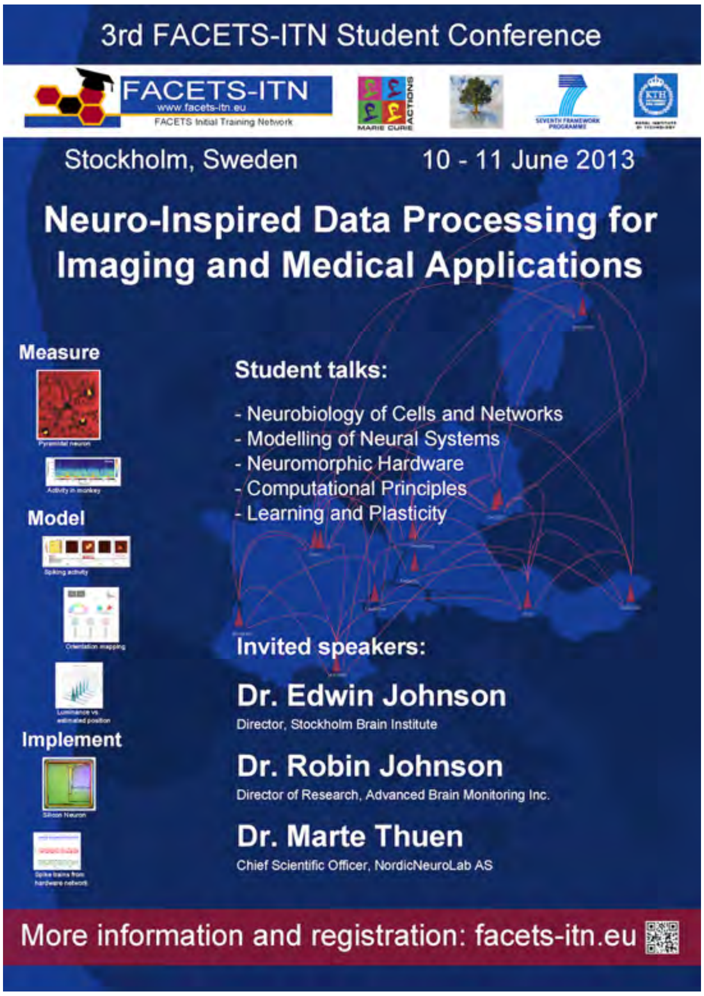
FACETS-ITN
http://www.facets-project.org/ITN
FACETS Initial Training Network

The FACET-ITN project, an EU funded Marie-Curie Initial Training Network, will end on 31 August 2013.

Student conferences

During the project the ITN students organized three "Student Conferences". For these conferences the students did the meeting organization all the way from selecting a topic for the conference, contacting speakers up to designing the conference announcement posters. The third and final of the conferences takes place on 10 and 11 June 2013 in Stockholm (Sweden)



3rd FACETS-ITN Student Conference

Stockholm, Sweden 10 - 11 June 2013

Neuro-Inspired Data Processing for Imaging and Medical Applications

Student talks:

- Neurobiology of Cells and Networks
- Modelling of Neural Systems
- Neuromorphic Hardware
- Computational Principles
- Learning and Plasticity

Invited speakers:

Dr. Edwin Johnson
Director, Stockholm Brain Institute

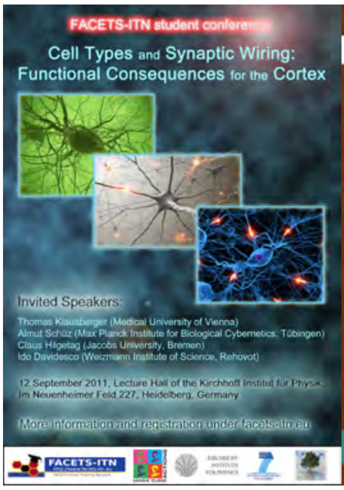
Dr. Robin Johnson
Director of Research, Advanced Brain Monitoring Inc.

