Excellence Cluster "Cognitive Interaction Technology" – Cognition as a Basis for Natural Interaction with Technical Systems

Exzellenzcluster „Cognitive Interaction Technology" – Kognition als Basis natürlicher Interaktion mit technischen Systemen

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Summary What is necessary to enhance the command of complex technical systems in order to reach the ease and naturalness of human communication? How can we endow technical devices with the necessary cognitive abilities to support humans at a high level of semantic interaction offering true flexibility by virtue of adaptivity, self-organization, and learning? These are the guiding questions of the Excellence Cluster "Cognitive Interaction Technology" established since November 2007 at Bielefeld University. It focusses the efforts of computer scientists, psychologists, linguists, physicists and biologists on the goal of establishing cognitive interfaces that facilitate the use of complex technical systems by providing a high level of semantic interaction. This combines interdisciplinary, basic, and applied research beyond the classical confines of artificial intelligence. It aims at a thorough understanding of the processes and functional constituents of cognitive interaction in order to replicate it in technical systems including the development of evaluation methodologies and tool-kits for such systems. The research agenda of the EC is organized around four central topic areas: Motion Intelligence, Attentive Systems, Situated Communication, Memory and Learning. In addition, the EC is offering a cross-disciplinary education program. ►►►

Zusammenfassung Wie können wir technische Systeme so gestalten, dass sie mit dem Menschen auf einer möglichst natürlichen, semantischen Ebene interagieren und dabei ihre eigenen Fähigkeiten durch Adaptivität, Selbstorganisation und Lernen an wechselnde Randbedingungen möglichst flexibel anpassen? Für die Lösung dieser Frage führt der Exzellenzcluster (EC) die Expertise von Informatikern mit einschlägigen Forschungslinien in der Physik, Biologie, Psychologie und Linguistik zusammen, um die Entwicklung technischer kognitiver Systeme durch Erkenntnisse über reale kognitive Systeme zu fundieren, innovative, über klassische KI-Ansätze hinausreichende Lösungswege durch Verbindung von Expertise aus Ingenieur-, Natur- und Humanwissenschaften zu erschließen, und disziplinübergreifende, international ausgerichtete Ausbildungs- und Forschungsprogramme für Nachwuchswissenschaftler zu etablieren. Vier Schlüsselfelder für kognitive Interaktion prägen das Forschungsprogramm des EC: Bewegungsintelligenz, Systeme mit Aufmerksamkeit, Situierte Kommunikation sowie Gedächtnis und Lernen. Leitvision ist die Schaffung einer stimulierenden Forschungsinfrastruktur, in der Nachwuchswissenschaftler in strukturierten Promotionsstudiengängen und durch eine vorgelagerte, sehr frühzeitige Integration in Forschungsarbeiten zügig an die internationale Spitze der interdisziplinären Forschung auf dem Gebiet kognitiver Systeme herangeführt werden.

KEYWORDS H.1.2 [Information Systems: Models and Principles: User/Machine Systems]; I.2 [Computing Methodologies: Artificial Intelligence]; I.4 [Computing Methodologies: Computer Vision]; I.5 [Computing Methodologies: Pattern Recognition]; J [Computer Applications]

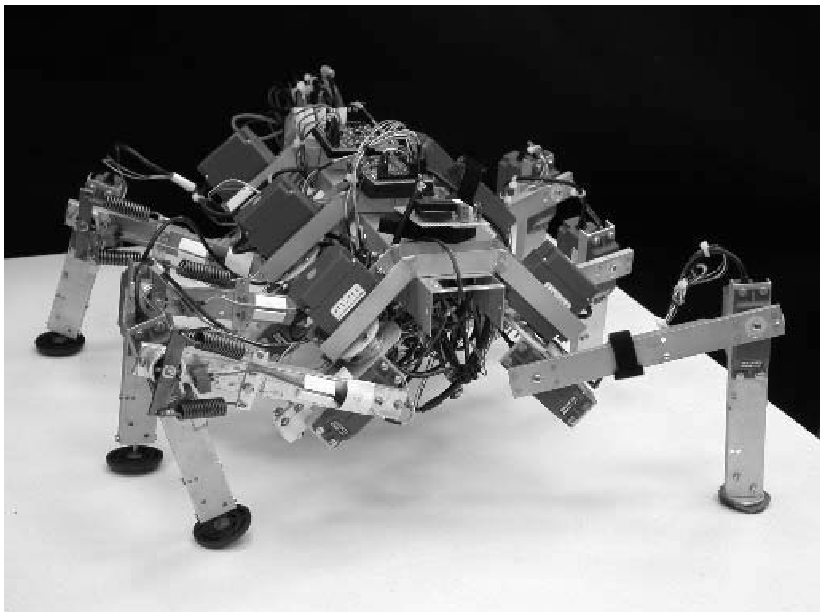

Figure 1 Robot TARRY: Walking based on biology-inspired algorithms.

