# Information driven self-organization of complex robotic systems

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In recent years, information theory has come into the focus of researchers interested in the sensorimotor dynamics of both robots and living beings. One root for these approaches is the idea that living beings are information processing systems and that the optimization of these processes should be an evolutionary advantage. Apart from these more principal questions, there is much interest recently in the question how a robot can be equipped with an internal drive for innovation or curiosity that may serve as a drive for an open ended, self-determined development of the robot.

The success of those approaches depends essentially on the choice of a convenient measure for the information. This paper studies in some detail the use of the predictive information (PI), also called excess entropy or effective measure complexity, of the sensorimotor process. The PI of a process quantifies the total information of past experience that can be used for predicting future events. However, the application of information theoretic measures in robotics mostly is restricted to the case of a finite, discrete state-action space.

This paper aims at applying the PI in the dynamical systems approach to robot control. Building on earlier work on linear systems[1], we study general nonlinear systems and derive exact results for the PI together with explicit learning rules for the parameters of the controller. Interestingly, these learning rules are of a Hebbian like nature and local in the sense that the synaptic update is given by the product of activities available directly at the pertinent synaptic ports. The derived learning rules are more simple than those of the homeokinesis approach[2] but produce similar results at the behavioral level.

The general findings are exemplified by a number of case studies. In particular, we observe spontaneous cooperativity in complex physical systems with decentralized control. Furthermore, in a hexapod system, complex motion patterns are observed which demonstrate a high degree of sensorimotor correlation emerging without giving explicit goals. With a humanoid robot on a swing and in a "Rhoenrad", we observe the automatic integration of exteroceptive sensors into the sensorimotor feed-back loop demonstrating the emergence of a "feeling" for dynamical contexts. Quite generally, we argue that maximizing the PI means to recognize and amplify the latent modes of the robotic system. The examples show that the learning rules derived from the maximum PI principle are a versatile tool for the self-organization of behavior in complex robotic systems.

# References

[1] N. Ay, H. Bernigau, R. Der, and M. Prokopenko. Information driven self-organization: The dynamical systems approach to autonomous robot behavior. *Theory Biosci., to appear*, 2011.

[2] R. Der and G. Martius. *The Playful Machine - Theoretical Foundation and Practical Realization of Self-Organizing Robots*. Springer, 2012.