UNIVERSITÄT LEIPZIG

Self-organization of sensorimotor coordination

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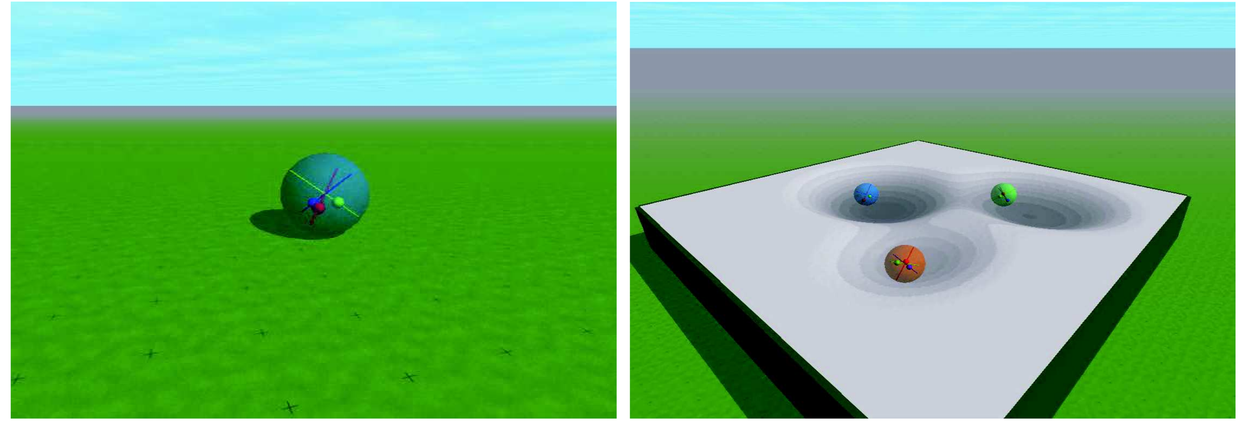
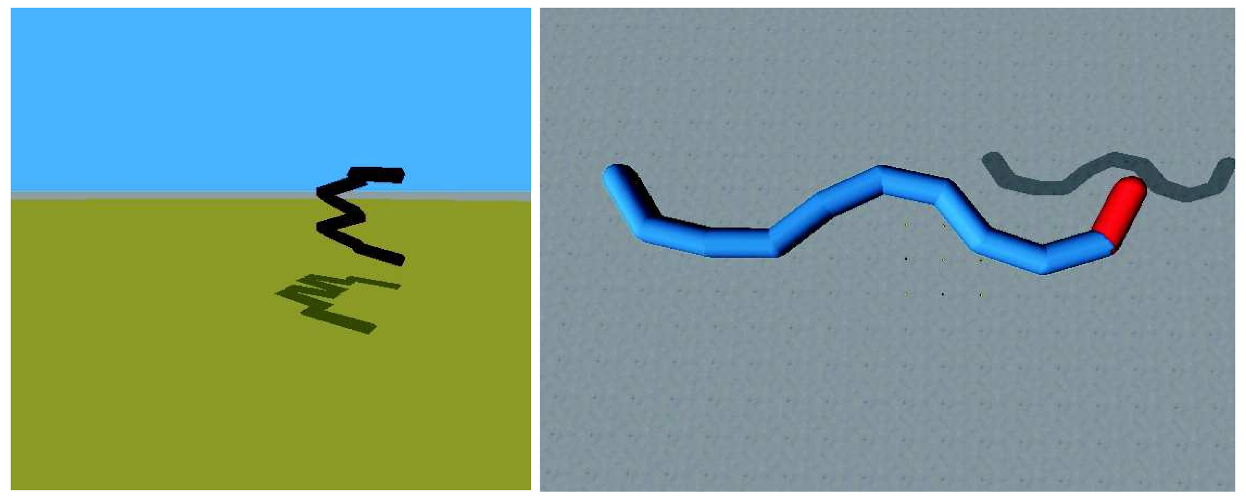