1 Introduction

The coming decade will bring everyday computers and storage capacities to the same level as small brains. Considering this, current interaction technology seems archaic as it still forces humans to follow highly stereotyped, narrow and often error-prone procedures in order to make computers, robots, or other machinery obey them. The vision behind the Excellence Cluster (EC) *Cognitive Interaction Technology* is to develop ways of interacting with technical systems that are as natural and smooth as the communication between humans.

Being aware that this is not only a technological challenge but also a task that is inseparable from significantly advancing our understanding of cognition itself, the EC brings together computer scientists, engineers, physicists, neurobiologists, linguists, cognitive psychologists, and sports scientists as founders of a new interdisciplinary field: *Cognitive Interaction Technology* (CIT).

2 Guiding Vision

The goal of CIT is to generate the scientific insights and the technological basis for creating systems that can interact at various levels of cognitive complexity ranging from specialized small-scale systems, for example for hand-held devices, to display-bound simulated agents in virtual worlds and finally to fully-blown anthropomorphic robots aiding the future needs in an ageing society.

While an important emphasis lies on the realization and portable implementation of partial functions in specific human-system interaction contexts, the long-term goal of the EC is directed at integrating these results into a larger picture: Semantic interaction as observed with humans is characterized by a remarkably high degree of coherence with regard to an amazing number of heterogeneous details. Likewise, much of the flexibility of technical cognitive systems will only come from integrating a large array of combined functionalities, requiring advances to control intelligent motion, realize high-level perception and attention, enable situated communication and implement semantic memory and learning. It seems that this cannot be achieved by the plain up-scaling or detailed blue-printing of all functional details that have to be considered. Consequently, an associated challenge will be to understand principles that enable a smoother and – at least partially – more self-organized integration of a multitude of functional heterogeneous constituents. Ideas from engineering, linguistics, biology and cognitive sciences will have to be combined with insights about structure formation in non-living materials and networks and approaches of statistical and cognitive learning to realize incremental, self-improving systems that do not require preprogramming in every detail, and to come closer to a scientific theory that can guide the technical synthesis of cognitive functions.

Figure 2 Studying human movement patterns to gain insights into motion intelligence.

3 Key Questions and Research Areas

To cope with the above challenges, the EC will structure its research along a number of key questions falling into four research areas.

Motion Intelligence

How can we integrate perception with action to allow robots to move smartly and to assist humans in unexpected, every-day environments?

Research along this question is directed at mechanisms and principles of biological and engineering sensorimotor control in order to realize capabilities ranging from

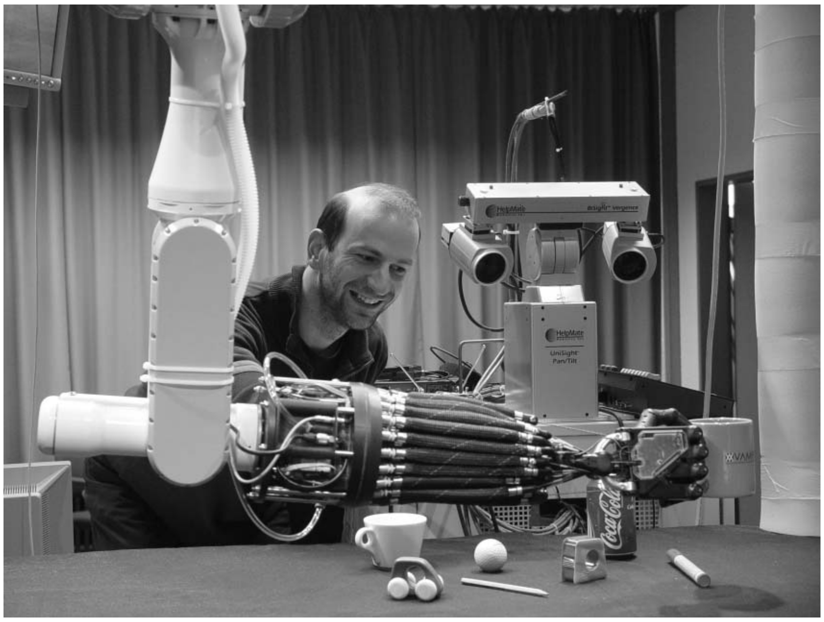

Figure 3 Dextrous hand-arm system actuated by artificial muscles.

