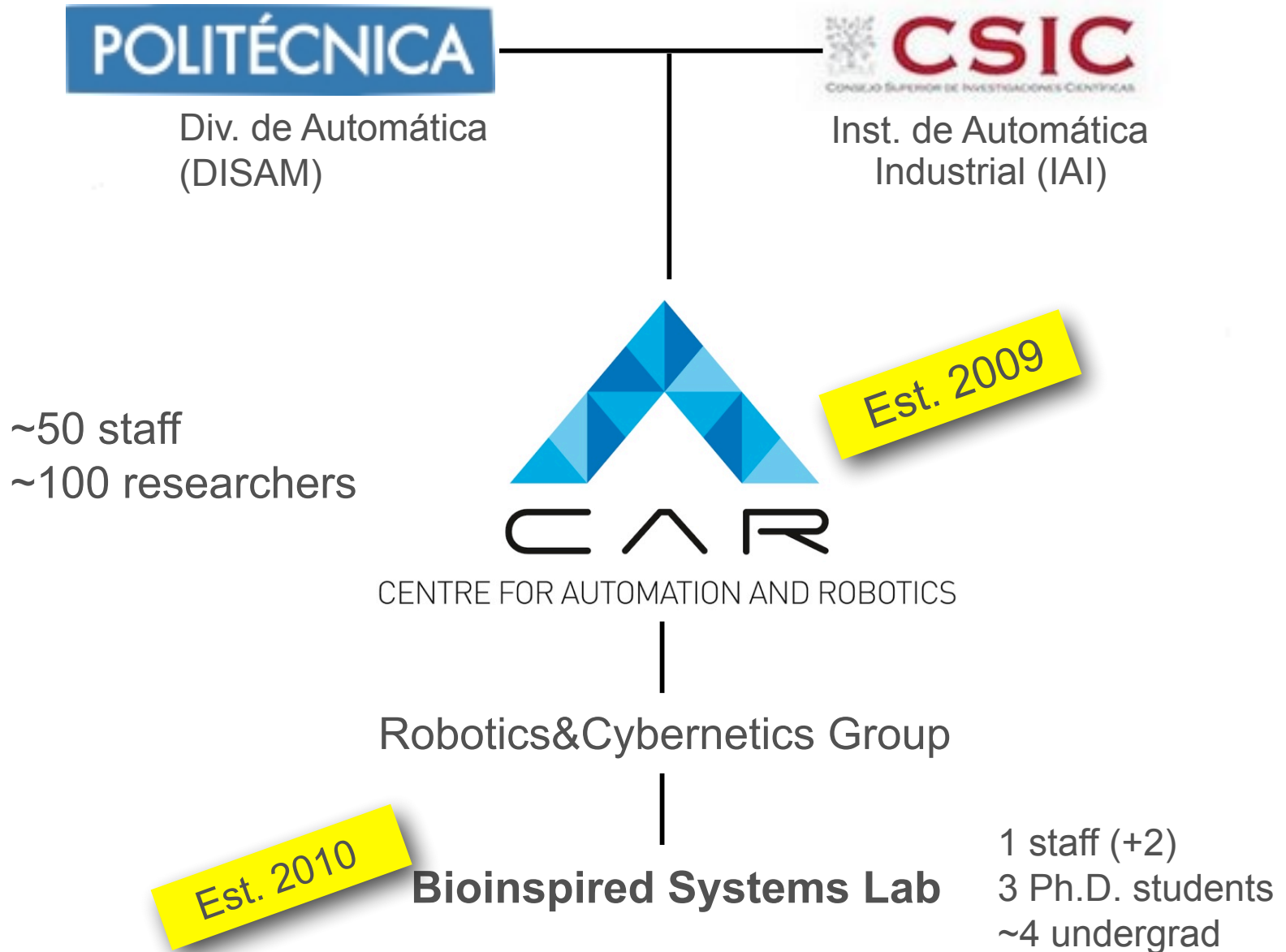




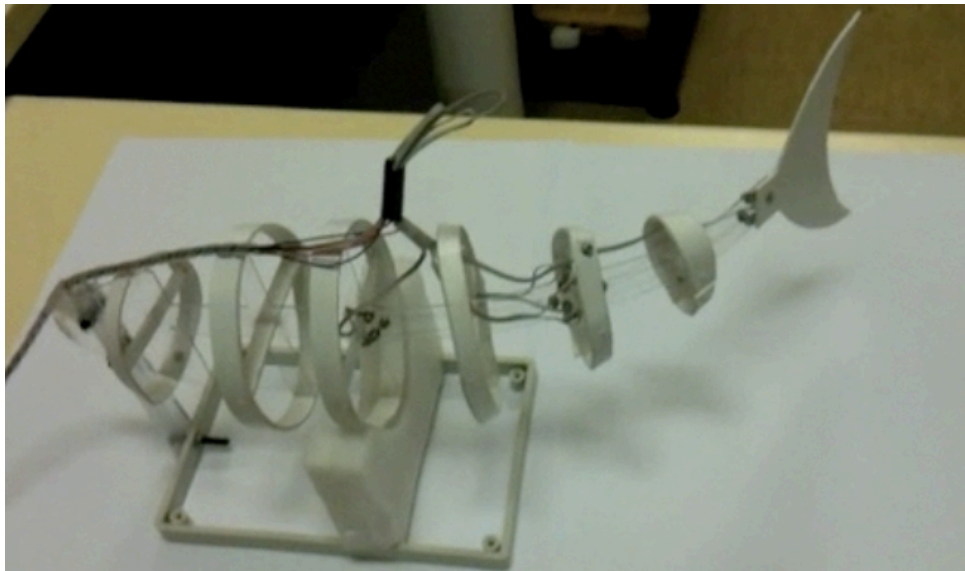
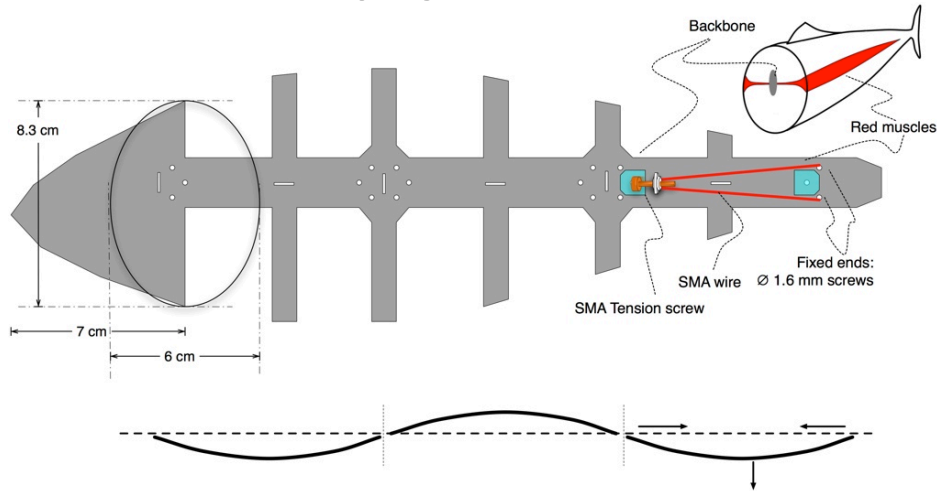
POLITÉCNICA

