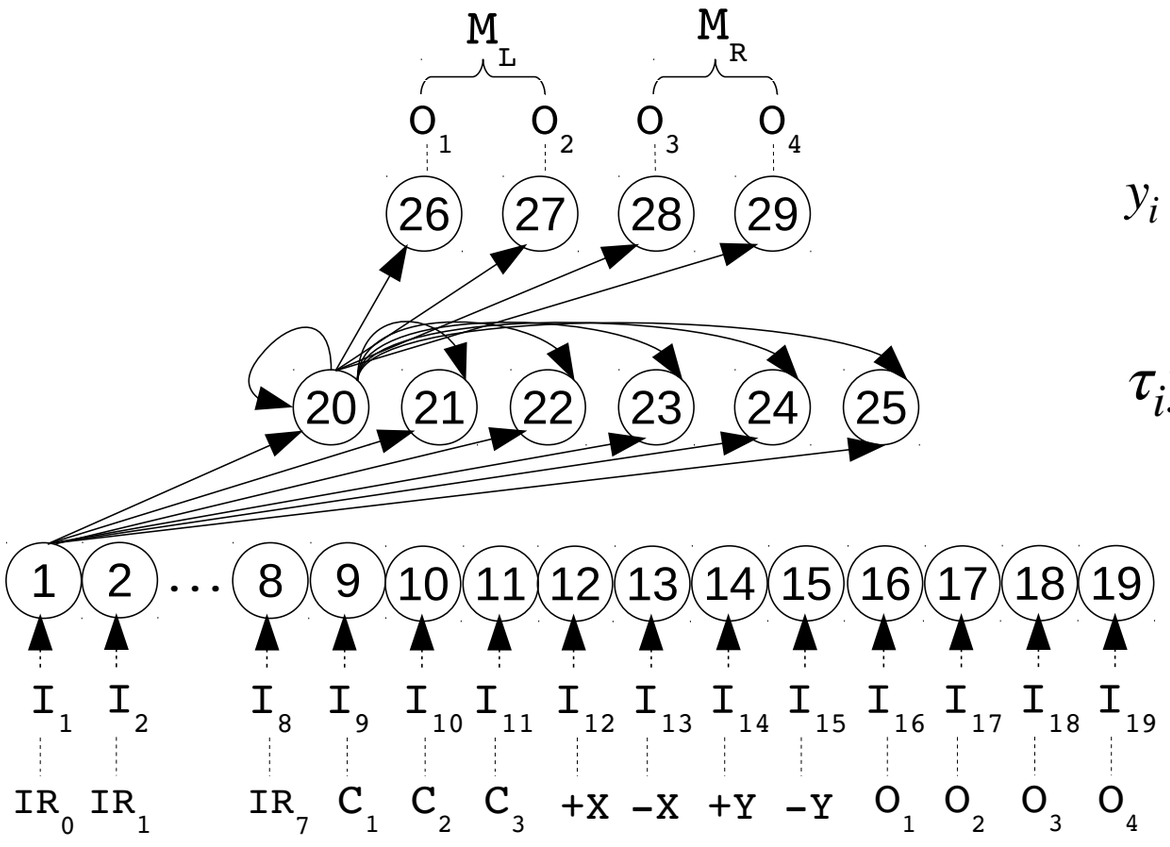

Evolutionary Swarm Robotics:

- Dynamics artificial neural networks
- Evolutionary computation techniques (GAs)
- Controllers designed in simulation and then ported onto real robots

Dynamic simulator - Bullet Physics Engine

# Swarm Robotics

## A case study: cooperative object transport




$$y_i = \sum_{j=N+1}^{j=N+6} \omega_{ji} f_j;\ i \in \{N+7,\cdots,N+10\};$$

$$\tau_i \dot{y}_i = -y_i + \sum_{j=1}^{j=N+6} \omega_{ji} f_j;\ i \in \{N+1,...,N+6\}$$