reflex-like behaviors up to the purposeful manipulation of objects during human-robot-cooperation.

It will connect robotics-oriented research of the computer science groups with basic research on motion and interaction control in the involved biology and psychology departments. This will allow the utilization of biological solutions for movement control and insights into human movement to inspire complexity reductions for tasks faced by robot systems.

Another line of research will investigate how different approaches to the shaping of movements in robotics, psychology, and biology can complement each other and enable novel shared methodologies. A related question will be how the different fields can integrate their partial insights into a coherent picture about the internal representation of our movement abilities. This will lead to better ways of matching robot motions to the expectations of humans in order to achieve smooth cooperation. Another important issue will be the connection between motion intelligence and higher forms of cognition and language. The EC provides the environment to advance our knowledge on these and related issues, none of which appear likely to be solved within a single discipline alone.

From a practical perspective, the long-term goal will be to endow robots with the sensorimotor intelligence required to assist daily human activities.

Attentive Systems

What mechanisms enable a system to understand and actively focus on what is important, to ignore irrelevant details, and to share attention with humans?

To create attentive robots so that they team up smoothly with their human instructors has become a major topic in current robotics. Trying to build attentive systems has also made researchers aware of the need for robots to be "more social" in order to gain acceptance for important application fields such as care for the elderly.

At the same time, attention continues to be a long-standing and very active research topic in psychology that ties together many facets of cognition. The research area *Attentive Systems* is bringing engineers and researchers in psychology into close interaction. This joint expertise will create novel perspectives on attention mechanisms that integrate computational, psychological, and social dimensions. Their implementation on a wide spectrum of technical platforms ranging from display-bound attentive user interfaces over aug-

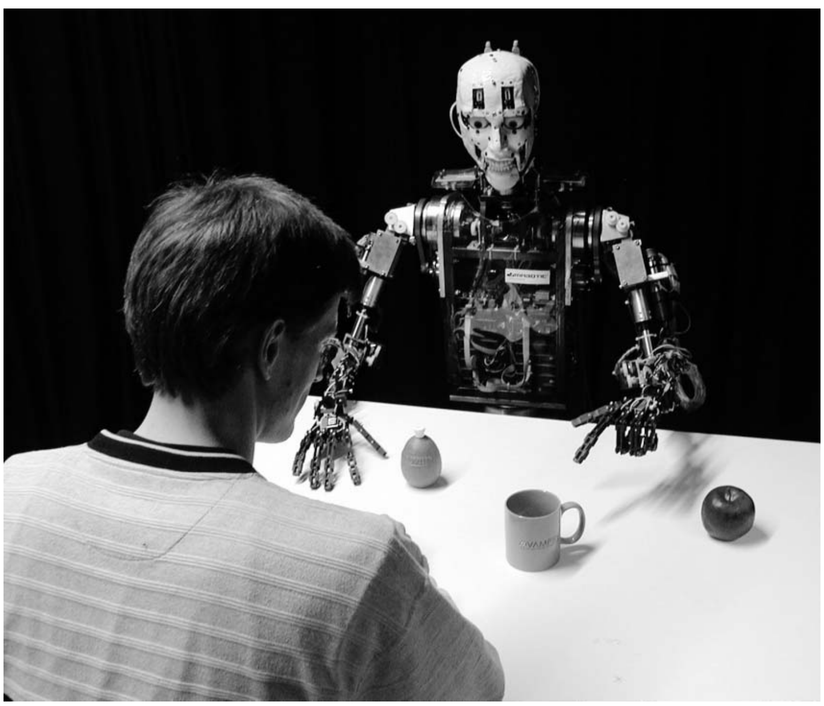

Figure 4 Situated communication with a humanoid robot.