Dr. Marte Thuen
Chief Scientific Officer, NordicNeuroLab AS

More information and registration: facets-itn.eu

The previous two Student Conferences were dedicated to:

- Cell Types and Synaptic Wiring: Functional Consequences for the Cortex (12 September 2011)
- Applications of Neuromorphic Hardware (27 September 2012)



FACETS-ITN student conference

Cell Types and Synaptic Wiring: Functional Consequences for the Cortex

Invited Speakers:
Thomas Klausberger (Medical University of Vienna)
Almut Schüz (Max Planck Institute for Biological Cybernetics, Tübingen)
Claus Hilgetag (Jacobs University, Bremen)
Ido Davidesco (Weizmann Institute of Science, Rehovot)

12 September 2011, Lecture Hall of the Kirchhoff Institut für Physik, Im Neuenheimer Feld 227, Heidelberg, Germany

More information and registration under facets-itn.eu

2nd FACETS-ITN Student Conference

Barcelona, Spain 27 September 2012

Applications of Neuromorphic Hardware

Invited speakers :
Marc-Oliver Gewaltig (EPFL)
Bernabé Linares-Barranco (IMSE)
Guy Paillet (Cognimem Technologies)
Narayan Srinivasa (HRL Laboratories)

More information under **facets-itn.eu**
FREE for the first 10 students to register

Ph.D. Thesis abstracts

For this final FACETS-ITN newsletter the ITN studen provided the following shortened abstracts of their Ph. thesis abstracts or a text describing a highlight of t respective thesis.

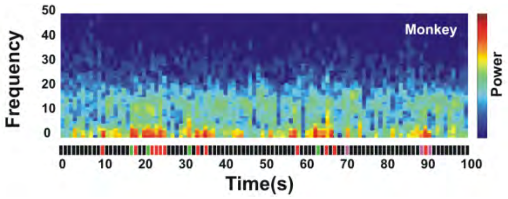
The full thesis texts will be made available (when ready. on June 2013 two thesis are available) on the FACET ITN website at:

http://www.facets-project.org/ITN

Area I: Neurobiology of cells an networks

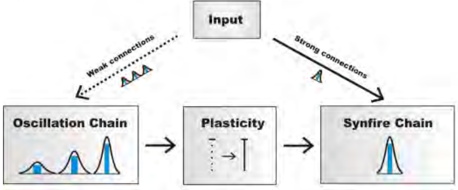
Gerald Hahn (CNRS-UNIC): Propagation of neuronal activity in vivo and in silico

My thesis work focused on properties of spontaneou activity in the primary visual cortex of cat and monke brains. We recorded spiking activity and local fie potentials with multi-electrode arrays and tested t presence of criticality in ongoing cortical dynamics. T theory of criticality attempts to explain the emergence complex dynamics which is said to optimize informati transmission, processing and storage in the brain. O results show that the cortex can switch between differe dynamical states with varying statistical features. We foun that power laws and long-range correlations, the hallma of critical systems, are only found in the most synchroniz states during which cortical activity is characterized large population bursts followed by periods of silence. contrast, when the cortex engages in desynchronized a irregular activity, measures of critical dynamics significan deviate from the predictions of criticality theory. The findings indicate that the cat and monkey cortex can exhi different dynamical states with both critical and non-critic atures which may serve different functions and can be odulated depending on computational demands.



gure: Spectrogram of spontaneous activity recorded from the primary ual cortex of a monkey showing different cortical states with large wer fluctuations in the 1-5 Hz range.