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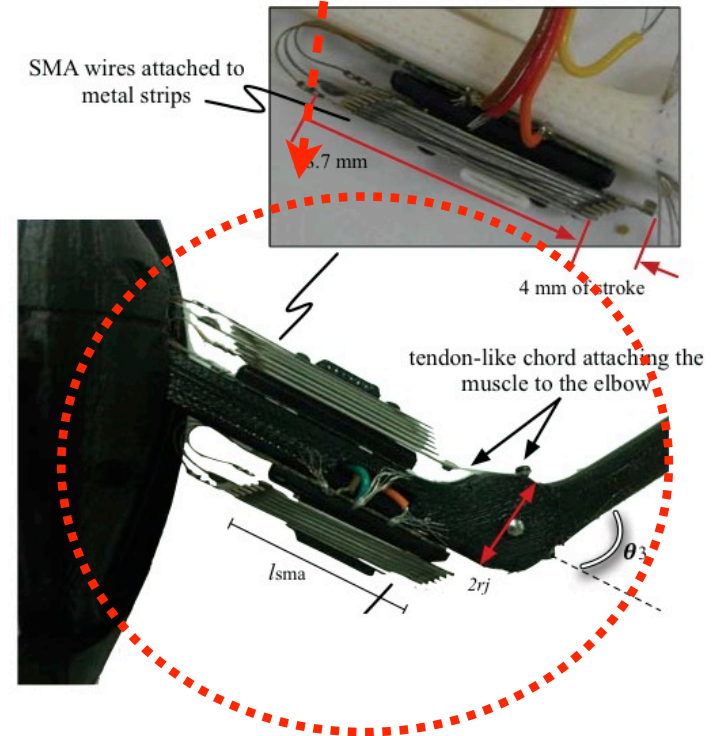
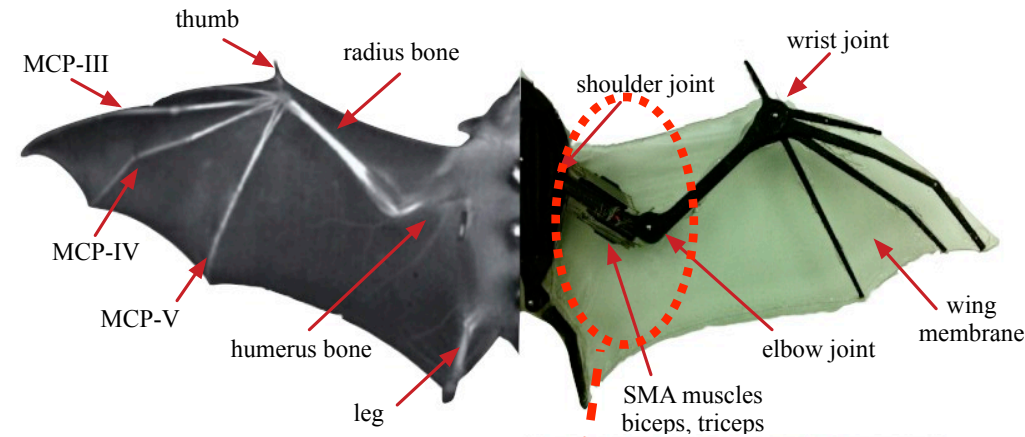
“**Engineering** the future”



## iTuna



## BatBot



SMA-based and piezo-electric artificial muscles

## Testbed for alternative technologies



\* *motor-less* and *gear-less* robots

- devoid of “conventional” electro-magnetic/pneumatic/hydraulic technology, no rotating parts → lighter, simpler, safer

# *Three Applications of Evolutionary Algorithms to Robotics*

**Claudio Rossi**

*2nd Extract-IT workshop, Brussels, June 2013*



CENTRE FOR AUTOMATION AND ROBOTICS

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 **CSIC**  
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

EVOLUTION

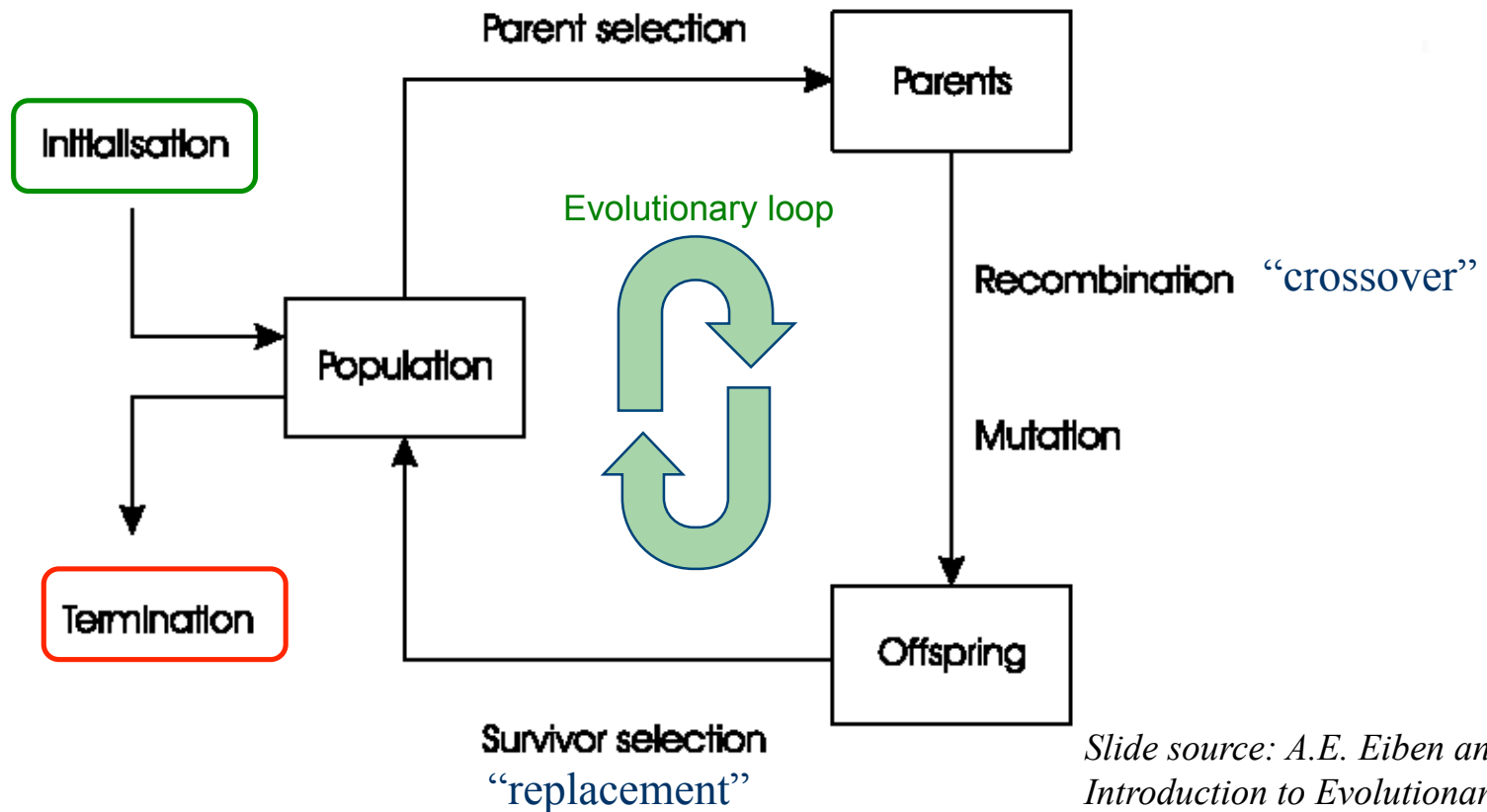
PROBLEM SOLVING

Environment ↔ Problem

Individual ↔ Candidate Solution

Fitness ↔ Quality

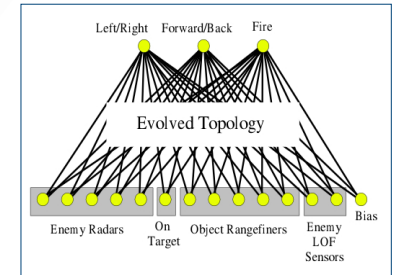
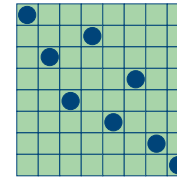
Population-based,  
stochastic search



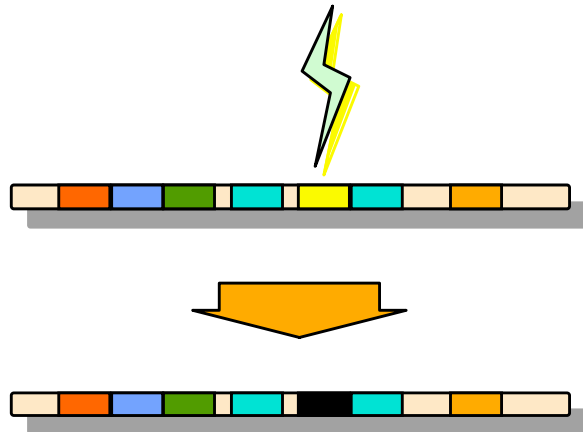
Slide source: A.E. Eiben and J.E. Smith, *Introduction to Evolutionary Computing*