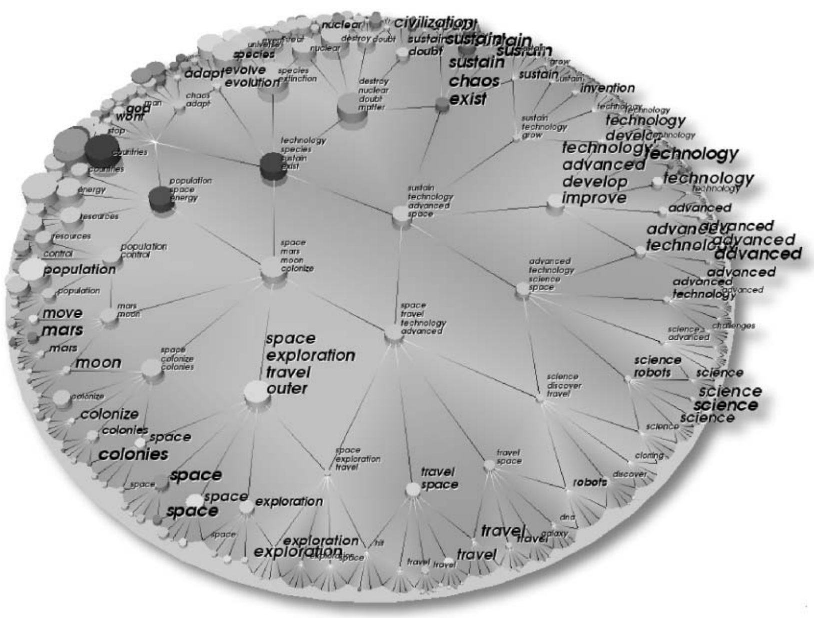

Figure 5 Self-organization of a semantic map.

mented reality systems to virtual agents or embodied anthropomorphic robot systems will not only open up novel applications, but also create new experimental methodologies for exploring and testing hypotheses about attention mechanisms. The deep understanding of these issues includes aspects such as intuitive "emotional" feedback and "social reactions" and can only arise from iterative advances in engineering science and insights and experimental work from psychology and linguistics.

Situated Communication

How can we coherently coordinate language, perception, and action so that cooperation between humans and technical systems takes place in natural efficiency?

The answer to this question requires ways of tightly connecting language, gesture, vision, and memory. Their complex interaction has stubbornly resisted countless attempts to break ground with simple heuristics or strategies resting on a narrow disciplinary base. The linguistic groups will interact with researchers from computer science and psychology in order to create the necessary integrated perspective to approach this challenge and to gain a deeper understanding of the multimodal web of processes that gives situated communication its superb economy and flexibility.

From a technical perspective, an important goal will be advances towards a smoother communication between humans and machines and the exploration of innovative approaches for enhancing natural and artificial styles of communication by combining visualization, sonification, haptic, and augmented reality devices in novel ways.

By iterating between large scale corpora-based research, modeling, theory building, and the implementation of technical systems as well as their evaluation, the EC will achieve the necessary balance to advance the frontiers of both basic research and application-directed technology.

3.1 Memory and Learning

What memory architecture provides generality, versatility, and scalability in order to enable autonomously intelligent systems to acquire, store, and retrieve knowledge about situations and events and improve their capabilities through learning?

Replicating such abilities will require the combination of insights from computer science, neurobiology, and neuropsychology in order to devise suitable representations to establish and maintain the linkage between conceptual and perceptual entities, and to develop learning architectures that can accumulate and self-structure information in flexible ways. To this end, we will be connecting the partial perspectives of the above mentioned fields to