nother line of research explored how neuronal networks mmunicate with each other and reliably route activity ross several processing stages in the brain. To date two eories offer a framework for neuronal communication tween different brain areas. The synfire chain hypothesis ates that the key to neuronal communication are nchronous spike volleys that propagate along a layered twork of neurons. The communication through herence (CTC) hypothesis suggests that information is ansmitted between oscillations of different brain areas th a consistent phase relationship. During my thesis a vel framework of neuronal communication was eveloped that links both the synfire chain and CTC potheses by the concept of oscillation chains. In such a ain synchronous spike volleys are amplified through sonance in recurrently connected networks of excitatory d inhibitory neurons and spread across a layered twork with weak connectivity as a coherent oscillation. ese coherent oscillations induce synaptic potentiation ich gradually strengthens synaptic weights and ansforms oscillation chains into more strongly connected nfire chains. We modeled our hypothesis in layered tworks of integrate and fire neurons[2] and found that cillation chains are indeed a powerful mechanism to ansmit neuronal activity even in the presence of weak uronal connectivity and can be converted into synfire ains by synaptic plasticity.



gure: Relationship between oscillation chains, synfire chains and naptic plasticity.

The monkey recordings were provided by Giacomo Benvenuti and édéric Chavane (CNRS-INT).

he simulations were performed in collaboration with Alejandro Bujan d Arvind Kumar (Bernstein Center Freiburg, Germany).

ahir Uddin (UD): Input-Output Constellation Of eurons At Pinwheel-Centers In Cat Primary isual Cortex

primary visual cortex, neurons are locally organized in ose proximity according to their orientation preference presenting the rays of 'wheel' arround the orientation nvergence point called ' Pinwheel centers'. In pinwheel nters, neurons are well tunned as in orientation domain owing spike response selectivity and on the other hand ey show deporization of the membrane to all the ientation which means neurons in pinwheel centre must share common orientation preference with the neurons of neighbouring locations in orientation domains.

We are intended to investigate the input-output characteristics and constellation to and from the neurons at pinwheel centre in connection with laterally arranged neurons in orientation domain (i) by assessing their synaptic input dynamics at the membrane potential level to complex visual stimuli, (ii) measure their output spiking activity (iii) as well as termination of the labeled boutons on other neurons.

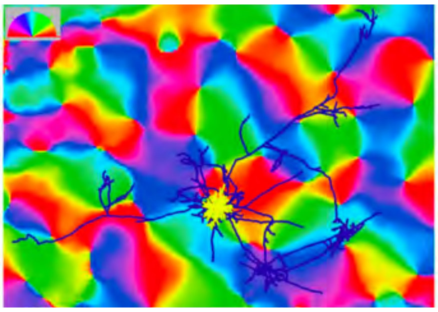
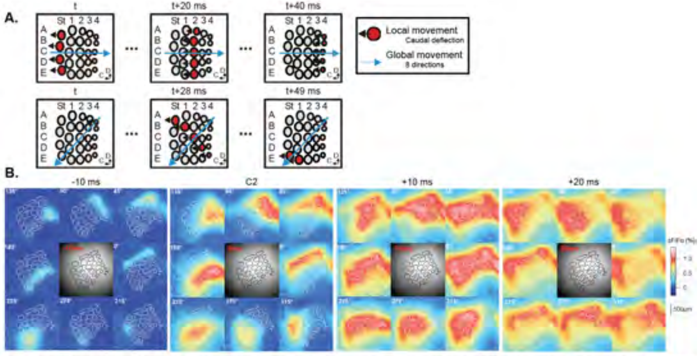


Figure: Horizotal cortico-cortical connections between cell (pinwheel center) and orientation domain.

Eugenia Vilarchao (CNRS-UNIC) - Representation of global motion in the somatosensory system of rodents

The tactile sensations mediated by the whisker-to-barrel cortex system allow rodents to efficiently detect and discriminate objects and surfaces. The temporal correlation between deflections occurring on several whiskers simultaneously varies for different tactile substrates. We hypothesize that tactile discrimination capabilities rely strongly on the ability of the system to encode different levels of inter-whisker correlations. Previous experiments in our lab with extracellular recordings showed that neurons in the rat barrel cortex and thalamus not only show a direction preference for local stimulation of the principal whisker but also for the direction of a global motion across the whisker pad (Jacob et al., 2008; Ego-Stengel et al., 2012).