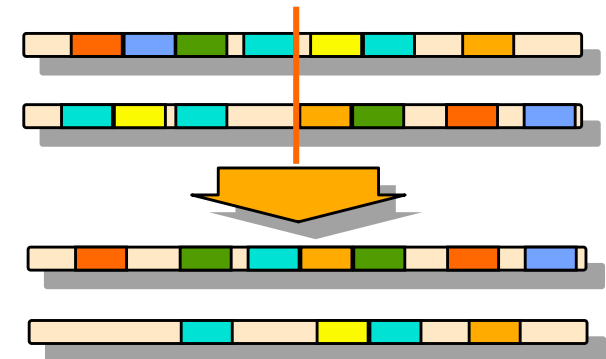
encoding = chromosome = genotype



candidate solution = phenotype



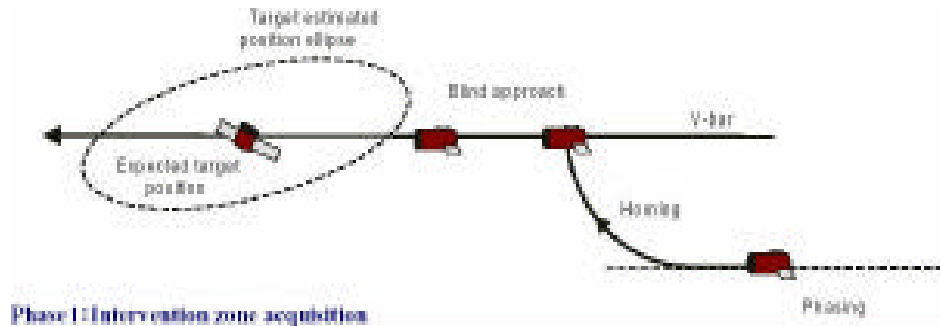
**mutation**



**recombination**

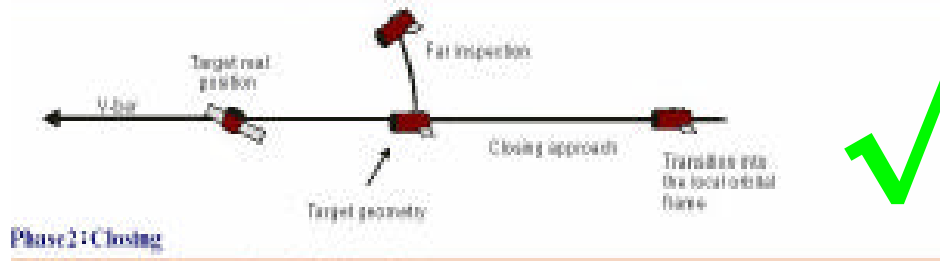
# 1. EAs in pattern marching for vision-based relative navigation

