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EDITORIAL

# Special Issue on Cognition for Technical Systems

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The face of computers and computer-equipped technical systems has drastically changed over the last decade and will continue to do so for some time. Illustrative examples of these developments are mobile phones. Nowadays, mobile phones are – for entertainment and other reasons – equipped with continuous sensors for self localization as well as with general purpose sensors such as cameras and microphones. They are also seamlessly connected to the world-wide web, the world's largest information source. Phones also have substantial computational resources causing the borderline between mobile phones and computers to fade. Indeed, some of the computer and mobile phone manufacturers are now competing in the same market. A number of mobile phone applications make good use of computational resources, the web and the sensors in order to turn phones into smart assistants such as travel guides.

Entertainment electronics, in particular in the games sector, is strengthening this development. It has developed powerful graphical processing units and new sensors, such as novel low-cost depth sensors, that enable computer games to observe the movements of human players to control their avatars in game environments. In other words, technical systems are being equipped with the perceptual and information processing means for real world problem-solving.

The vision of generally useful technical systems implies its own big challenges. Today, it is still not technically feasible for an autonomous robot to pick and place chess pieces with the dexterity of a five-year old, while Deep Blue [3], a computer program for playing chess, successfully beats the world champion. While this might be surprising upon first glance, it has taught us researchers what the difficult computational and control problems really are. We now know that, in many application domains, the problem is less in solving the problem itself but rather in solving the problem flexibly, reliably and competently in a wide range of contexts, in real time, and under uncertainty. The human brain is a computational device that is tailored for flexible, reliable and efficient real-time motion control [4, 6].

The complexity of the motion and action control problems solved by humans and animals can be estimated by looking at how long it has taken nature and evolution to arrive at their highly specialized and optimized solutions. Anybody who has tried to develop autonomous robot control for a rather simple manipulation task, such as setting a table or cleaning up, deeply admires the solutions nature has come up with. It also suggests that understanding the information processing principles will help us in the development of flexible, robust and competent robots and other technical systems.

The term of cognition is difficult to define in a general sense. Indeed, the euCognition community has put forward a collection of definitions that give a good perspective on the breadth of possible views on cognition (www.eucognition.org/euCognition_2006-2008/definitions.htm). We use the following working definition that is particularly useful for the control of technical systems (and which is similar to the view in the European projects PACO-PLUS (www.paco-plus.org) and RobotCub (www.robotcub.org)). We consider cognition-enabled control of technical systems to be the kind of control that acquires models of the consequences of actions and uses these models in order to act more flexibly, reliably and competently. In a way, cognitive technical systems viewed in this way are systems that know what they are doing [2].

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The methods that are used for realizing cognition-enabled control are, in particular, automated learning, reasoning and planning – methods that are key subject matters in Artificial Intelligence. So what is the difference between Artificial Intelligence and cognitive technical systems? Again, it is difficult to draw an exact line, but one can certainly see a strong difference in terms of emphases. While AI focuses on representations and algorithms, research in the area of cognitive technical systems is typically more system-oriented. Perhaps this difference is best illustrated by two research questions that are investigated in the respective fields. When applying AI methods to cognitive technical systems, AI researchers face the so-called *symbol-grounding problem* [5], the question of how symbolic representations are formed from the sensor data of the technical system and how symbolic action representations are translated into physical actions, i.e. voltages to motors.

In contrast, cognitive systems research often investigates the co-development of data structures and (computational and control) processes with symbolic representations being a subset of the suitable data structures. The latter view is particularly evident in the research directions of *embodied intelligence* [7] and *developmental robotics* [1, 9]. A success story of the AI-based research path is certainly *probabilistic robotics* [8], where symbolic representations can be learned, perhaps even as joint probability distributions, over sensed data and used to control robots such that they are reliable and can maximize the expected utility of their actions.

