Emerging behavior of autonomous agents

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Aims

- Creation of machines with emerging capabilities by exploiting the general principles of self-organization as known from natural sciences.

- In the RoboCup domain: Exploration of cluttered environments and playing ball as emerging phenomena.

The nature of self organization

Physics: The conflict between

the global constraints of a system

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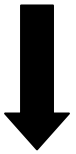
self-amplification of constraint breaking fluctuations



Emergence of new spatio-temporal modes of behavior by spontaneous symmetry breaking

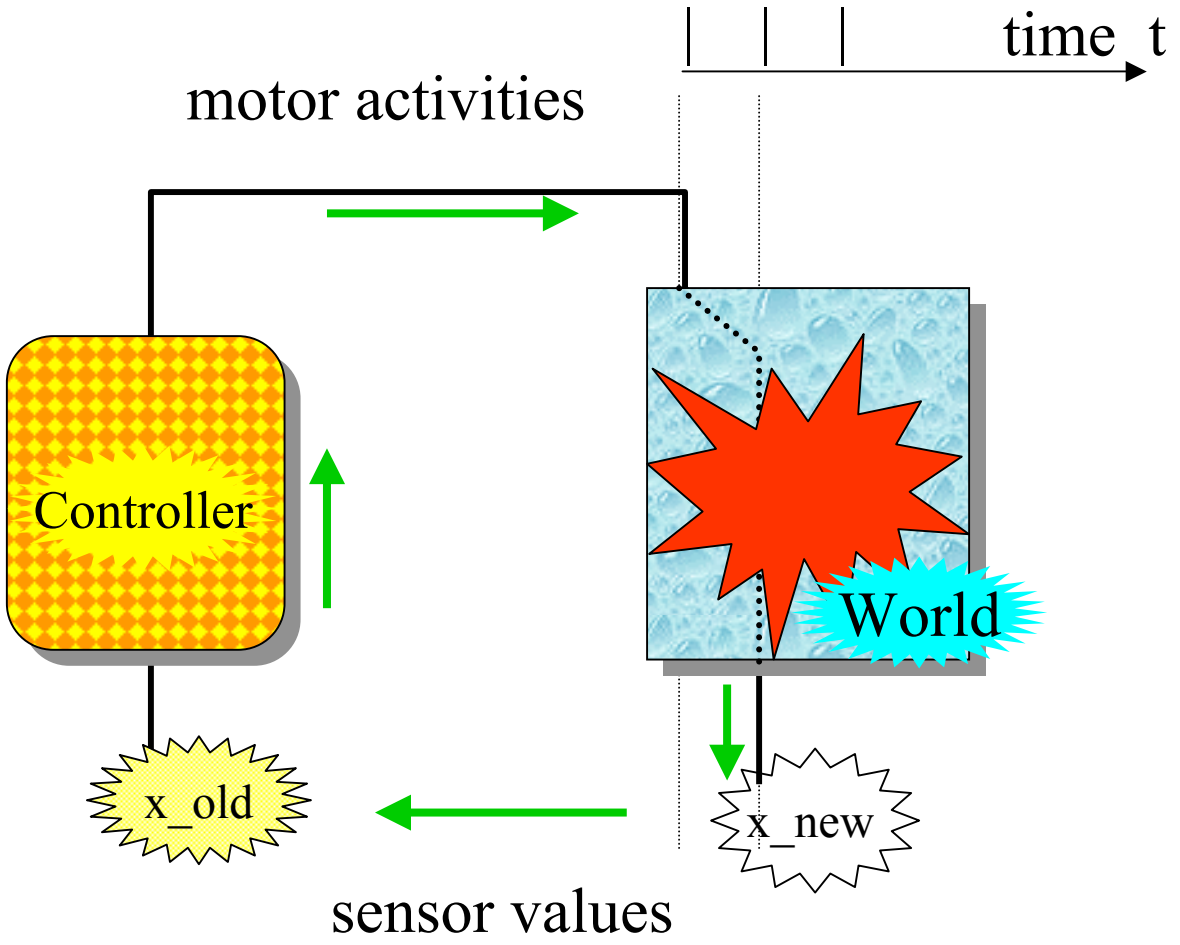
Our aim: Behavior of artificial beings as spatio-temporal modes of a self-organizing system