## Vision-based satellite relative navigation



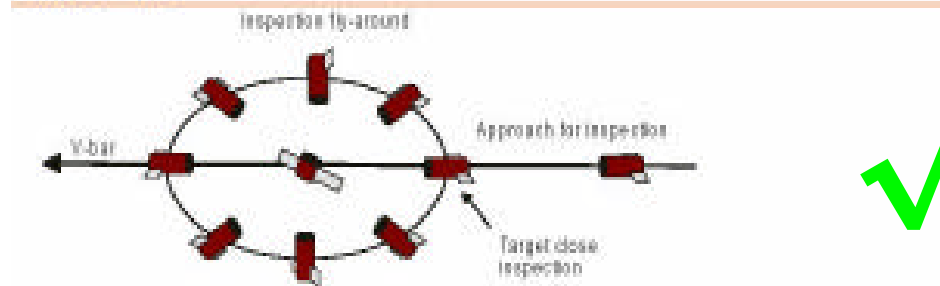
Ballistic stage

Phase 1: Intervention zone acquisition



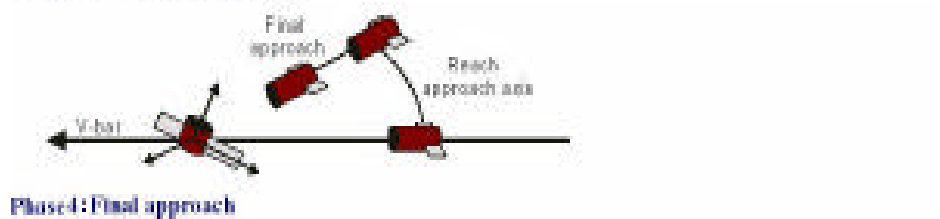
Reaching stage

Phase 2: Closing



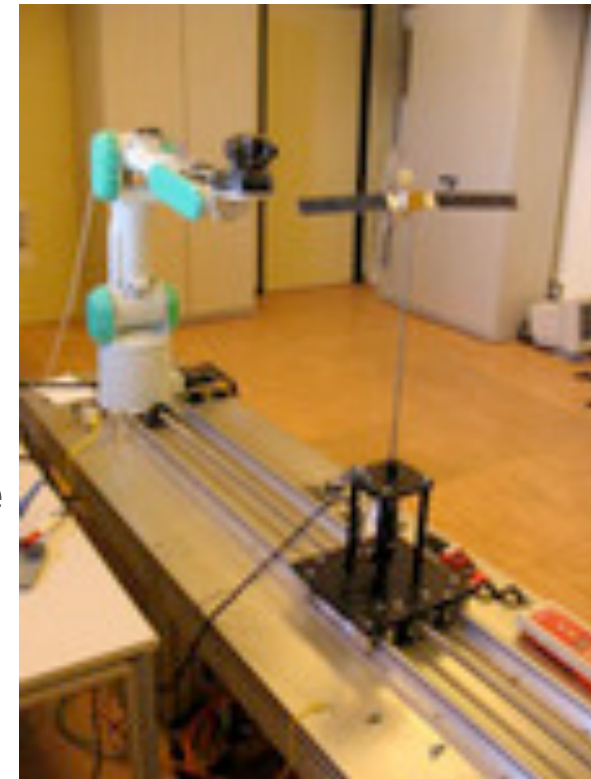
Inspection stage

Phase 3: Close inspection phase



Docking

Phase 4: Final approach

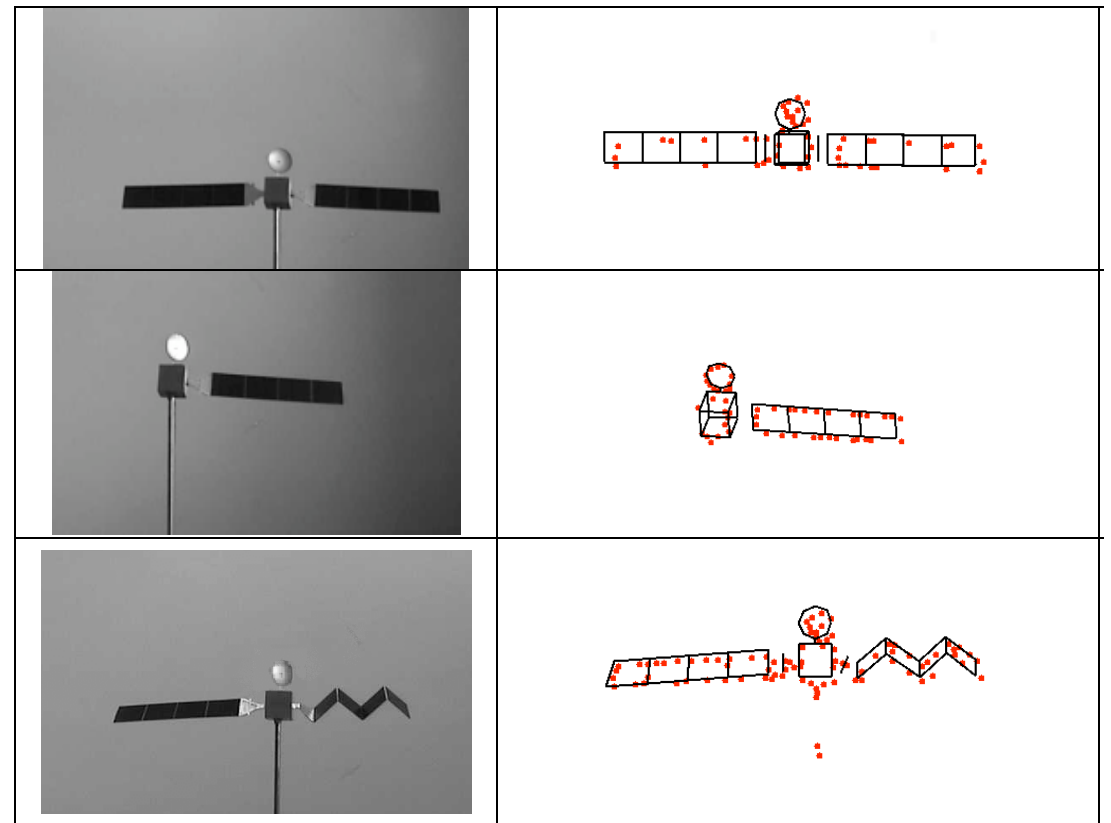
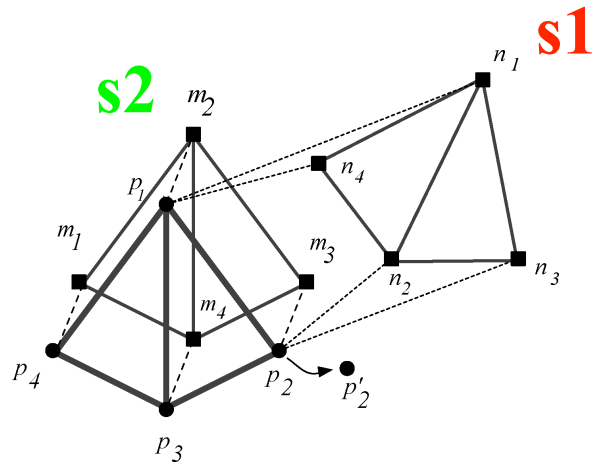
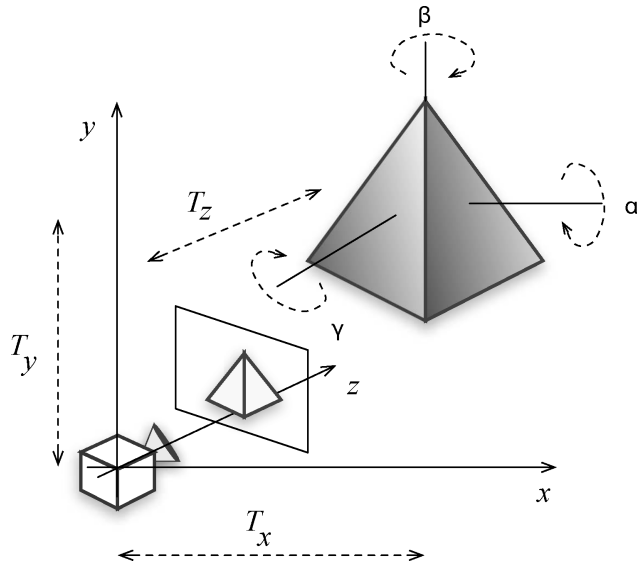


*Model-based pose estimation* → *optimization*

$$\min(d = \sum_i |p_i - m_i(s)|),$$

$$p_i, m_i \in \mathbb{R}^2$$

$$s = (T_x, T_y, T_z, \alpha, \beta, \gamma)$$





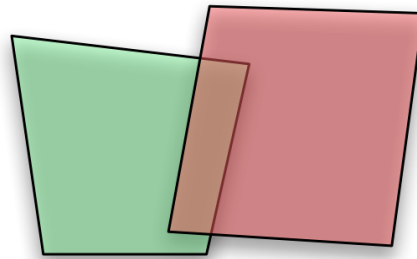
Relative  
localisation

## **2. EAs in agent-based negotiations for robot coordination**

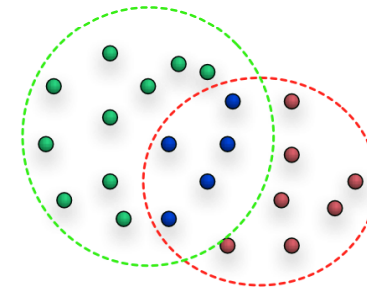
### Requirements:

- ▶ Can be instantiated for different tasks
- ▶ Suitable for heterogeneous robots
- ▶ Distributed approach

### “Tasks”

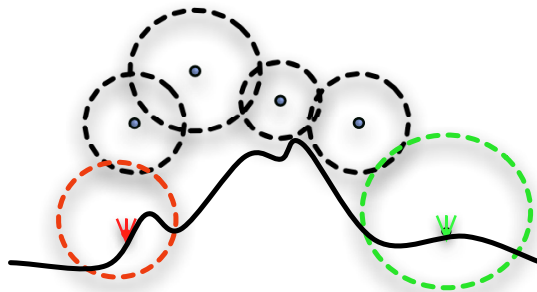


(a)  $x = ((x_1, y_1), \dots, (x_k, y_k))$

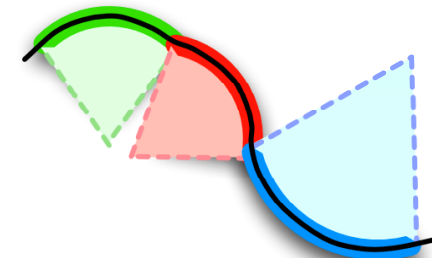


(b)  $x = ((x_1, y_1, v_1), \dots, (x_k, y_k, v_k))$

*A task is described by a set of  $n$  “parameters”*

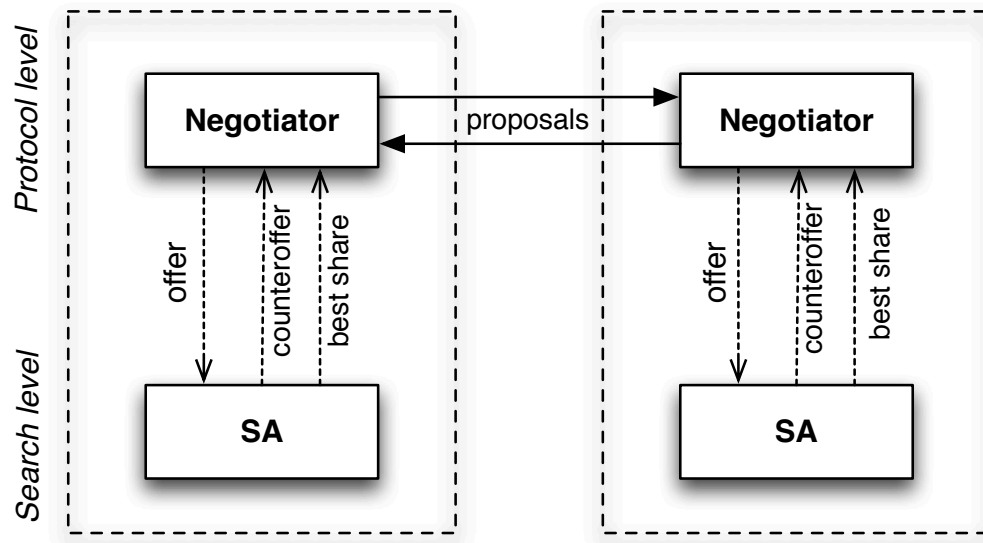


(c)  $x = ((x_1, y_1, z_1, r_1), \dots, (x_k, y_k, z_k, r_k))$

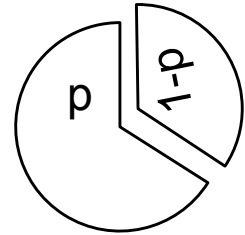


(d)  $x = ((x_1, y_1, \phi_1, \sigma_1), \dots)$

$$T(x) = \{T_1(x^{(1)}), \dots, T_R(x^{(R)})\}, \quad R = \text{number of robots} \quad \bigcup_{i=1}^R T_i = T \quad T_i \cap T_j = \emptyset,$$

