# A Primer on Embodiment – On the Interaction of Brain, Morphology, Materials, and Environment in Adaptive Behavior

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**Abstract**

Traditionally, in artificial intelligence, neuroscience, and robotics there has been a focus on the study of the control or the neural system itself. Recently there has been an increasing interest into the notion of embodiment in all disciplines dealing with adaptive behavior, including psychology, philosophy, and linguistics. In this tutorial, I introduce the basic underlying principles of embodiment and explore its far-reaching and often surprising implications. While embodiment has often been used in its trivial meaning, i.e. „intelligence requires a body“, there are deeper and more important consequences, concerned with connecting brain, body (morphology, materials), and environment, or more generally with the relation between physical and information (neural, control) processes. A number of principles will be introduced that characterize embodied systems. For example, morphology and materials can take over some of the functions normally attributed to control (the principle of “ecological balance”). Also, it can be shown that through the embodied interaction with the environment, in particular through sensory-motor coordination, information structure is induced in the sensory data, thus facilitating perception and learning (the principle of “information self-structuring”) which is an important way in which “the body shapes the way we think”, so to speak. A number of case studies are presented to illustrate the concepts introduced. Moreover, a basic theoretical framework for the study of intelligent adaptive systems is introduced.

**Reading**

Rolf Pfeifer and Josh Bongard (2007). How the body shapes the way we think – a new view of intelligence. Cambridge, Mass.: MIT Press.

Rolf Pfeifer, Max Lungarella, and Fumiya Iida (2007). Self-organization, embodiment, and bio-inspired robotics. Science, Vol. 318, 16 November 2007, 1088-1093.

## Tutorial description

**Target audience**

Interdisciplinary for students, researchers, teachers, professionals from all areas, e.g. engineering, ethology, computer science, neuroscience, psychology, philosophy, material science, etc.

**Form**

- half-day tutorial, 3 lectures of 50 minutes; discussions with participants

**Contents**

*Lecture 1: Basic concepts of embodiment and morphological computation*

- traditional and embodied approaches to cognition
- prerequisites for a theory of intelligence (diversity-compliance, frame-of-reference, synthetic methodology, time perspectives, self-organization and emergence)
- morphological computation: introductory examples
- form of theory: design principles for intelligent systems
- summary

*Lecture 2: Design principles for intelligent systems*

- real worlds and virtual worlds
- properties of complete agents
- the quadruped "Puppy" as a dynamical system
- theoretical framework for intelligent behavior
- illustration of selected design principles:
  - self-organization and self-stabilization ("cheap design")
  - exploitation of interaction with environment
  - "parallel, loosely coupled processes"
  - "ecological balance"
  - morphological computation through reconfiguration
- summary

*Lecture 3: Completing the story*

- illustration of selected design principles (ctd.):
  - "cheap design" / redundancy
  - interaction of physical and information processes: sensory-motor coordination / information self-structuring
- development and high-level cognition
- evolution
- collective intelligence, modular robotics
- application areas (participants' choice, e.g. ubiquitous computing, human memory, designing business, companion robots)
- summary

**Short Bio**

M.Sc. in physics and mathematics and Ph.D. in computer science from the Swiss Federal Institute of Technology (ETH), Zürich. Three years as a post-doctoral fellow at Carnegie-Mellon University and at Yale University. Since 1987, professor of computer science at the Department of Informatics, University

of Zurich, and director of the Artificial Intelligence Laboratory. Visiting professor and research fellow at the Free University of Brussels, the Beijing Open Laboratory for Cognitive Science, the MIT Artificial Intelligence Laboratory, the Neurosciences Institute (NSI) in San Diego, and the Sony Computer Science Laboratory in Paris. 2003/2004: "21st Century COE Professor Information Science and Technology" at the University of Tokyo; the first global, fully interactive, videoconferencing-based lecture series "The AI Lectures from Tokyo" (with Tokyo, Beijing, Jeddah, Munich, Warsaw, and Zurich). Research interests: embodiment/embodied cognition, biorobotics, artificial evolution and morphogenesis, self-assembly and self-reconfiguration, and educational technology.

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