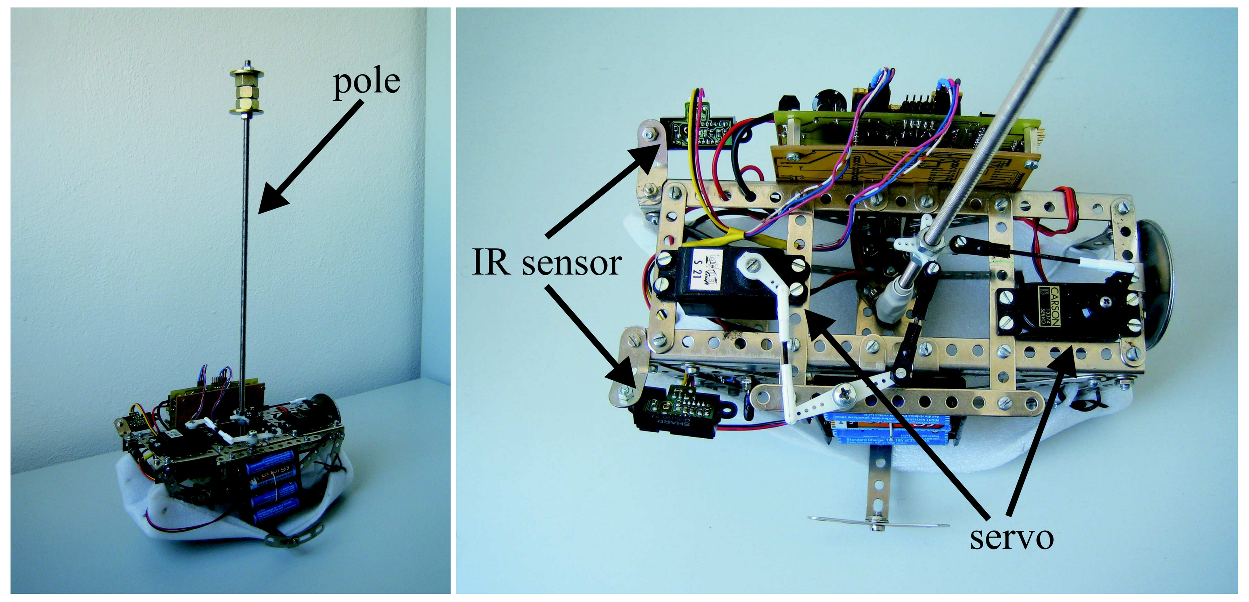
Spherical Robots - inspired by Julius Popp

The sphere is driven by moving internal masses situated on three orthogonal axes. Sensor values are the projections of the internal axes on the z-axis of the world coordinate system. Motor values are the position of each of the masses on its axis. Both sensor and motor values are related to the motions of the sphere in a very complicated manner. Nevertheless in the experiments the spheres roll long distance, can stop and turn. In the wells of the landscape (right) the spheres even roll circles at constant heights or escape. The behaviors manifest the emerging sensorimotor coordination.



Multidimensional Systems (see [2])

Our "snakes" consist of six up to twenty segments connected by either one- or two-dimensional joints (makes up to forty motors to control). Only proprioceptive sensors (angular velocities) are used in the simulation. So no information about the angles, the masses and geometry of the body, or other environmental observables is available to the controller. During the experiments collective modes of behaviors emerge, like opening and closing motions, crawling or jumping.