The aim of my project is to further understand how the integrative properties of the somatosensory network could sustain different processing modes for the local and global tactile scenes. For this we are using a combination of classical – intra and extracellular recordings- and optical electrophysiological techniques – voltage-sensitive dye (VSD) imaging – while applying global tactile stimulation using a 24-multidirectional whisker stimulator.



A. Global motion protocol. Multiwhisker stimuli were locally invariant (caudal deflections of each whisker) but globally coherent (spatio-temporal sequences of whisker deflections). Illustration of three steps of the protocol for two directions (blue arrow) out of eight presented.

B. VSD imaging snapshots of activity in L2/3 at four different timings (-10, 0, +10 and +20 ms) of the 'global motion' protocol for eight directions of apparent motion. The average activity of the different directions was aligned in time to the stimulation of the whisker C2 (time 0 ms).

Preliminary results of cortical VSD imaging in anesthetized mice indicate no intra-barrel spatial organization of the direction selectivity in layer 2-3 and the existence of a map in the barrel cortex where dorsal and ventral global motions are overrepresented in partial pinwheel-like structure.

Giacomo Benvenuti (CNRS-INT) - Motion integration along a trajectory by neuronal population in alert monkey V1

Vision is traditionally viewed as hierarchical and feed-forward processing of the retinal input (Livingstone and Hubel 1988). In this framework information is supposed to be successively extracted by local filters of increasing size and sophistication.

In contrast with this general model, anatomical evidences show that the main part of excitatory input to V1 neurons, the first relay area of the visual information in primate cortex, comes from horizontal connections (Markov et al 2011).

Therefore a V1 neuron not only can integrate input from the retino-thalamic pathway and feedbacks from downstream cortices but importantly, also activity laterally propagating within the same area. Information carried by this lateral propagation of activity in a retinotopic reference frame could be particularly useful in processing motion.

We have shown that a bar approaching the receptive field (RF) of a V1 neuron along a long trajectory can generate an “anticipatory” response that builds up gradually with time before the bar actually enters into the classical RF of the cell and modulates the response within the RF (Benvenuti et al. 2011, SfN). This study was conducted in alert monkeys over a population of 83 V1 neurons, recorded in different sessions, in response to a bar moving along straight trajectories of different length and orientations before entering the RF center. We proposed that this "anticipation" results from the integration of convergent horizontal propagations of activity dynamically recruited along the neuronal population that is getting gradually activated by the retinal input.

Using a similar experimental paradigm, I am further studying this trajectory-dependent response at the level of V1 population of alert fixating monkey chronically implanted with multi-unit UTAH array (96 electrodes on a squared matrix of 4mm). It gives us the opportunity to record simultaneously single-unit, multi-unit and LFP from a population of neurons with partially superimposed RFs and different tunings properties over multiple recording sessions. I am still working to replicate these data but our preliminary results suggest that this trajectory-dependent response is a contextual priming signal that influences the detection and the identification of various properties of the moving stimulus.