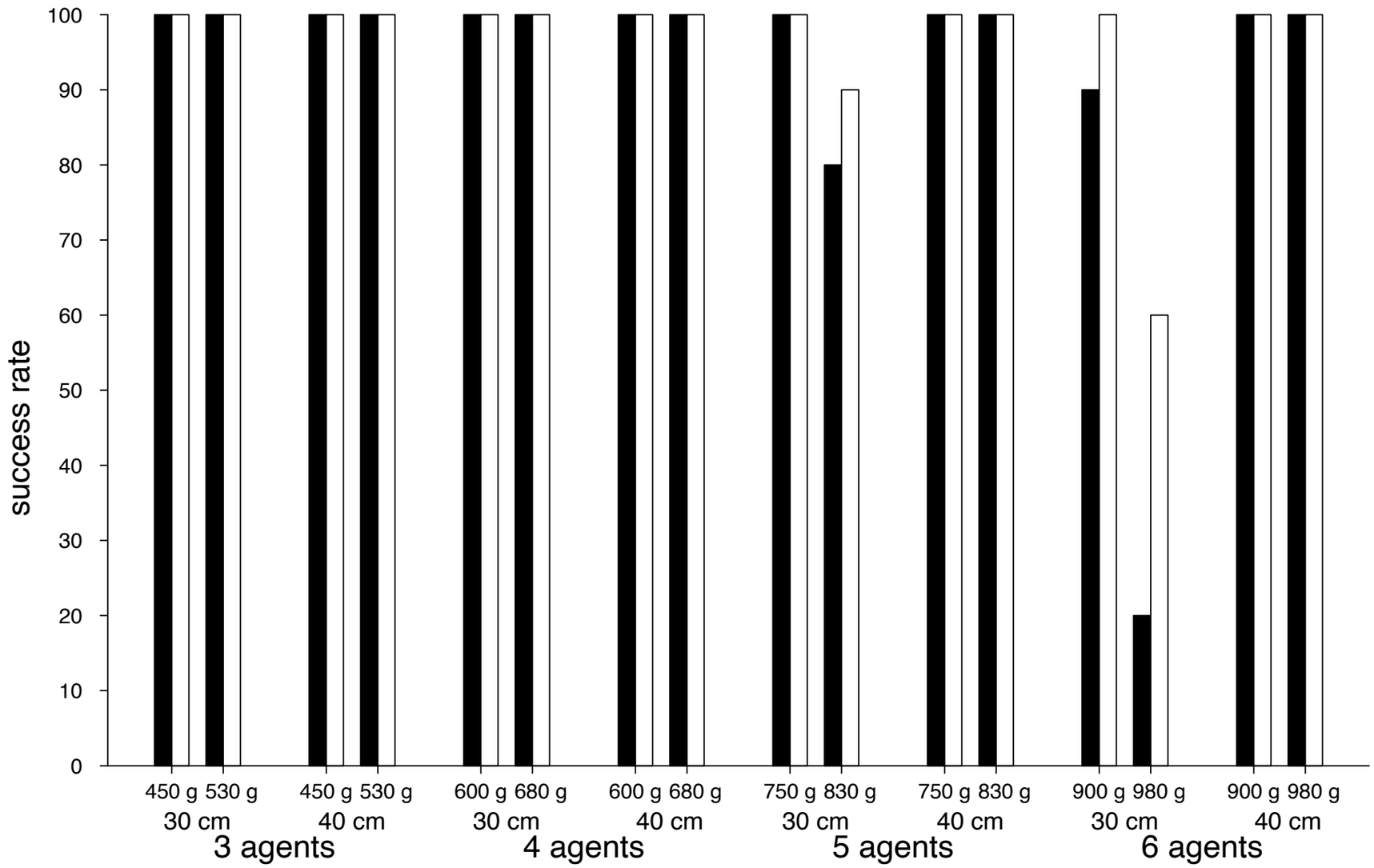
$$y_i = gI_i;\ i \in \{1,\cdots,N\}; \quad \text{with } N = 19;$$

