Neurorobotics

From computational neuroscience to intelligent robots and back

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The Human Brain Project

The Human Brain Project (HBP) is a European Commission Future and Emerging Technologies Flagship Program[1] intended to advance our understanding of the brain. It is designed to run for a period of 10 years with strong collaboration between 116 partnering organizations from all over Europe. With total planned funding of roughly one billion Euros, HBP is a large effort with very complex problems and goals. As such, HBP effort is divided into 12 unique but interconnected research areas (so-called subprojects, see Fig. 1) designed to foster interdisciplinary collaboration between research laboratories across Europe [1].

Experts in the fields of neuroscience, biology, medicine, computation, robotics, and many more combine their efforts towards common goals. HBP researchers have published over 250 academic papers since the program's inception in 2013, and many exciting research efforts are underway. This article will focus on the Neurorobotics subproject, which is led by Technical University of Munich and is intended to place computational brain models within virtual robotic bodies that can interact within simulated environments. Imagine a computational brain model being able to sense – see or feel – the world around it and richly interact – through movement or manipulation. The goal of the subproject is to help understand the concept of neurorobotics from computational neuroscience to intelligent robots and back.

Background on computational neuroscience and intelligent robots

In recent years, there has been significant research towards the development of brain models – from single cell behavior at the fundamental biological level to population-level group dynamics within specific brain regions that replicate recorded behavior to whole brain behavioral models.

Computational neuroscience investigates the nervous system, connecting it to numerous fields such as computer science, electrical engineering, and physics. This allows researchers to create new types of biologically inspired models and systems that mimic the mind. These models are intended to explain everything from complex cellular activity on a short-time scale to long-term mechanisms of chronic disease and degeneration. The mouse brain has been thoroughly researched at every level, and some very specialized areas are now fairly well understood. These mouse models are comparable to human models, and although many differences exist, they serve as an important basis of understanding of the human brain.

Robotic control and intelligence is a broad field of research involving the development of advanced motor control systems and artificial intelligence. Within neurorobotics, this takes the form of biologically inspired analogues of muscles and highly specialized brain models. There is considerable

[1] https://www.humanbrainproject.eu

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Abstract
The field of neurorobotics encompasses the intersection of computational neuroscience and robotics. The TUM-led neurorobotics subproject of the Human Brain Project is actively researching concepts within the field and developing the tools to allow researchers to fully explore simulated robotics driven by computational neuroscience models. Further, the development of biologically inspired, tendon-driven robotics systems provides a unique research platform. These efforts allow researchers to explore the interesting space from computational neuroscience to intelligent robots and back.

ongoing research towards understanding how biologically inspired models behave compared to conventional control systems and even how they could potentially produce more natural and human-like behavior and responses.

Whole brain models with the capability to fully control a complex human or mouse-like system do not currently exist. The ability to complement highly specialized computational neuroscience models of very specific areas (e. g., vision or motor control) with generalized robotic control models allows researchers to focus on specific research areas while also leveraging libraries of stable components and behaviors from the robotics community.

The Neurorobotics subproject

The Neurorobotics subproject primarily develops the Neurorobotics Platform (NRP), which offers scientists and developers all over the world the opportunity to connect brain models to robot models in various virtual environments. These neurorobotics experiments are executed in real-time on high performance supercomputing clusters through an easy to use web interface. This enables users around the globe to access otherwise unavailable performance from their browsers, even from mobile devices.

In addition to developing the publicly available platform, also contemporary topics such as biologically inspired robotics and learning are investigated. Much of this research focuses on the mouse – from fundamental biology to advanced simulations. Real mice are studied while their virtual counterparts are further developed. This complex and ambitious effort serves as an intermediary step towards the ultimate goal of understanding the human brain.

The role of TUM in HBP

As presented in a paper recently published in Science [2], neurorobotics is a central pillar of HBP.