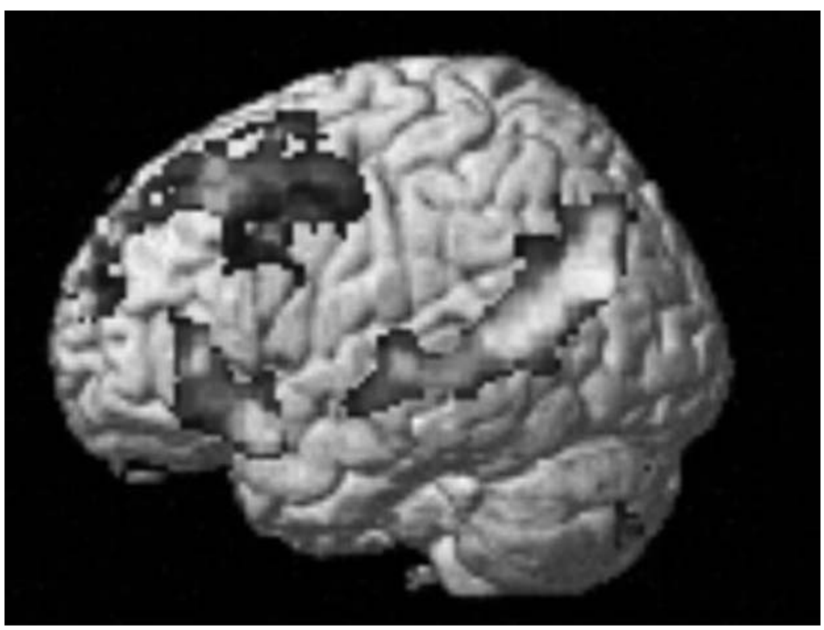

Figure 6 Observing the specialization of brain areas for cognitive tasks.

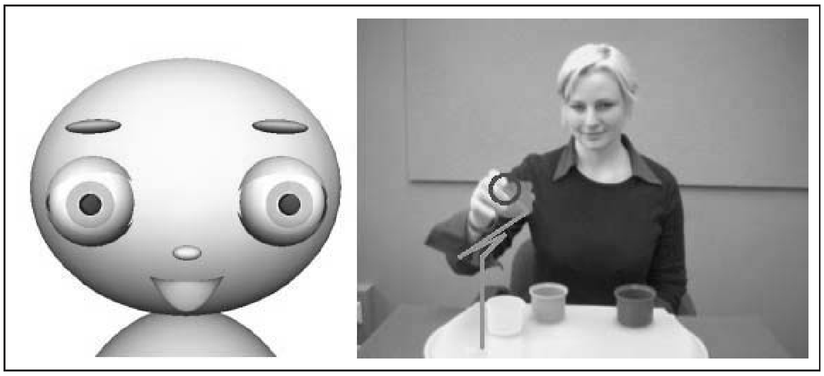

Figure 7 Teaching a virtual robot by demonstration.

advance the key question of how complex behavior is grounded in numerous kinds of dynamic knowledge including the aspects of the continual (re-)organization and acquisition of this knowledge. Modern memory devices begin to match the storage capacity of biological brains. How can we turn these vast capacities into active and evolving memories supporting flexible and associative representations? What are the required representations and how do they have to interact with each other? How can we integrate new pieces of knowledge, and what might be the use of forgetting in a technical system? Neuropsychologists and biologists working on the brain and its architecture will share their insights and those of their field with computer scientists and researchers working on cognitive development and learning. They seek to answer these questions and to create the foundations for memories of technical systems and agents that are more like our own.

3.2 Cross-disciplinary Integration

In order to approach these challenges, the EC will proceed in an evolutionary and step-by-step process iterating between systems engineering, experiments, and theory building to achieve the fast integration of advances across the pertinent disciplines into the realization of sophisticated systems, intedgrating capabilities from several modalities in non-trivial ways.

A shared goal between all groups is the portability of results into technical applications. Procedures to be established will ensure that well-understood functions of cognitive elements become available as components of a portable and commonly shared tool kit. The development of evaluation criteria and a definition of benchmark problems will provide standards for the new field of CIT and aid to measure progress on a quantitative scale.

4 Organization and People of the EC

The EC is constituted as a *Central Scientific Institute* of the University, allowing it to operate across the borders of the five cooperating faculties (Faculty of Technology (TEC), Faculty of Biology (BIO), Faculty of Physics (PHY), Faculty of Linguistics and Literary Science (LILI), Faculty of Psychology and Sports Science (PSY)) and the European Centre for Mechatronics (ECM, which is an external partner).

It has 13 principal investigators: Philippe Blanchard (PHY), Holk Cruse (BIO), Paul Drews (ECM), Martin Egelhaaf (BIO), Peter Ladkin (TEC), Hans Markowitsch (PSY), Ralf Möller (TEC), Gert Rickheit (LILI), Helge Ritter (TEC), Gerhard Sagerer (TEC), Thomas Schack (PSY), Ipke Wachsmuth (TEC), York Winter (BIO).