$$f_j = \sigma(y_j + \beta_j); \quad \sigma(x) = (1+e^{-x})^{-1};$$

$$\tau_i, \quad \beta_i, \quad \omega_{ij}$$

# Swarm Robotics

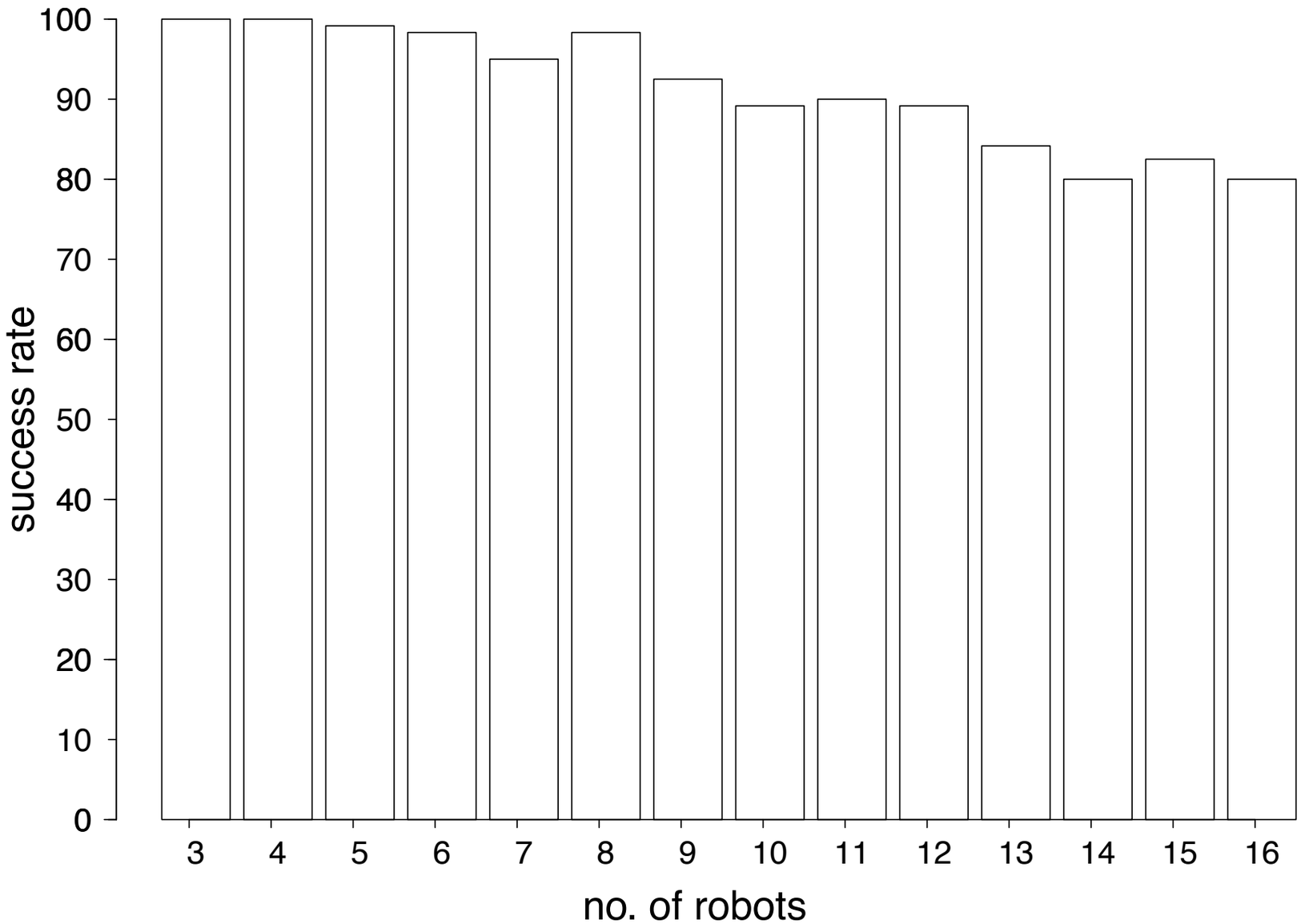
## A case study: cooperative object transport




Robustness to variation of the mass and the size of the object

# Swarm Robotics

## A case study: cooperative object transport



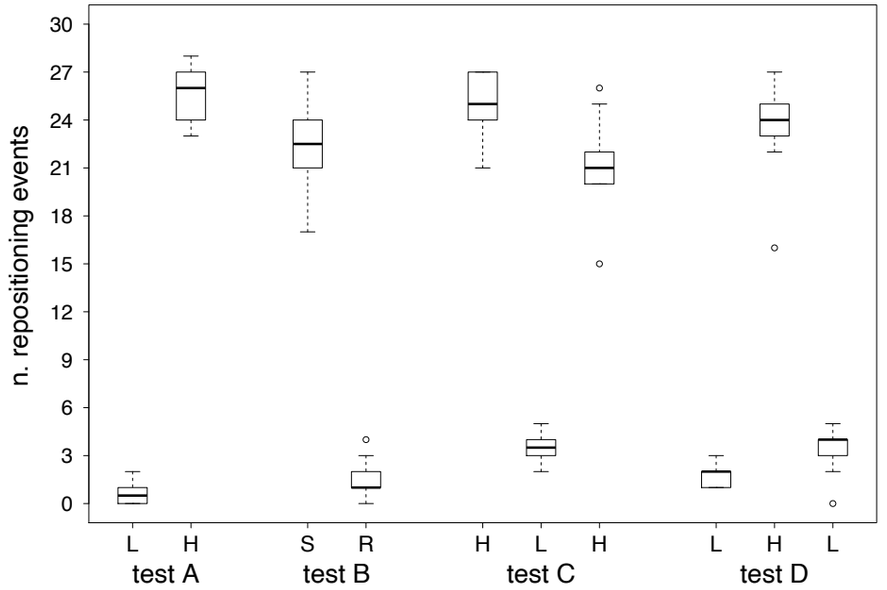

Scalability test

# Swarm Robotics

## A case study: cooperative object transport

### Behavioural rules

- Keep on pushing if the object moves
- Change position (in the proximity) if the object does not move
- Change position (as far away as possible) if the object moves against you



# Conclusions

## Swarm robotic systems

- what they are,
- what they can do,
- the design problem / evolutionary swarm robotics

## Cooperative object transport

- the evolutionary approach is suitable to get effective, robust, and scalable group transport strategies
- no feeling of forces needed/working hypothesis for entomologist

## Other classic swarm robotics tasks

- aggregation
- task-allocation
- shape formation
- collective navigation and exploration
- human-swarm interaction

## Non classic swarm robotics applications

- Swarm robotics to study cognition (Swarm Cognition)