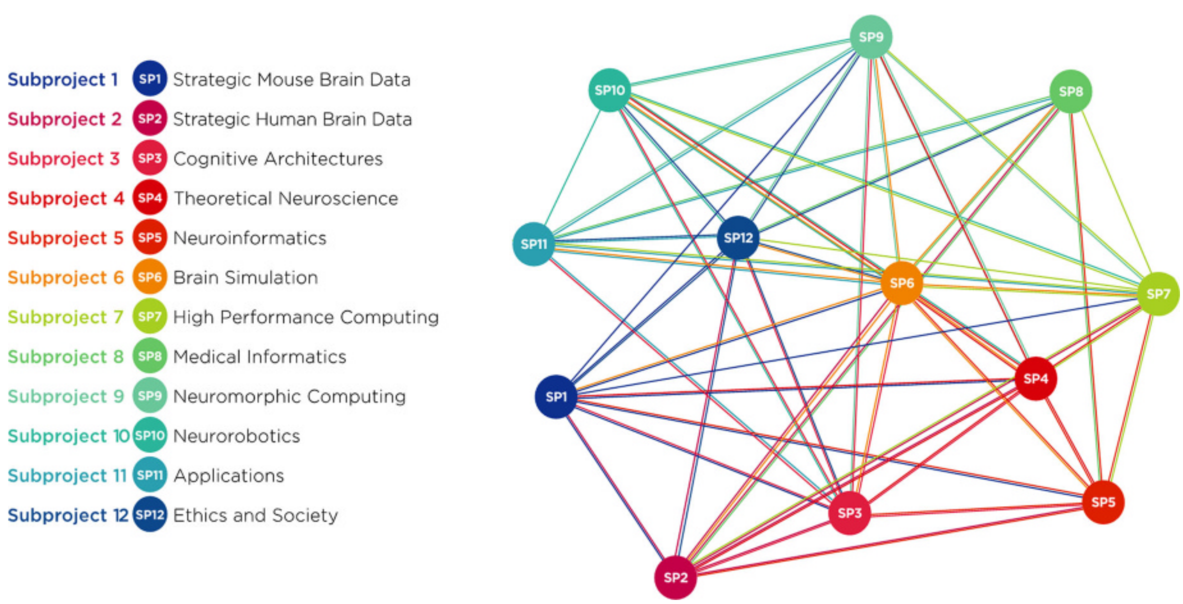

Fig. 1 Human Brain Project: organization of subprojects

Zusammenfassung

Das Forschungsgebiet der Neurorobotik befindet sich an der Schnittstelle zwischen theoretischer Gehirnforschung und Robotik. Das gleichnamige, von der TU München geleitete Teilprojekt im Human Brain Projects erforscht innovative Konzepte dieser Forschungsrichtung und entwickelt Werkzeuge, die es Forschern ermöglichen, Experimente mit simulierten Robotern durchzuführen, die mit Gehirnmodellen angesteuert werden. Des Weiteren ermöglicht die Entwicklung von an die Biologie angelehnten, durch Seilzüge aktuierten Robotiksystemen eine einzigartige Forschungsplattform für physische Roboter. Diese Forschungen versetzen Wissenschaftler in die Lage, den Bereich von theoretischer Gehirnforschung hin zu intelligenten Robotern und auch zurück zu erkunden.

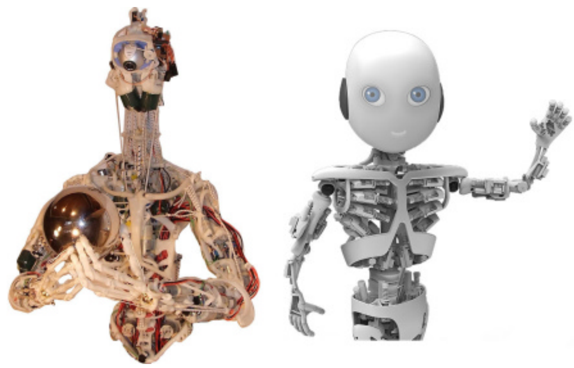

*Fig. 2 ECCEROBOT (*left*) and Roboy (*right*)*

TUM has many years of experience developing biologically inspired robotics. Projects such as ECCEROBOT[2] and Roboy[3], which are depicted in Fig. 2, are rooted in Munich [3] and have grown over the last years.

ECCEROBOT showcases early stage tendon-driven robotics research, while Roboy demonstrates modern advancements and engineering. The work on Roboy is ongoing, and the team officially joined HBP in April 2016. Roboy is unique in its design with its versatile tendon-driven muscle design and 3D printed skeletal structure. Biologically inspired robotics such as Roboy will be available within NRP, allowing researchers a unique option that lies between purely biological animal models and more traditional robotic models. These models can be used to design and develop real hardware and capabilities that would otherwise be impossible to produce.

The Neurorobotics Platform

The NRP is an open source cloud-based system for neurorobotic simulations that aims to provide researchers with software and hardware tools to aid in the investigation of the intersection between computational neuroscience and robotics. The hardware tools include supercomputing cluster nodes at several sites within Europe, including the Swiss National Supercomputing Center in Lugano, Switzerland. The software tools include a web-based user interface designed to develop brain models, build and edit virtual environments, equip robots with sensors and actuators, and link robot components to brain models.

It can be thought of as a virtual lab, where neuroscientists can exploit these tools to perform simulated experiments within sensory-rich environments. Moreover, NRP also supports roboticists by providing the ability to investigate the use of brain models instead of traditional controllers for robotic locomotion and manipulation tasks using traditional robotic platforms.

This virtual lab is made possible through eight software modules that include four designers (Robot Designer, Environment Designer, Experiment Designer, and Brain Interfaces & Body Integrator), three simulation engines (World Simulation, Neural Simulation, and Closed Loop), and an Experiment Simulation Viewer. These eight modules allow users to design experiments from scratch, re-run previous experiments with different parameters, robots, or brain models, visualize experiments in real time, and analyze and share experiment results. A team of highly skilled developers is continuously working on improving the platform and providing new features to meet users' needs. Figure 3 illustrates how models have advanced towards realism in NRP over the short development period.

NRP was officially released in March 2016, and the user base has been growing constantly. Researchers and the general public can request an

[2] http://eccerobot.org/
[3] http://roboy.org/

***Fig. 3** Evolution of two exemplary models in the Neurorobotics Platform from the first release shown in the top row to the second release at the bottom*

account to access this platform, more information can be found at http://neurorobotics.net.

Conclusion and Outlook

Only a few years after its launch in 2013, HBP has come a long way. Its organization has been refined and improved. The TUM-led Neurorobotics subproject has been progressing significantly, collaborating across subprojects, and generating results across its research and development efforts. Three separate chairs and the Fortiss Institute are directly involved, and thus it is also one of the biggest partners in its subproject.

In January 2017 TUM was the host to this year's HBP Neurorobotics Performance Show, as it has been numerous times in the past. Frequent exchanges between the research community and the developers ensure that the NRP development goals actually align with the scientific research goals and the needs of users. Although there is still much research and development to be done, the subproject is well on track and already now offers a powerful and versatile tool to researchers all around the globe.

Acknowledgements

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References

1. Amunts K (2016) The Human Brain Project: Creating a European Research Infrastructure to Decode the Human Brain. Neuron
2. Knoll A, Gewaltig MO (2016) Neurorobotics: A Strategic Pillar of the Human Brain Project. Science Robotics
3. Rüth C (2013) Human Brain Project. Das Gehirn im Supercomputer. Faszination Forschung 12/13