Looking at the worldwide research landscape, research on cognitive technical systems is strongly investigated within Europe and in particular within Germany. Europe managed to establish strong networks of excellence in the field, most notably ECVision, Euron and EuCognition. In terms of research projects, research was driven by integrated European projects including Cogniron (The Cognitive Robot Companion), CoSy (Cognitive Systems for Cognitive Assistants), RobotCub (Development of the iCub Cognitive Humanoid Robot), CogX (Cognitive Systems that Self-Understand and Self-Extend), GRASP (Emergence of Cognitive Grasping through Introspection, Emulation and Surprise), and ITALK (Integration and transfer of action and language knowledge in robots).

In Germany, strong research centers have established themselves and synergetically cover the field. Two excellence clusters, one in Bielefeld and one in Munich, investigate cognitive mechanisms for technical systems. Where the excellence cluster "Cognitive Interaction Technology" in Bielefeld focuses on interaction and interaction understanding, the research activities in Munich's cluster "Cognition for Technical Systems" concentrate on integrated autonomous control for achieving flexible, reliable and competent problem-solving behavior in human living and working environments. Besides these excellence clusters, the collaborative research center "Humanoid Robots" in Karlsruhe is complementing the research by focusing on the mechatronic and control engineering aspects as well as on research questions in developmental robotics. Specific reasoning mechanisms for realizing cognitive technical systems are investigated in the SFB Transregio "Spatial Cognition", whereas another SFB Transregio in Ulm and Magdeburg investigates the application of cognitive technology for the realization of companion systems. These big research institutions are described in greater detail in separate overview articles of the respective research centers. Furthermore, a new DFG priority program focusing on "Autonomous Learning" has been initiated and will start in fall 2010.

In addition to these research enterprises, the field also gains momentum through the rapid establishment and growth of open-source communities providing software toolboxes that substantially ease the development of integrated technical systems such as autonomous robots. Among the largest and most influential of these communities are ROS (Robot Operating System, ros.org), YARP (Yet Another Robot Platform, eris.liralab.it/yarp) and OpenRTM (Open Robot Technology Middleware, openrtm.org).

Another driving force is the emergence of quasi-standard robot platforms that are sophisticated enough to serve as research objects in the investigation of cognitive technical systems. These platforms certainly include new developments such as the iCub (icub.org), Nao (aldebaran-robotics.com/en/Nao.php), youBot (kuka-youbot.com), Care-O-bot (care-o-bot.de) and the PR2 robots (willowgarage.com/pages/robots/pr2-overview).

The combination of these developments, the research initiatives, the rapid development of open-source research communities, as well as the recent availability of quasi-standard platforms lead us to expect a quantum leap in the field of cognition for technical systems.

Besides the overview articles on the excellence clusters and collaborative research centers, this special issue contains four research articles. In the first one, Jonathan Maycock and his colleagues investigate the phenomenon of manual intelligence. They argue that grasping and manual interaction is such a difficult control task that a successful solution does not only require the consideration of physical and control aspects but must also focus on the cognitive nature of human skills. The second research article by Rüdiger Dillmann and his colleagues explains the leading edge approaches taken in his group to program robots by human demonstration. They advance the field of robot programming through demonstration with methods that can acquire generalized models of human demonstration and adapt the generalized methods to new situations. Sonja Stork and Anna Schubö explore cognition from the psychological point of view and in a human worker factory scenario. They explore how complex manual assembly tasks performed by human workers can be simplified by presenting and highlighting the relevant information and planning the work steps. Finally, Michael Beetz, Martin Buss and Bernd Radig explain in their article how they develop cognition-enabled robot control systems for everyday manipulation tasks that are inspired by insights into how humans perform their daily chores.

The special issue is completed with an interview with Eric Berger, the co-director of the personal robotics program of Willow Garage and an extended abstract of the doctoral thesis “Semantic 3D object maps for everyday manipulation in human environments”.