Self-organization by way of autonomous learning

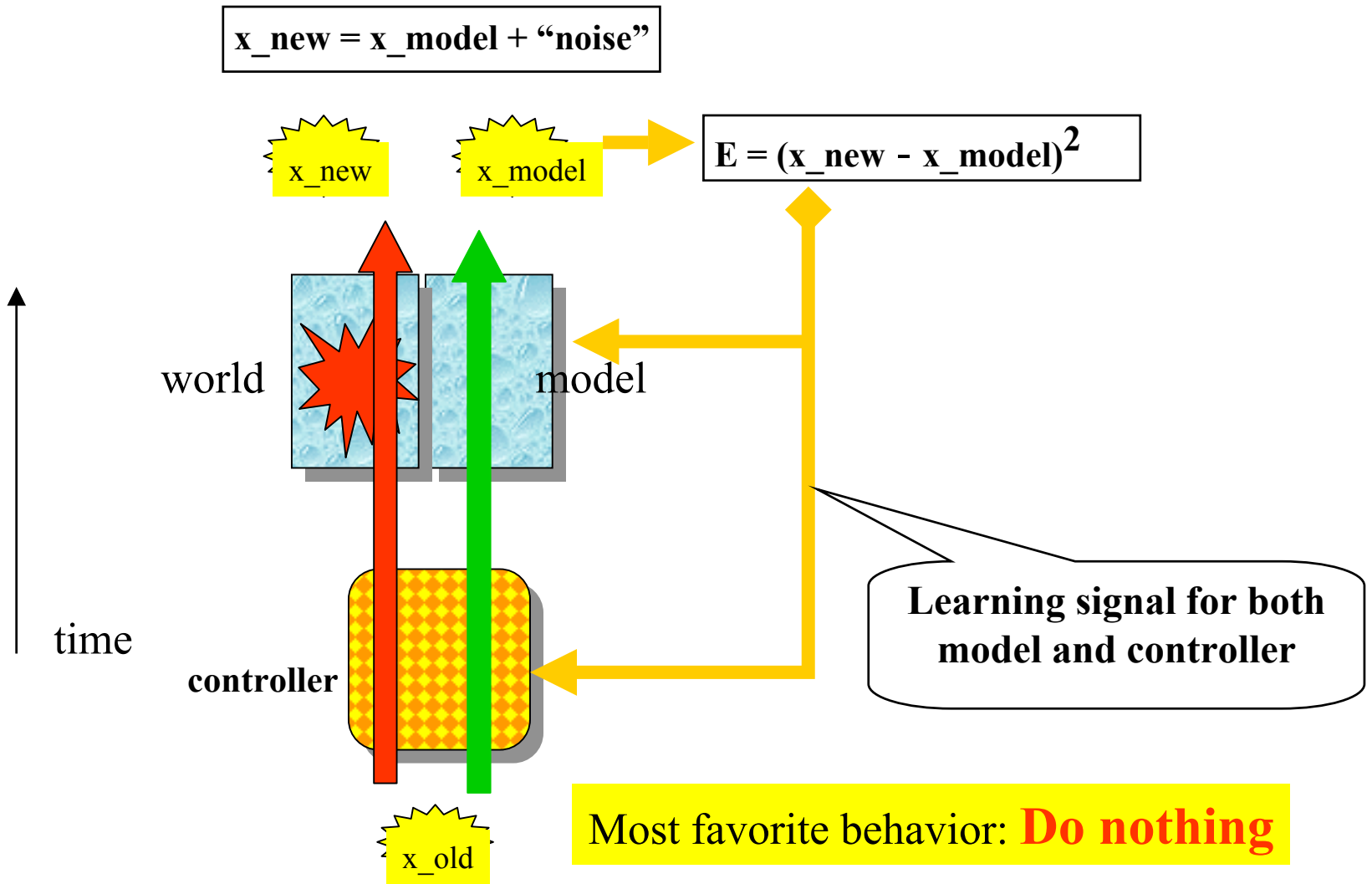
- **Autonomous learning:** Supervised learning of the controller with learning signals generated by principles completely internal to the agent.

- **Our approach**: Minimize the error between model and true behavior.
- Behavior model is an adaptive model of the dynamics of the sensorimotor loop.