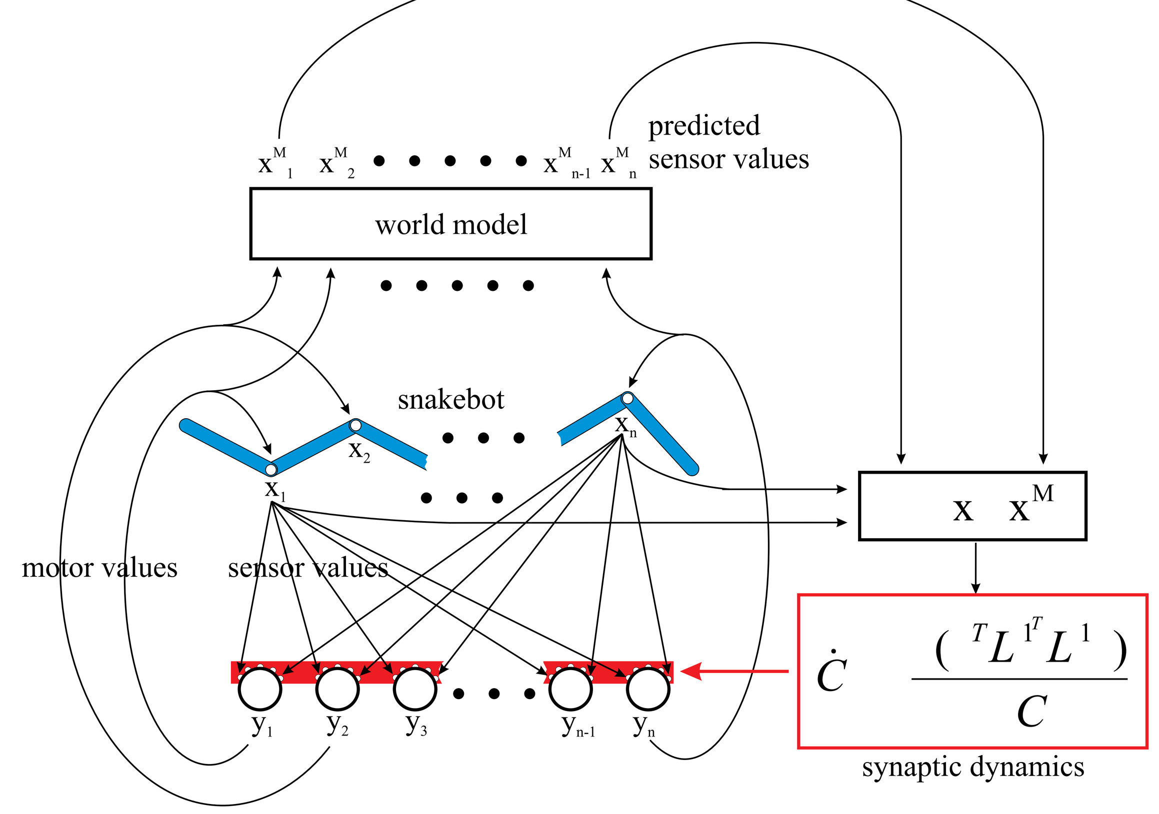
Rocking Stumper (see [2])

The stumper consists of a trunk with a pole driven by two servomotors. Controller outputs are the angles of the pole relative to the trunk. The two (or four) infrared sensors are looking downward and are only coarsely related to the motions of the body. Nevertheless our algorithm is able to close the sensorimotor loop and produce oscillations leading to rocking or walk-like modes of behavior. So the sensorimotor coordination (manifested by the arising oscillations) is achieved on the basis of extremely unreliable information.

Between Sensitivity and Predictability
- A Route to Self-Organization -

We consider robots controlled by a neural network with fast synaptic plasticity. The dynamics for the parameters c of the network are derived from the following requirements to the behavior of the robot:

1. Maximum sensitivity to current sensor values. This induces a self-amplification of changes in the sensor values and thus is the source of activity.
2. Maximum predictability of future sensor values. This keeps the behaviour in "harmony" with the physics of the body and the environment.



Sketch of overall system for the case of a snakebot

The resulting behaviors are a compromise between these two antagonistic objectives. Starting from a "do nothing and know nothing" initialization each robot is seen to develop behaviors of its own related to its body and the interactions with the environment.

Technical Details:

The synaptic dynamics is realized by a gradient descent

$$c \qquad \frac{\quad}{c} E$$

on the error function E given by the weighted matrix norm

$$E \qquad {}^{T} L^{1^T} L^{1}$$

where c is any synaptic strength and L is the Jacobian matrix of the sensorimotor loop