These groups plus a newly created group in Computer Graphics (Mario Botsch) bring in about 100 project scientists. They have

Figure 8 Artificial agent MAX.

been strengthened through the EC funding by four newly established research groups (T. Hermann – Ambient Intelligence, S. Kopp – Sociable Agents, K. Rohlfing – Emergentist Semantics, Pia Knoeferle – Language and Cognition). Additionally, four reappointments have been closely coordinated with the research objectives of the EC and been partially supported with EC-funding: two linguistics groups (J. P. de Ruiter – Psycholinguistics, P. Wagner – Phonology) and two psychology groups (W. Schneider – Cognitive Psychology, G. Dreisbach – General Psychology).

At the time of this writing, five further research groups (Active Sensing, Gender and Emotion in Cognitive Interaction, Text Technology, plus two further open-topic research groups) and two professorships (Mechatronics and Semantic Databases) are in the process of becoming filled (all these groups are newly created through EC funding). In the end configuration, this comprises a set of 16 newly filled professorships that are closely committed to the EC and that all have a long-term perspective beyond the current EC funding phase.

This scientific staff is supported by an administrative office with a general manager and adjunct managers responsible for the areas public understanding of science, gender issues and financial administration. The scientific affairs of the EC are directed by a scientific board regularly meeting in short intervals to coordinate the cluster.

Cooperating Institutions

An additional strong pillar is the recently established *Research Institute for Cognition and Robotics* (CoR-Lab). It is another Central Scientific Institute within Bielefeld University founded on the basis of a special joint funding between Honda Research Institute Europe and the State of NRW. The researchers in CoR-Lab and its integrated graduate school strengthen the EC in particular with respect to the sector of cognitive robotics and industrial cooperations in this area. It also offers a unique research laboratory with exclusive access to two humanoid ASIMO robots for investigating advanced issues of cognitive human-robot interaction.

This base in personnel and the additional experience from two Collaborative Research Centers (CRC 360: *Situated Artificial Communicators* (terminated in 2006) and CRC 673: *Alignment in Communication*) between the computer science and linguistics groups provide the basis for the above sketched research program of the EC.

As a further strengthening measure, the EC has established a *Virtual Faculty* of renowned scientists from fields pertinent to CIT. These colleagues will visit the EC repeatedly, contributing research seminars and cooperation projects, and in this way add to the profile of the EC for attracting the best young researchers world-wide.

The interaction of the Virtual Faculty with the university-based EC researchers is organized through the Center for Interdisciplinary Research (ZiF) – a center for advanced study closely operating as a special unit of the University, and the European Center of Mechatronics (ECM) located at the nearby Crassenstein Castle, offering a unique atmosphere for research, tutoring, demonstration and transfer and complementing the ZiF as an international seminar center for scientists from all over the world.

Figure 9 Utilizing ASIMO robots as a research tool for shaping cognitive interaction.
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Transfer Concepts and Partnerships

In order to deploy Cognitive Interaction Technology in applications, the EC has strategic partnerships with key industrial partners addressing the full spectrum of CIT ranging from "unembodied" CIT in media and information systems to CIT for enhancing functions in typical consumer household applications and finally to the ambitious goal of contributing core technology for shaping the future generation of fully embodied anthropomorphic robot assistants.

At the present stage, three major partnerships are already in place (Bertelsmann AG, a global player in modern media technology; Miele Cie. KG, Germany's leading company for high-quality household appliances; and Honda Research Institute Europe, the developer of the cognitive system of the world-renowned ASIMO robot). As an additional partner, WEGE GmbH Bielefeld supports networking activities into the local industry.

These cooperations connect the research activities in the EC with problems arising in the marketplace.

5 Promotion of Young Researchers and Gender Issues

The involved scientists coordinate their efforts for an academic education program that puts a high priority on rapidly advancing young scientists to the forefront of their research field, making them a part of the international research network, developing their work- and interpersonal skills, and, last but not least, making them strive for excellence. To achieve this, the EC implements an International Graduate Program comprising distinctive elements such as an embedded *Career Skill Programm*, regular *Research Retreats* to enhance mentoring, *International Fellowships* encouraging participants to spend one semester at a foreign institution as well as frequent *Visiting Lectures* by renowned visiting scientists.

Acknowledgements

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