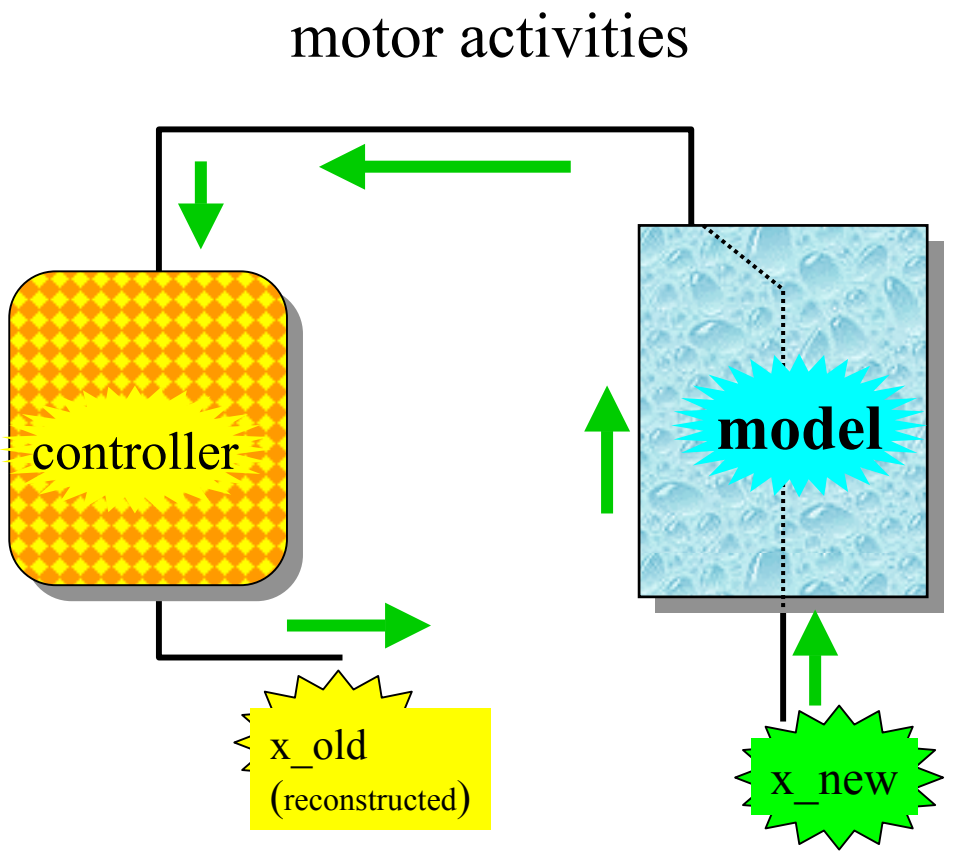
The sensorimotor loop



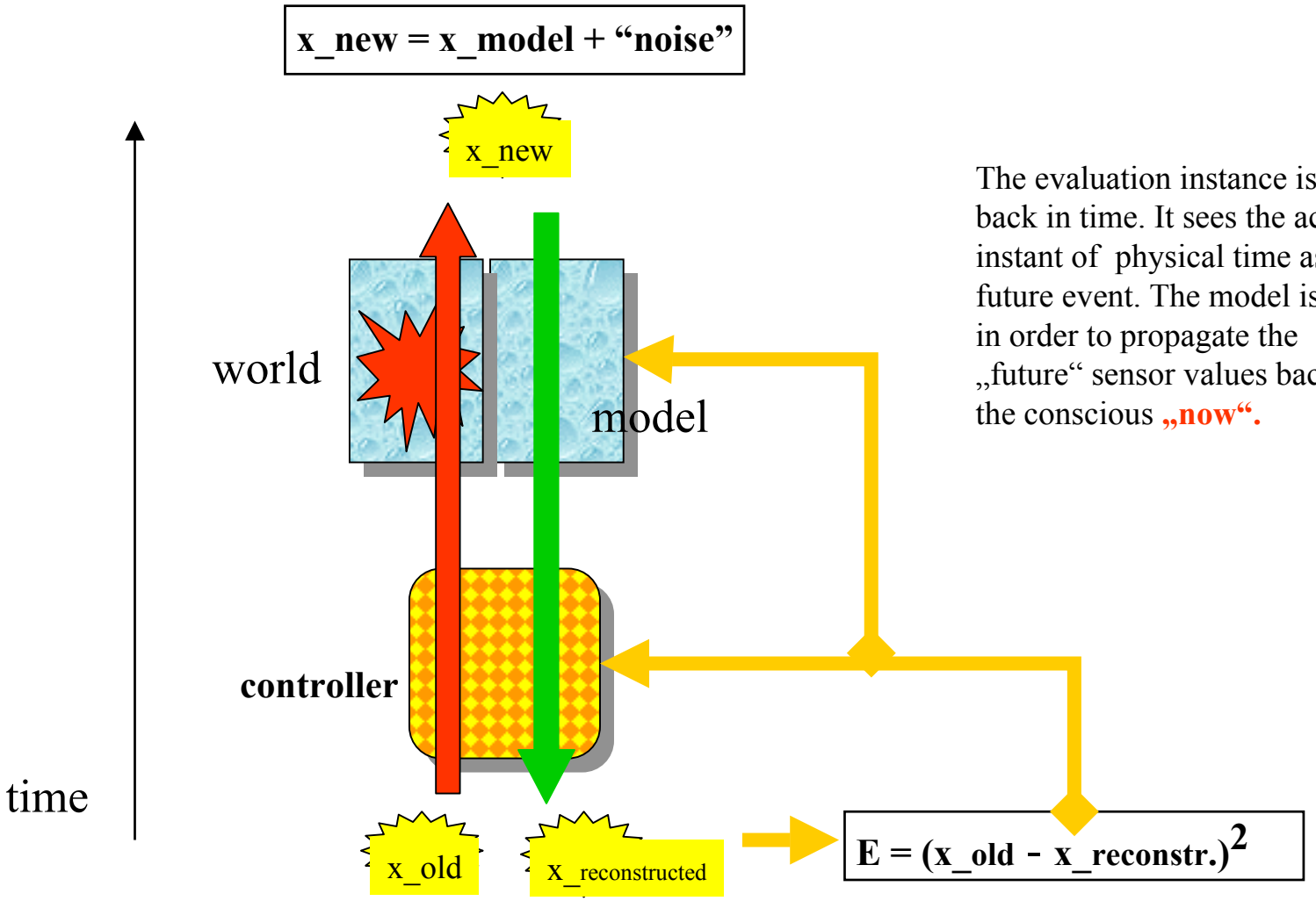
Modeling forward in time



The time inverted sensor-motor loop

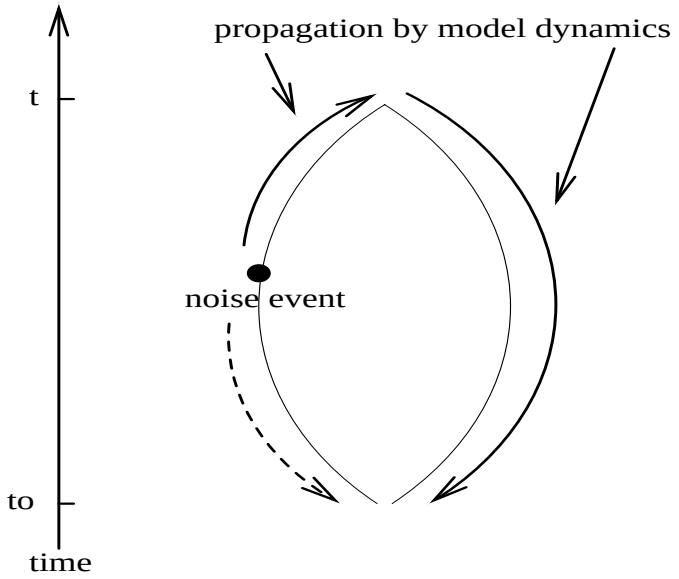


Modeling backward in time – The time loop