$$x_{t\ 1} \qquad x_t \qquad {}_t$$

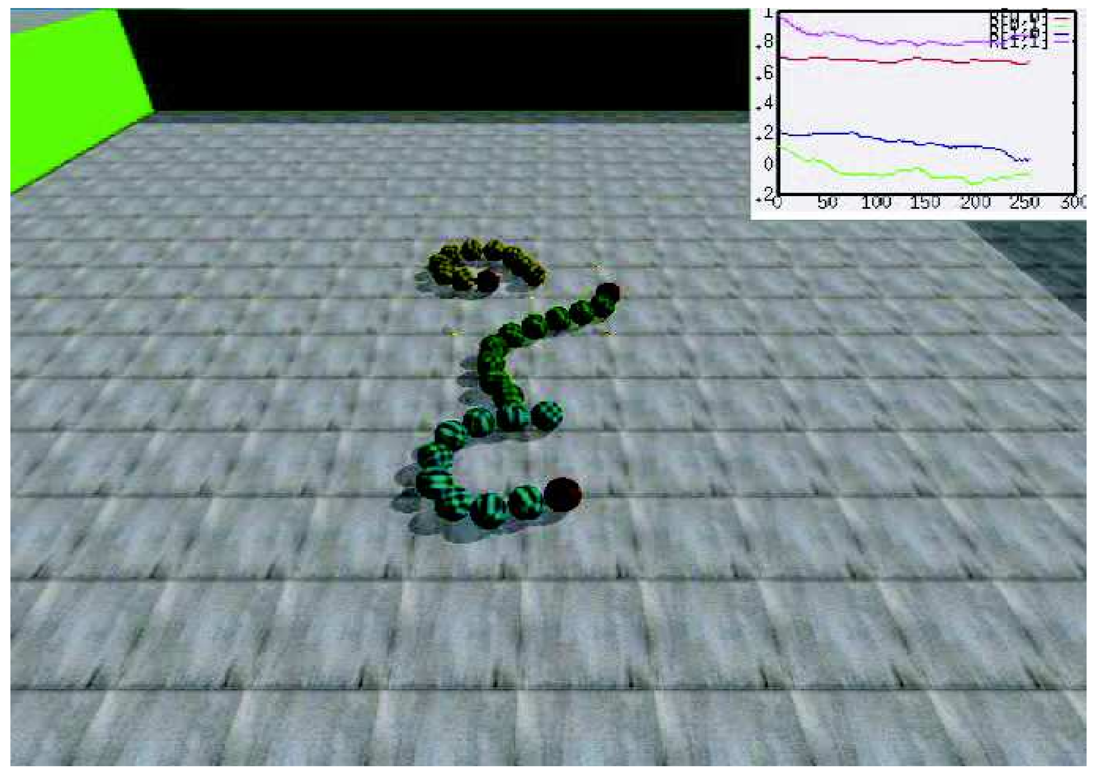
with $x_t \quad R^n$ being the vector of sensor values at time t, and $\quad : R^n \quad R^n$ is the model of the sensorimotor dynamics comprising both the world model and the controller.

Since L occurs in the denominator and in the nominator minimizing E corresponds indeed to the maximization of both the instability (=sensitivity) and the predictability of the perception-action cycle, see [1], [2] for details.

[1] R. Der, F. Hesse, and R. Liebscher.
Contingent robot behavior generated by self-referential dynamical systems.
Autonomous robots, submitted, 2005

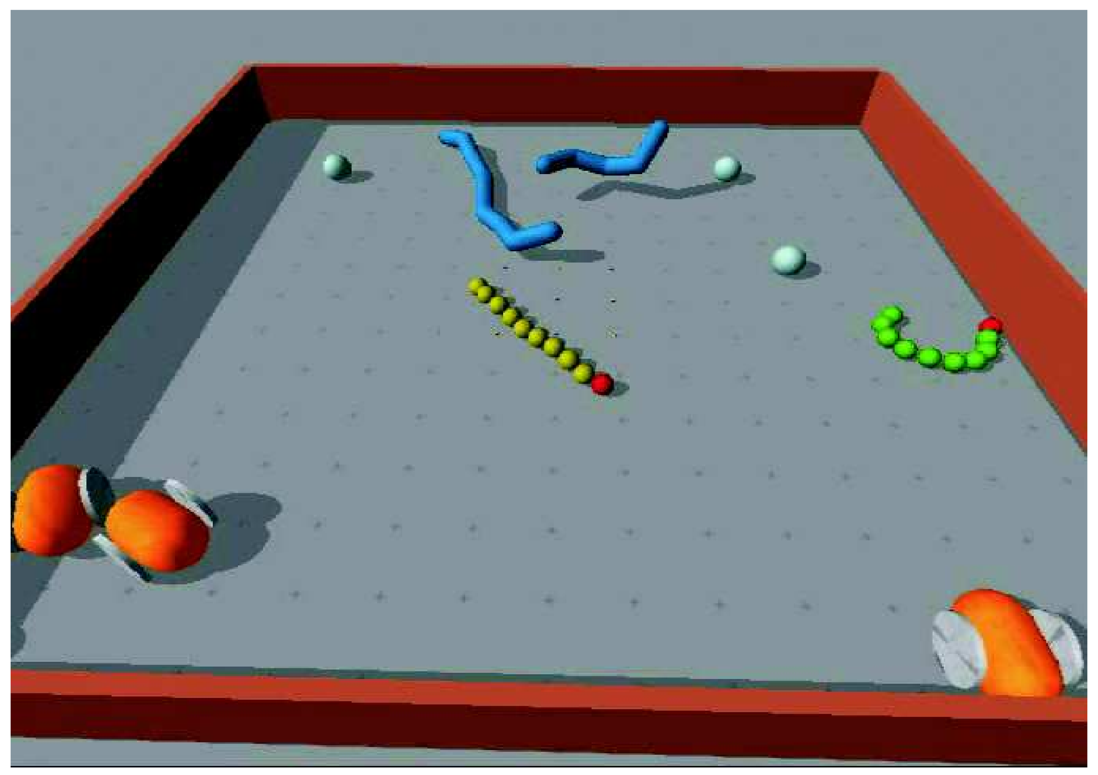
[2] R. Der, F. Hesse, G.Martius: Rocking stumper and jumping snake from a dynamical system approach to artificial life.
Proc. ECAL2005, Canterbury, Kent(UK)