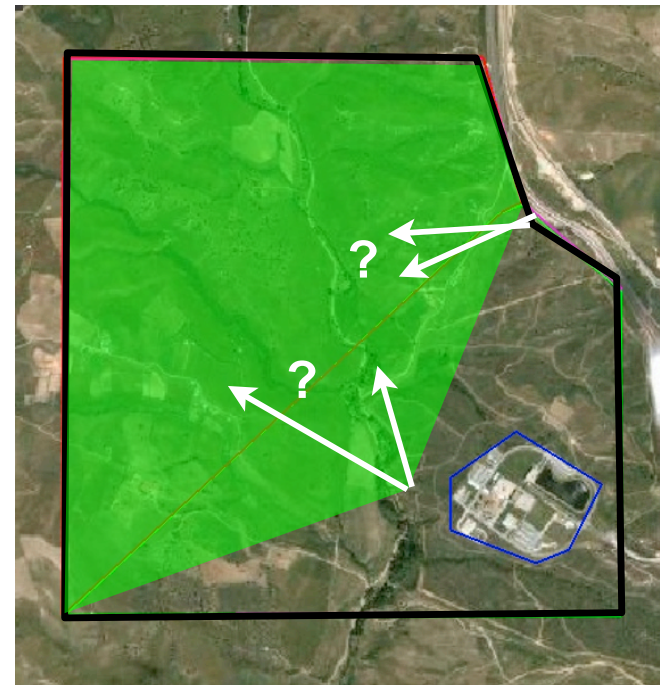
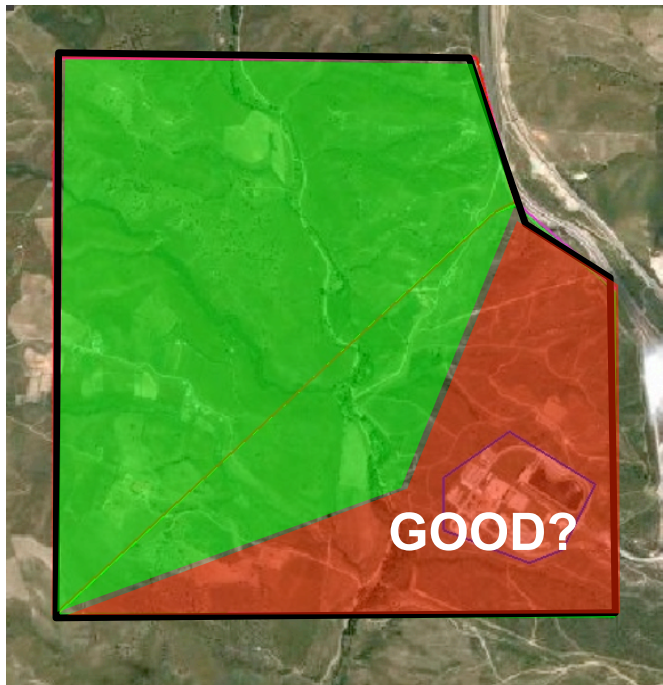


