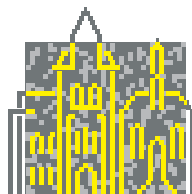


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## **Embodied Artificial Intelligence**

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Das Internationale Begegnungs- und Forschungszentrum für Informatik (IBFI) Schloss Dagstuhl ist eine gemeinnützige GmbH. Sie veranstaltet regelmäßig wissenschaftliche Seminare, welche nach Antrag der Tagungsleiter und Begutachtung durch das wissenschaftliche Direktorium mit persönlich eingeladenen Gästen durchgeführt werden.

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- Universität Stuttgart
- Universität Trier
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## Scientific highlights

One of the most significant achievements of the Dagstuhl Seminar on Embodied Artificial Intelligence is that a productive worldwide scientific community of the field has been formed, which consists of researchers from many different disciplines such as biology, neuroscience, robotics, computer science, and psychology. The diversity of backgrounds of the community member provides a broader perspective of the most significant open problems and challenges. In addition, the active contributions of the young researchers to the conceptual discussions confirm a promising development of the field toward the future.

One of the main highlights of the seminar was the oral and poster presentations followed by active discussions. The topics covered a range from the “low-level” topics such as materials for robot construction, neuron-cell activities, to the “high-level” conceptual issues of representation and consciousness. Particularly, the trend such as open-ended development of embodied agents leads to highly stimulating debates. Owing to the thoughtful, constructive and original comments and feedbacks by the leading researchers of various fields, every speaker and participant had a unique opportunity to look into not only technical details but also important conceptual issues underlying each research area. From the dynamics of the participants’ interactions, a number of interesting ideas have been generated, which provided excellent materials for the organized discussion sessions reported below.

In addition to the presentations, several emergent discussion sessions had been organized, where conceptual issues of design principles of intelligent agents, methodology/evaluation, and challenges toward the future were discussed. Although the results of these discussions is still somewhat inconclusive given the current developing stage of the field, we have reached a considerable level of consensus toward establishing the “Theory of Embodied AI”.

One of the central discussion topics for the design principles was the notion/definition of embodiment. The main questions were centered around how we could deal with the concept of “embodiment” in the simulated/real-world research, and how to conceptualize it in a theoretical domain.

Very briefly, some of the important aspects can be summarized as follows:

- (1) An embodied agent should physically interact with environments
- (2) An embodied agent should exploit the laws of physics
- (3) An embodied agent can structure the sensory information from the environment by properly exploiting the physical interaction.

For the future work, therefore, the design principles of “cheap design”, “ecological balance”, “sensory motor coordination” and “redundancy” should be the crucial issues. In this sense, a non-modularized design strategy of artificial systems, in other words “everything is connected to everything” fashion design, could be another aspect to be considered. This approach would lead to a more comprehensive understanding of the concept of embodiment.

Methodology and evaluation of the research contributions is particularly important for a successful development of the field. One of the essential strategies for a plausible

methodology/evaluation is to preserve the diversity of the studies, whereas some intensive research targets should be explored in parallel.

Examples are:

- (1) Repeatable robotic experiments
- (2) Comparative studies of embodied agents
- (3) Quantification of environments
- (4) Performance evaluation for the multiple-task systems.

Moreover, these methodology/evaluation criteria should be considered in the review process of the publications.

Some challenging research issues toward the future have been discussed. Given the common goal of the field is to understand the design principles for a general-purpose system, the current interest of research is mainly how to proceed the research in the direction of a significantly more complex agent which adaptively interacts with a dynamic environment. As one of the approaches toward tackling this problem, the open-ended development of embodied agents has been extensively discussed.

More clearly,

- (1) Open-ended evolution for the design of an artifact;
- (2) Evolution versus development (i.e. time-perspectives);
- (3) Rewards/value-systems that go beyond basic values such as pain and pleasure;
- (4) The role of embodiment in the context of developmental process;
- (5) Quantification of "ecological balance" (information theoretical and statistical methods).

## **Training**

The majority of the participants to the seminar consisted of younger researchers such as graduate-students, pos-docs, junior-professors. Although the moderators of the discussions were senior researchers, many of the above-mentioned ideas had emerged from active interaction between senior and junior researchers. Furthermore, the organizational initiatives of the seminar have been taken by young generation.

## **Publicity and Additional Information**

In addition to an abstract booklet which has been published before the seminar, we have agreed on a few follow-up activities for publicity on the basis of the constructive discussion during the seminar. The publication plan includes a proceeding book from Lecture Note in Computer Science of Springer (LNCS), and making a documentary film of the seminar.

## Participants

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