[3] R. Der, F. Hesse, R. Liebscher: Self-organized exploration and automatic sensor integration from the homeokinetic principle.
Proc. SOAVE04, Ilmenau 2004



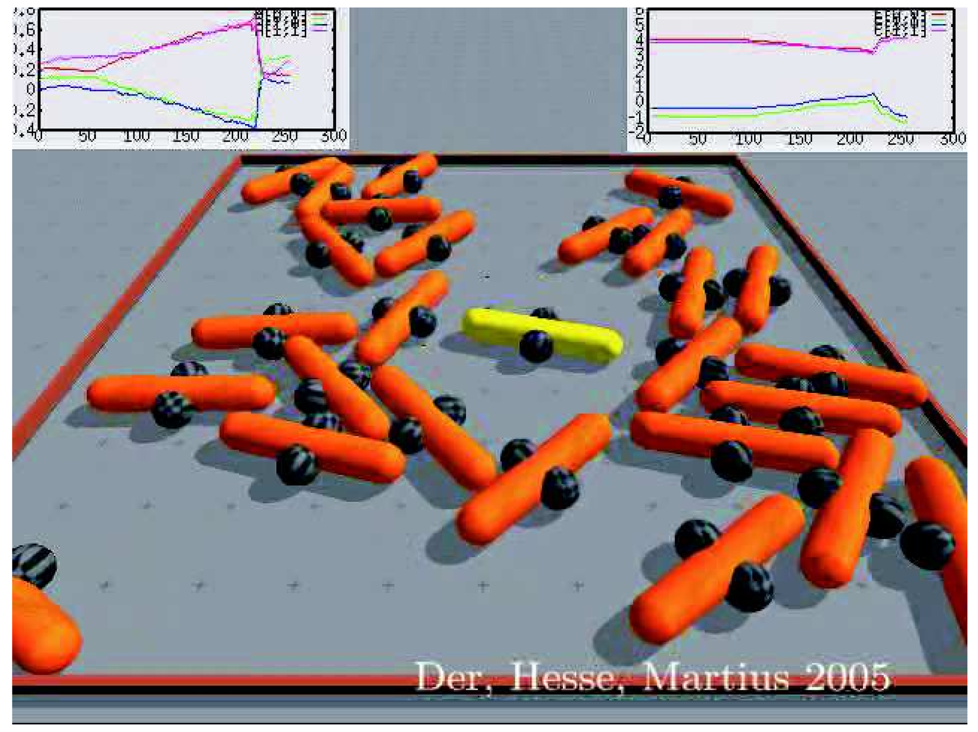
Skidding Snake

This creature consist of a string of spheres with an active head. The force driving the head is so weak that only rolling lateral motions are possible. Nevertheless, after some time the controller develops a "feeling" for the swaying of the body. So it can drive the snake into a rotational mode. These modes appear and decay repeatedly in the course of time but are also stable against perturbations by the environment or other agents.