**Bargaining:** based on Rubinstein's uni-dimensional good alternate-offers protocol

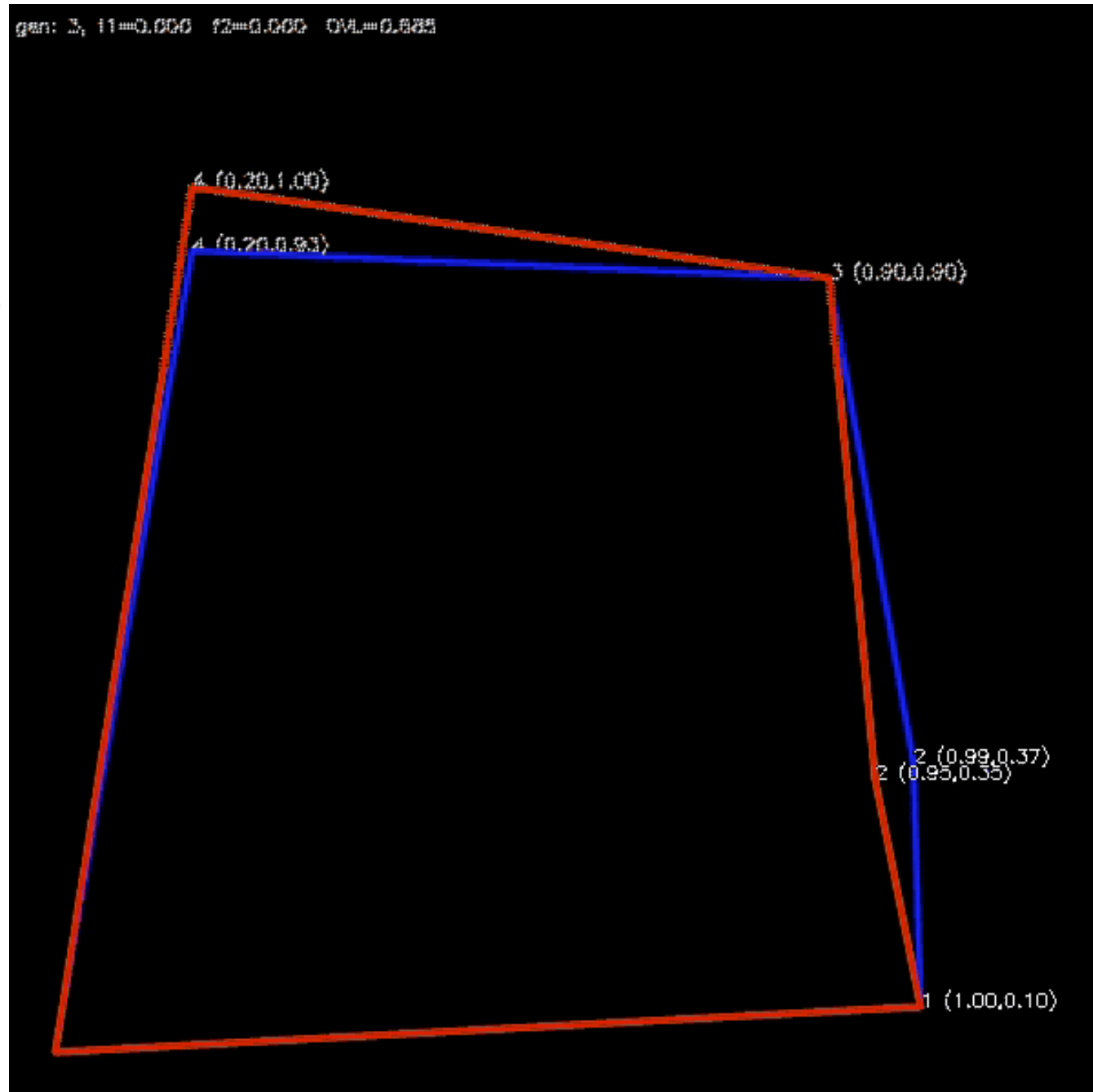


**Extension to n-dimensional goods:**

- ▶ Evaluate offer (search!)
- ▶ Search for good counter-offer



**Co-evolution !**

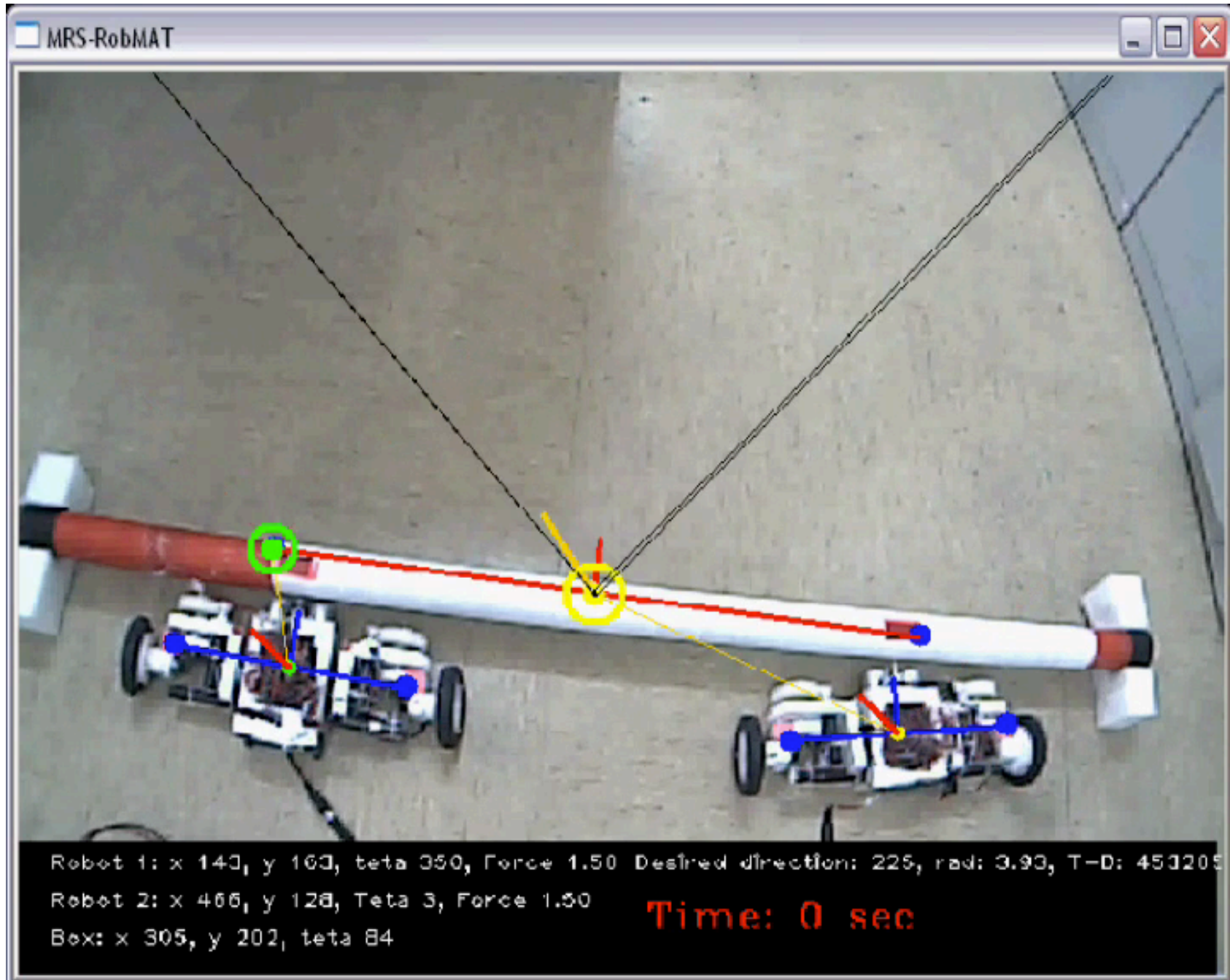


2x





3x





CAR

CENTRO DE AUTOMÁTICA Y ROBÓTICA

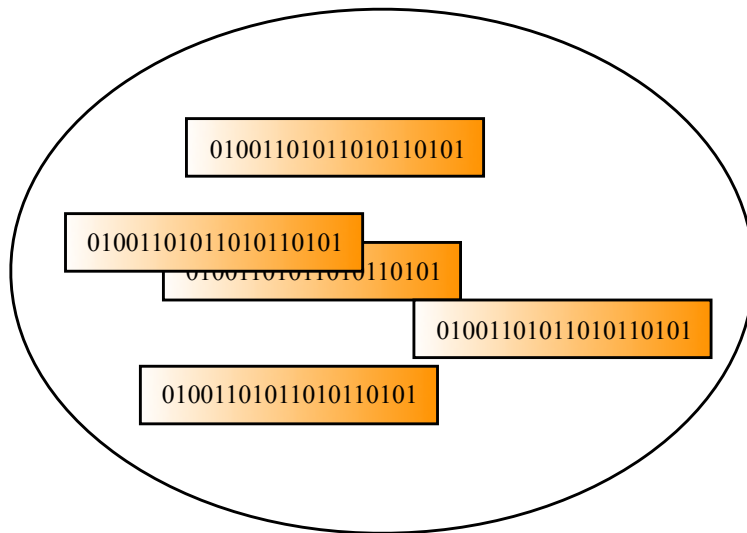
POLITÉCNICA

### 3. Evolutionary Robotics

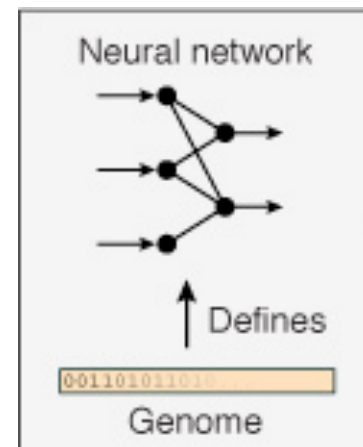
## EAs - evolutionary robot controllers (learning)

Much work on it !

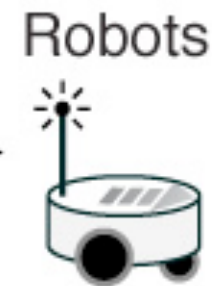
Population of candidate controllers (genotypes)



Instantiation (phenotype, e.g. neural network)



Evaluation (run!)



**Off-line, off-body**

#### Our approach:

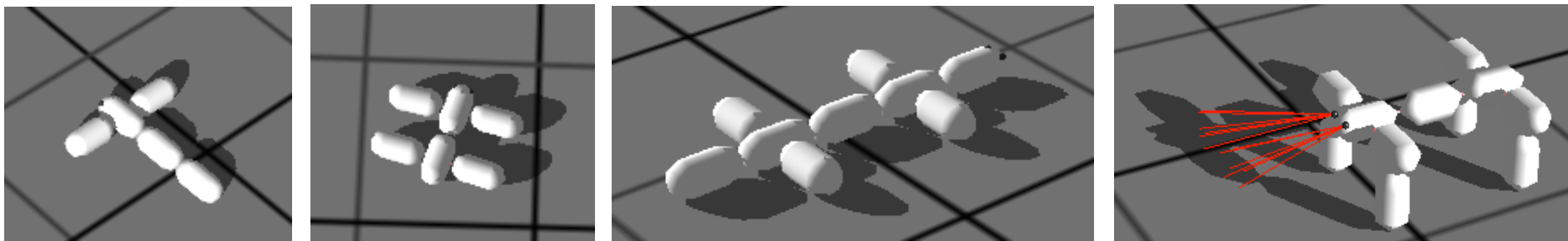
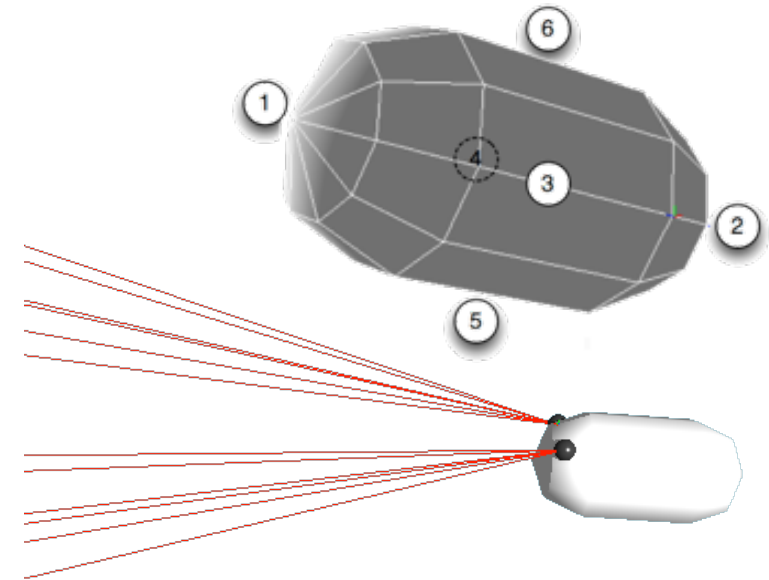
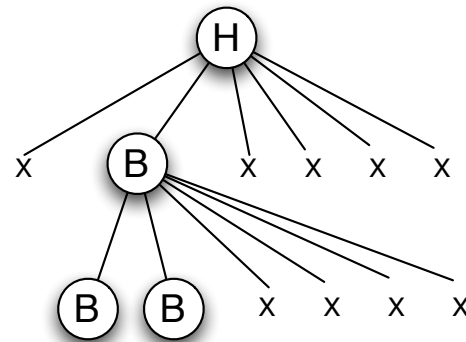
- ▶ On-line: an ecosystem of individuals (in a virtual world)
  - ▶ “Real” mating: new morphologies derived from crossing over
  - ▶ Newborns shall learn...
    - how to move
    - to find energy sources
    - to find mates
- ...before being released into the world (“robot school”, A.E. Eiben)
- 
- ▶ Open-ended evolution: robots just have to survive
    - ▶ but environment can be tailored to drive evolution towards desired behaviors