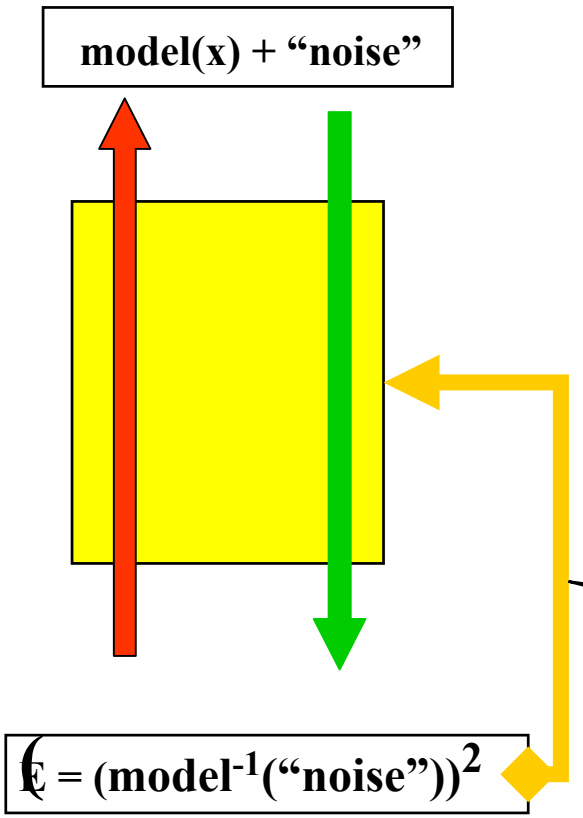
The evaluation instance is set back in time. It sees the actual instant of physical time as a future event. The model is used in order to propagate the „future“ sensor values back to the conscious **„now“.**