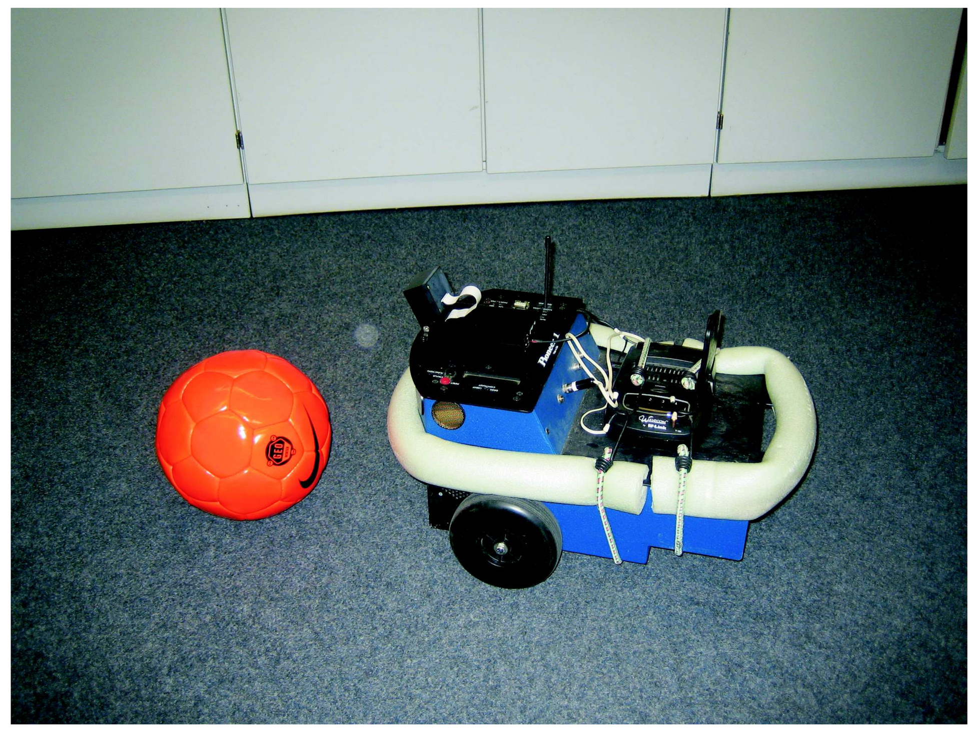
The Zoo

All creatures are controlled by our algorithm, the differences being only in the number of controller neurons, the quality of sensors and technical details. Each of the agents develops a behavior of its own which is emerging from the interplay of its body with the environment. Behaviors are relatively stable despite heavy interactions with the obstacles in the arena and with other agents. The latter kind of interactions makes the zoo a highly dynamic environment.



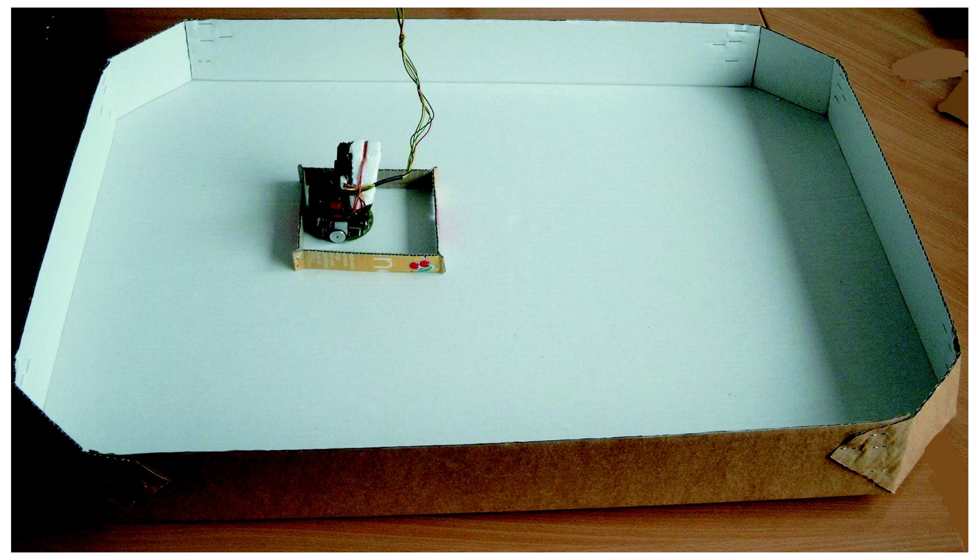
The Havanna Case

An overcrowded arena with each wheeled cigar controlled by our algorithm individually. The wheel counters are the only sensors. The vehicles show an explorative but sensitive behavior and do not get stuck even in very long runs.



Playing Ball

In addition to the wheel velocities the velocities of the ball in the camera plane are used as sensors. The algorithm forces the closing of the sensorimotor loop over the camera and so an explorative behavior with a ball playing mode is generated.



Acting by Understanding (see [3])

In the experiments with the Khepera robot we use both the infrared sensors and the wheel counters. In the beginning the world model has not yet learned the reactions of the IR sensors so that the robot seemingly is "scared" of the moveable box. However, with each sensor activation its predictions improve, and with increasing understanding of the world the robot becomes more "brave" and starts pushing the box. After some time it moves the box through the whole playground but still changes direction when colliding with fixed walls since these produce

printed at the computer center of Leipzig University