## Learning by evolving controllers for modular robots

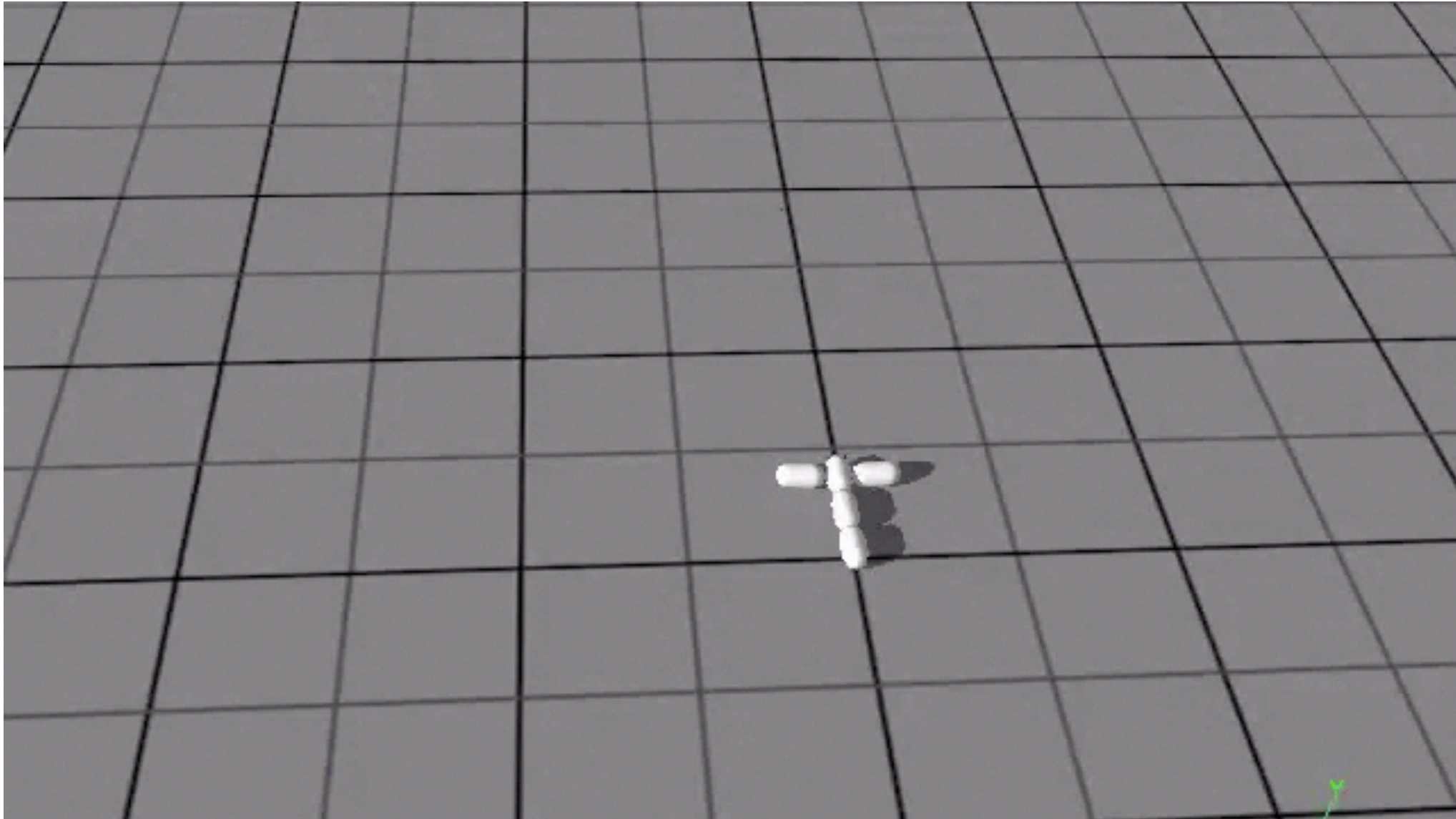
Modules:

- 6 connection points (front, rear, left, right, top, bottom), 2DOF
- Head: 2 range sensors

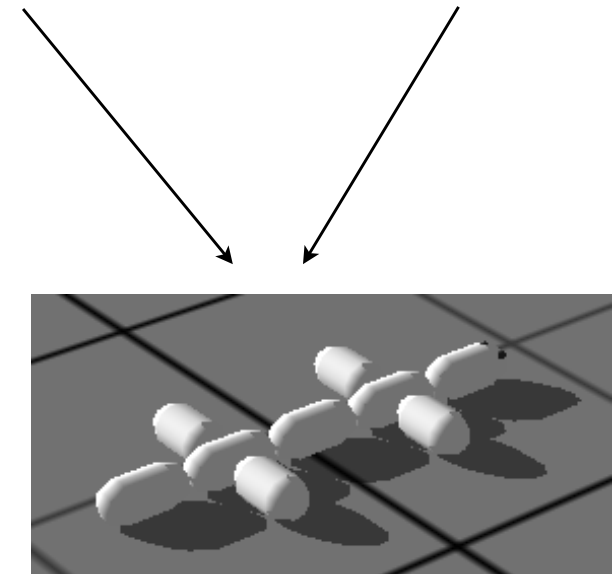
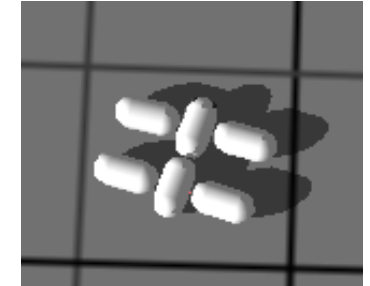
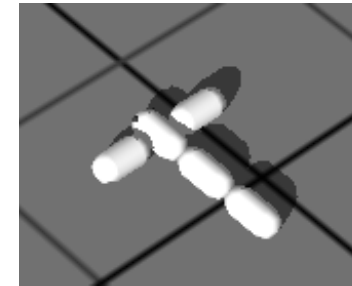
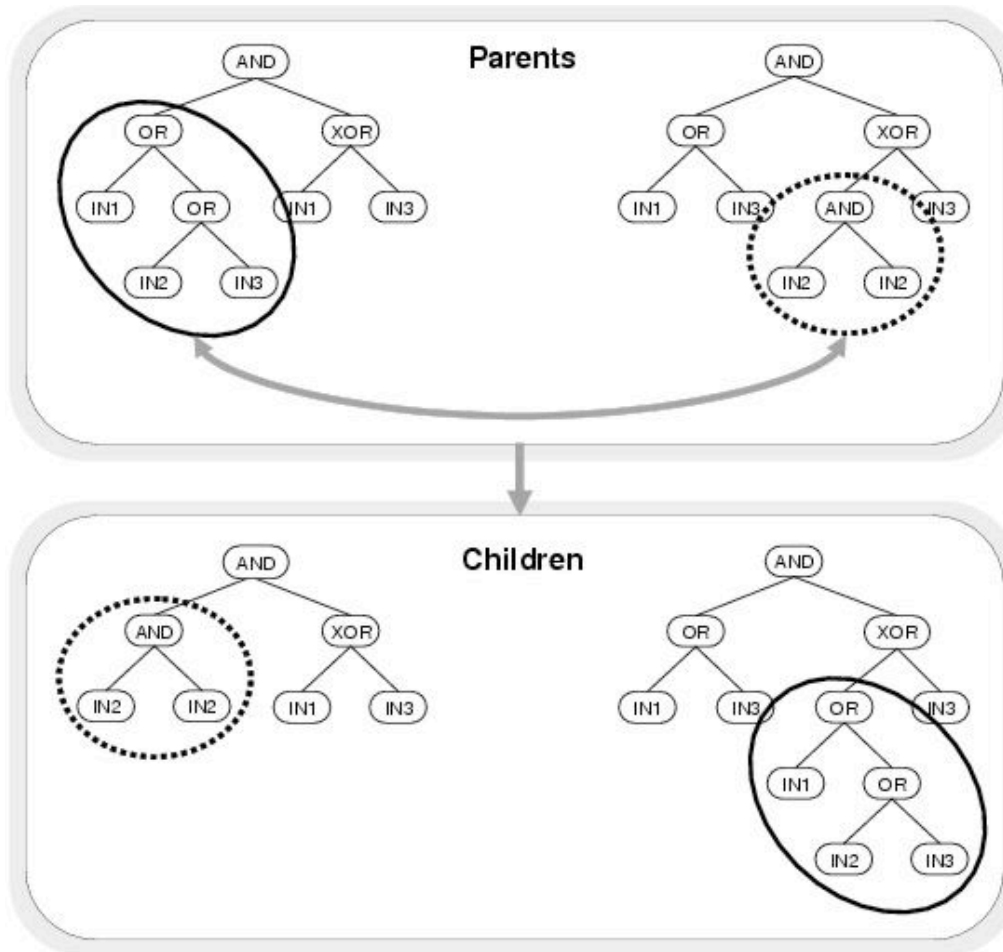
- Encoding: tree