The time loop effekt drives self-organization



The time loop effect. In the linear approximation the full dynamics (left branch of the time loop) can be viewed as the superpositon of noise events which are propagated from the time t_n of the event to the current time t by the model dynamics. Then the result is propagated back from t to the reference time t□ by the model dynamics again. Since the model dynamics forward and backward in time cancel the net effect is a propagation backward in time from t_n to t□ (dashed arrow).

Behavior from minimizing the time loop error



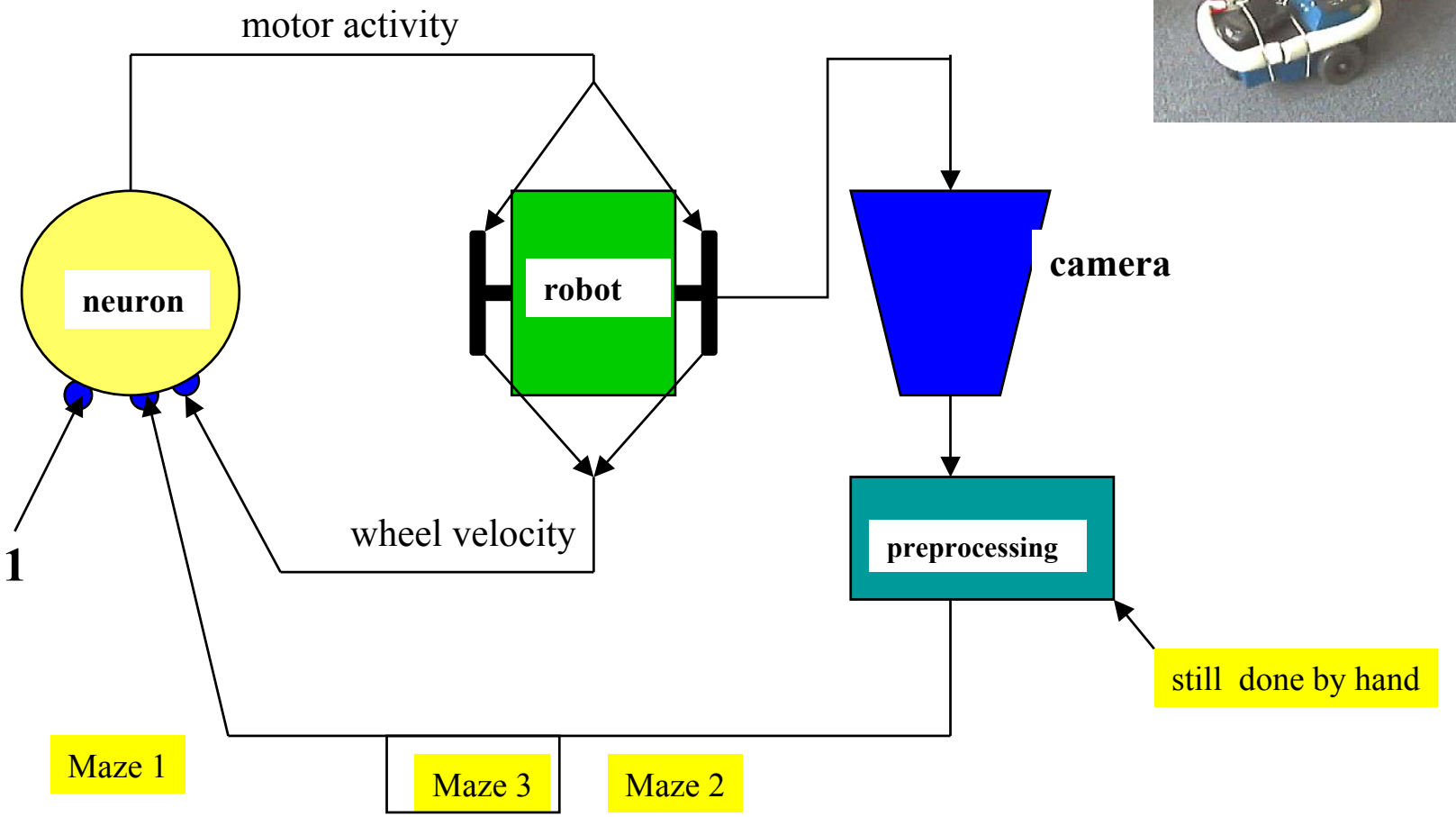
- **Backward in time the „noise“ is damped if behavior is instable so that the learning dynamics generates activity in the sensorimotor loop by self-amplification of fluctuations.**