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## 1 Content

### 1.1 Fachbeiträge

- Approaching Manual Intelligence
  Jonathan Maycock, Daniel Dornbusch, Christof Elbrechter, Robert Haschke, Thomas Schack, Helge Ritter
- Advances in Robot Programming by Demonstration
  Rüdiger Dillmann, Tamim Asfour, Martin Do, Rainer Jäkel, Alexander Kasper, Pedram Azad, Aleš Ude, Sven R. Schmidt-Rohr, Martin Lösch
- Cognition in Manual Assembly
  Sonja Stork, Anna Schubö
- Learning from Humans—Cognition-enabled Computational Models of Everyday Activity
  Michael Beetz, Martin Buss, Bernd Radig

### 1.2 Projekte

- Cognitive Interaction Technology—Goals and Perspectives of Excellence Cluster CITEC
  Helge Ritter
- CoTeSys—Cognition for Technical Systems
  Martin Buss, Michael Beetz
- Spatial Cognition: Reasoning, Action, Interaction
  Christian Freksa, Holger Schultheis, Kerstin Schill, Thora Tenbrink, Thomas Barkowsky, Christoph Hölscher, Bernhard Nebel
- Von kognitiven technischen Systemen zu Companion-Systemen
  Susanne Biundo, Andreas Wendemuth

### 1.3 Interview

- Interview with Eric Berger (Co-Director, Personal Robotics Program, Willow Garage)

### 1.4 Dissertation

- Semantic 3D Object Maps for Everyday Manipulation in Human Living Environments
  Radu Bogdan Rusu

## 2 Service

The area of Cognition for Technical Systems covers a very wide spectrum of sciences and communities. This means that it is represented in conferences and journals on Artificial Intelligence, Robot Control, Systems Engineering, Psychology, Neurology, Cognitive Science and others. Listing all the relevant conferences and journals is beyond the scope of this editorial. In the following, we provide resources that we believe to be good reference points for the state of the art in the field.

### 2.1 Research Networks & Information Platforms

- EURON (European Robotics Research Network) www.euron.org
- EUCogII (2nd European Network for the Advancement of Artificial Cognitive Systems, Interaction and Robotics) www.eucognition.org
- Pascal2 (Pattern Analysis, Statistical Modelling and Computational Learning) www.pascal-network.org
- EUROP (European Robotics Technology Platform) www.robotics-platform.eu
- Willow Garage www.willowgarage.com

### 2.2 Roadmaps

- EURON Roadmap www.cas.kth.se/euron/euron-deliverables/ka1-3-Roadmap.pdf
- A Roadmap for US Robotics www.us-robotics.us/reports/CCC%20Report.pdf
- InterLink (International Cooperation Activities in Future and Emerging ICTs) interlink.ics.forth.gr/staticPages/Files/InterLink_D4.3_V2.pdf
- Foresight Cognitive Systems Project www.foresight.gov.uk/OurWork/CompletedProjects/Cognitive/index.asp
- EUROP Strategic Research Agenda for robotics www.robotics-platform.eu/cms/index.php?idcatart=119&client=1&lang=1?

### 2.3 EU-FP7 Projects (completed and ongoing)

- BACS (Bayesian Approach to Cognitive Systems) www.bacs.ethz.ch

- PACO-PLUS (Perception, action and cognition through learning of object-action complexes) www.paco-plus.org
- COGNIRON (The Cognitive Robot Companion) www.cogniron.org
- COSY (Cognitive Systems for Cognitive Assistants) www.cognitivesystems.org
- RobotCub (Development of the iCub Cognitive Humanoid Robot) www.robotcub.org
- CogX (Cognitive Systems that Self-Understand and Self-Extend) cogx.eu
- GRASP (Emergence of Cognitive Grasping through Introspection, Emulation and Surprise) www.grasp-project.eu
- ITALK (Integration and transfer of action and language knowledge in robots) www.italkproject.org

A complete list of relevant European projects can be found at cordis.europa.eu/fp7/projects_en.html.

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