FACETS-ITN: From Neuroscience to Neuro-Inspired Computing

Scientific Achievements

The FACETS-ITN PhD student network addressed several unsolved question of how the brain computes with a concerted action of neuroscientists, computer scientists, engineers and physicists. To address such a major scientific challenge required a link to external research structures formed by experienced scientists with a very high international standing. This scientific background was provided by the highly acclaimed EU projects FACETS and BrainScaleS.

The ITN network involved 15 groups located at European research universities, research centres and industrial partners in 6 countries. The 4-year project ended in August 2013. 22 Ph.D. positions were funded in the FACETS-ITN project in the following scientific work areas: Neurobiology of Cells and Networks, Modelling of Neural Systems, Neuromorphic Hardware and Computational Principles in Neural Architectures, Mechanisms of Learning and Plasticity.

This report highlights major scientific achievements in all 4 research areas. It is essential to realize, that the specific work carried out in the individual research areas always depended on the interdisciplinary collaboration among them. This concept was at the heart of the FACETS-ITN network. All scientific achievements described below are published in international journals or conference proceedings and a complete overview of all publications can be found on the network website.

Neurobiology of Cells and Networks

The observation of synchronous behaviour in neural systems was among the central themes of this area of research in FACETS-ITN. The groups from Freiburg and UNIC jointly studied the propagation of synchronous activity through network resonance and the structure of stimulus induced correlations in random networks with distance dependent connectivity. In the same context, the Freiburg group showed that membrane potential statistics reveal a detailed correlation structure. Research on neuronal avalanches in spontaneous activity in-vivo was a major activity followed by the UNIC group. Complex systems give rise to events that are clustered in space and time thereby establishing a correlation structure that is governed by power law statistics. The results suggest that spontaneous activity of the visual cortex under anaesthesia has the properties of neuronal avalanches.

Modelling of Neural Systems

Modelling in the FACETS-ITN network focussed on specific systems with interesting computational properties. As an example the Stockholm group performed research on action selection performance of a reconfigurable basal ganglia inspired model with Hebbian-Bayesian Go-NoGo connectivity. Other activities of the Stockholm group concerned a spiking neural network model of self-organized pattern recognition in the early mammalian olfactory system and the anisotropic connectivity implementation of motion-based prediction in a spiking neural network. The latter work was carried out in collaboration with the Marseille group of FACETS-ITN. Also, as collaboration between Stockholm and Marseille the signature of an anticipatory response in area

V1 as modelled by a probabilistic model and a spiking neural network has been studied.

Neuromorphic Hardware

The work on neuromorphic hardware included both, experiments with existing systems and development of new ones. In a joint project between the partners Graz and Heidelberg it was demonstrated, how short term plasticity implemented in inhomogeneous hardware can lead to stable network operation. A major activity involving the groups of Heidelberg, Dresden, Stockholm, UNIC and Jülich developed and described a complete workflow from network definition and description to actual execution of a neuromorphic platform. The Bordeaux group carried out research on automated parameter estimation of the Hodgkin - Huxley model using the differential evolution algorithm. The results have then been applied to neuromimetic analog integrated circuit design. Based on this research the group also developed a tuneable neuromimetic integrated system for emulating cortical neuron models. The system was used to carry out a Bifurcation analysis in a silicon neuron.

For the hardware development in the BrainScaleS project, an ITN student from Heidelberg contributed to the VLSI implementation of the adaptive exponential integrate-and-fire neuron model. The Dresden group in this context worked on packet based communication network for a neuromorphic VLSI system. Together with the industry partner ZMD the Dresden group developed a packet based communication network for a neuromorphic VLSI system. The group also worked on the development of chip design methods, specifically an Integrated design management solution for complex IC design. As FPGA chips form an essential component of the BrainScaleS neuromorphic system, the Dresden group also designed a dedicated FPGA communication architecture for a large-scale neuromorphic system. Together with ZMB also the design of printed-circuit-boards was studied and further developed.

Outside the core activity of novel hardware architectures, ITN members from INRIA also carried out studies on neuronal simulation on graphical processing units (GPUs).

Computational Principles, Mechanisms of Learning and Plasticity

Among the most visible research with the highest impact has been the development of concepts for sampling with stochastic neurons. The Graz group has published a highly recognized paper on a Model for stochastic computation in recurrent networks of spiking neurons. This work has a substantial impact on the BrainScaleS project with several follow up publications and led to a close collaboration between the Graz and Heidelberg groups.. Another fundamental study performed with contributions from ITN students concerned homeostatic plasticity in Bayesian spiking networks as expectation maximization with posterior constraints.

An important activity of the ITN network has been the study of plasticity. As a highlight leading to a publication in the journal *Science*, the EPFL group demonstrated, that inhibitory plasticity balances excitation and inhibition in sensory pathways and memory networks. Further work of that group studied inhibitory synaptic plasticity and specifically spike timing-dependence and putative network function. The group also demonstrated that synaptic plasticity in neural networks needs homeostasis with a fast rate detector.

The theory section of FACETS-ITN also involved fundamental studies involving pure mathematical methods. The INRIA group succeeded in producing a mean field description of and propagation of chaos in networks of Hodgkin-Huxley and Fitzhugh-Nagumo neurons. They also investigated finite size effects in the correlation structure of stochastic neural networks and carried out an analysis of different connectivity matrices and failure of the mean-field theory. Another research line concerned the correlation structure of stochastic neural networks with generic connectivity matrices.

Summary

The FACETS-ITN network students made substantial contributions to understanding computation in the brain. The have successfully worked in a highly interdisciplinary and intellectually stimulating environment. The project and the students are one prerequisite for the recently awarded European Human Brain project, which will further develop this research on a larger scale.