- **On the other hand the „noise“ is the larger the more irregular the behavior.**

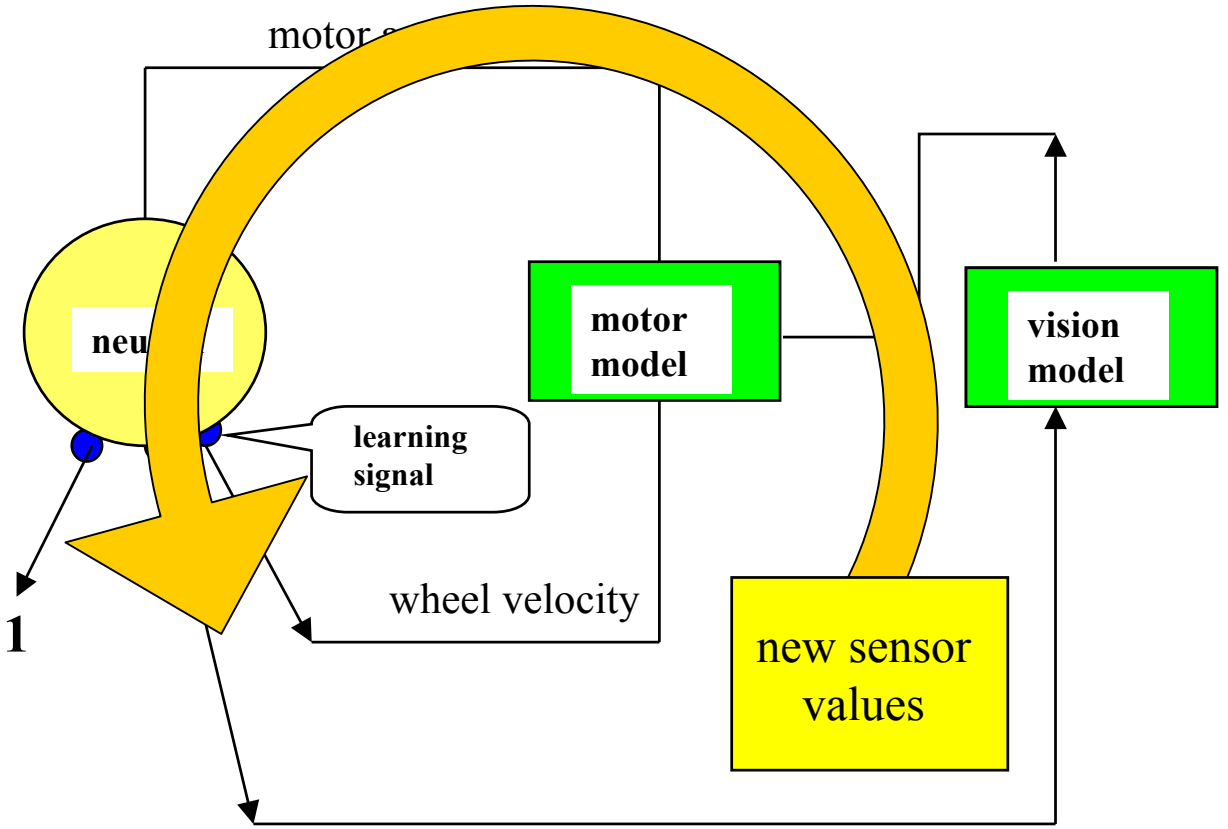
- **The balance of the two effects fosters the emergence of domain related activities of the agent.**

Learning signal for both model and controller

Sensorimotor loop in the robot domain



The time loop effect enforces sensorimotor integration



Further steps

- Self-organized sensor fusion (second phase of the project). „Straightforward“ since the time loop effect enforces sensorimotor integration.
- Combination with the distal learning (Jordan and Rumelhart) paradigm.
- Combination with reinforcement learning and evolution strategies.

These approaches based on the fact that the present behavior explores the sensorimotor capabilities of the agent so that a wealth of behavioral primitives related to specific domain related situations are emerging. By cataloguing these behavior primitves behavior space is built on which more complicated intentional (conscious) behaviors may be grown.