## Phase 1: individual learning



## Phase 2: morphology crossover (in progress!)

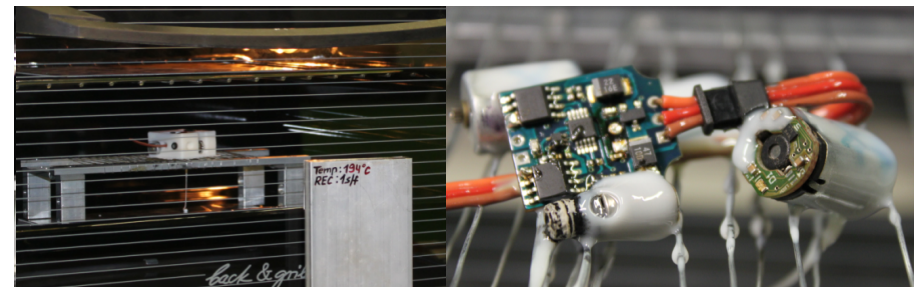


## Evobody (EU FET Proactive Initiative SA on AWARENESS)

Also discussed in EVLIT

### “Embodied evolution”

- Towards self-replicating non-biological systems
- Use e.g. of 3D printing on-the fly, plus basic actuators/sensors modules
- Recycling of materials and building blocks (“closed ecosystem”)



Genotype → blueprint

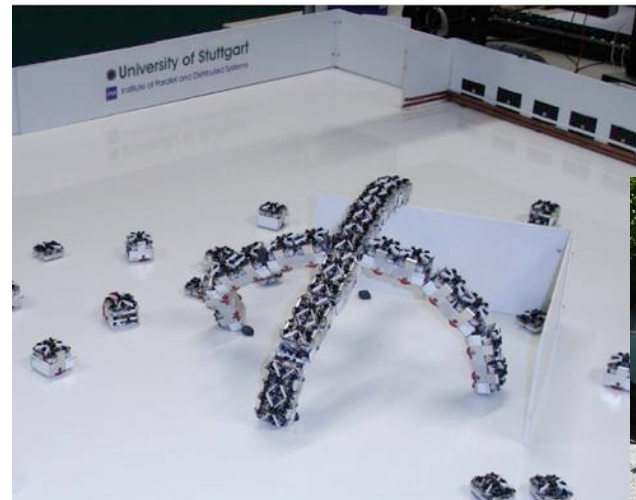
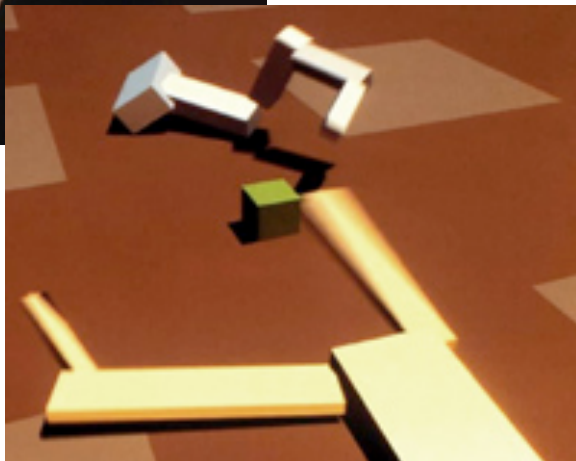
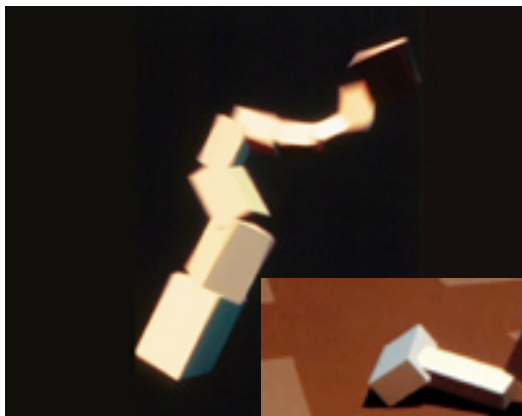
Phenotype → physical agent (i.e. “robot”)

-- more in general, “evolution of “things”

## EAs - evolutionary modular robots

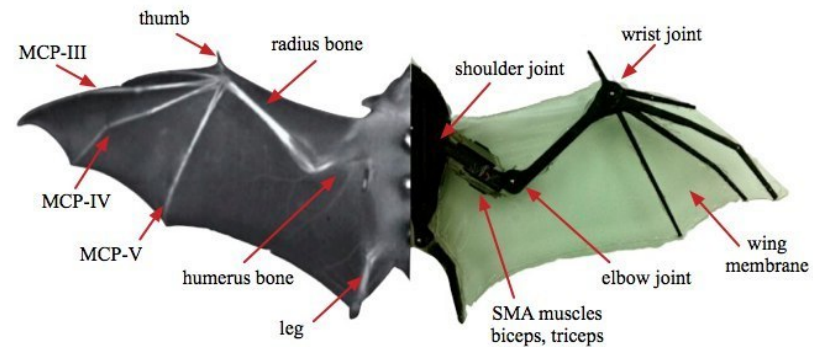
Again, a **lot** of work done and on-going

- Sims: evolved virtual creatures (1994!)
- Replicator/Symbion: evolution of symbiotic multi-robot organisms
- J. Bongard (on the role of morphology)
- SwarBots (evolution of cooperation)



- C. Rossi, M. Abderrahim, J. C. Diaz, "EvoPose: A Model-based Pose Estimation Algorithm with Correspondences Determination", IEEE ICMA (Int. Conf. on Mechatronics and Automation), Niagara Falls, Ontario, Canada. 2005.
- J.C. Diaz, M. Abderrahim, C. Rossi, "Satellite Relative Navigation based on Visual Feedback", 8th International symposium on Artificial Intelligence, Robotics and Automation in Space (SAIRAS), Munchen, Germany. 2005.
- J.C. Diaz, M. Abderrahim, C. Rossi, M.A. Salichs, "Experimental Simulation of Satellite Relative Navigation Using Computer Vision", 2nd International Conference on Recent Advances in Space Technologies, Istanbul, Turkey, 2005.
- C. Rossi, M. Abderrahim, J.C. Diaz, "An Evolutionary Algorithm for Model-based Object Pose Estimation and Tracking", IEE International Conference on Visual Information Engineering, Glasgow, UK, 2005.
- Claudio Rossi, Antonio Barrientos, Leyre Aldama, "Simultaneous Task Subdivision and Allocation using Negotiations in Multi-robot Systems", International Journal of Advanced Robotic Systems, 2015
- C. Rossi, L. Aldama, A. Barrientos, "Simultaneous Task Subdivision and Assignment for Teams of Heterogeneous Robots", International Conference on Robotics and Automation (ICRA), Kobe, Japan, 2009.
- C. Rossi, L. Aldama, A. Barrientos, "Negotiation of Target Points for Teams of Heterogeneous Robots: an Application to Exploration", IEEE International Conference on Intelligent Robots and Systems (IROS), St. Luis, MO, USA, 2009.
- José Baca, Prithvi Pagala, Claudio Rossi, Manuel Ferre, "Modular robot systems towards the execution of cooperative tasks in large facilities", Robotics and Autonomous Systems 01/2015 (in press).
- C. Rossi, A.E. Eiben, "Simultaneous versus Incremental Learning of Multiple Skills by Modular Robots", Evolutionary Intelligence, Volume 7, Issue 2, 2014.
- C.Rossi, D. Pérez-Moneo Suárez, "Evolutionary learning of basic functionalities for snake-like robots", ROBOT 2013, Madrid, Spain, November 2013.
- Dámaso Pérez-Moneo Suárez and Claudio Rossi, A comparison between different encoding strategies for snake-like robot controllers, 15th European Conference on the Applications of Evolutionary and bio-inspired Computation (EvoApplications, EVOSTAR2013 conference), Vienna, Austria, April 2013.

Thanks !



## CONTACT

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