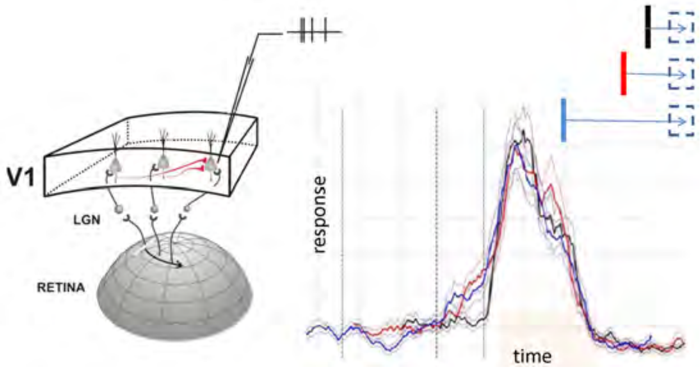


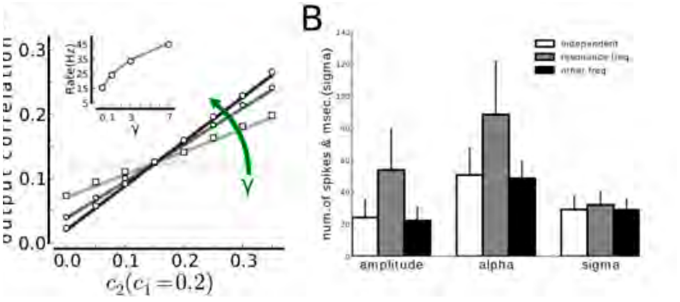
Figure: Horizontal propagation and anticipatory response for an approaching bar in V1 of the awake monkey. On the left a sketch of the early visual system activated by moving a bar (in white) along a straight trajectory. This bar activates the primary visual cortex (V1) throu feedforward streams (gray) and horizontal connections (in r converging on a neuron recorded with an electrode. On the bottom lef sketch of 3 bars following 3 trajectories of different lengths bef crossing a receptive field (dotted line squares). On the bottom right, wit corresponding color code, the superposition of the PSTHs elicited by t 3 stimuli averaged across 60 neurons. The dotted lines represent wh the 3 bars appear and the yellow shaded region the time window duri which the bars are inside the receptive field. An anticipatory activity observed when the bar follow a long trajectory before entering the RF.

Area II: Modelling of Neural Systems

Aljeandro Bujan (ALUF) – Modulation and propagation of correlated activity in neuronal networks

Correlated activity of neurons is a wide spre phenomenon in the brain. The natural question is wheth correlated activity is important for processing information whether it is just an epiphenomenon. This question lies the heart of neuroscience since it is related with the m fundamental question, namely, how information is bei processed in the brain. The role of correlated activi depends on the coding framework that is being considere On the one hand, there is abundant experimental eviden that suggests that information is encoded in the frequen of activation of the neurons, a quantity known as rate. Ra signals that are contaminated with correlated noise, a generally more difficult to decode and, in that sens correlated activity would be an undesirable effect. On t other hand, individual neurons are more sensitive correlated inputs. In other words, the probability of neuron to become active is higher when its input sign are correlated. There is also some experimental eviden that supports the idea that the brain may have evolved use correlated activity to process information, mai involving the routing of neuronal signals throughout t brain.

These frameworks are not mutually exclusive and there no strong evidence against the idea that both coexist in t brain. Therefore, during my PhD studies we have work on two different model mechanisms and each of them related with one of the aforementioned coding framework In the first of these models we presented a nov mechanism by which the brain can actively modulate t noise correlations, and we proposed that the brain m use it to improve signal decoding. The advantage of o model over other previously proposed mechanisms is th it is easier to relate it with experimental observations th indicate the presence of attention and perception-induc regulation of the noise correlations at relatively fa timescales. In the second model we proposed mechanism by which correlated signals can propaga through weak connections. It was long thought th propagation of correlated activity through different bra areas required the presence of strong connectivi between them, and we have shown that it is possible use the intrinsic resonance properties of the local neuron networks to amplify the weakened activity at every rel station and thus to make it possible for the activity to rea its target. The proposed mechanism has also t advantage that it allows us to explain the appearance different oscillatory activity patterns observed in the brai as well as the presence of long communication dela between different brain areas.



jure: Panel **A** shows the output correlation as a function of input signal rrelation (c_1). Noise correlation is fixed and strong (c_2=0.2) and the nnectivity structure is represented by gamma (γ). The panel shows that certain connectivity structures (large γ) the neurons produce a weakly rrelated output when the signal correlations are weak even in the esence of strong noise correlations. Panel **B** shows the network sponse when the input is a pulse of correlated spikes or a train of lses. White bars represent the effect of a single pulse. Gray bars show effect of a train of pulses with frequency equal to the network sonance frequency. Black bars are the same as gray but the frequency other than the network resonance frequency. In the x axis, “amplitude” licates maximum number of induced spikes, “alpha” total number of ikes and “sigma” the time difference between the first and last spikes. It early shows how a network can amplify its response when the stimulus periodic and matches its resonance frequency.

jith Padmanabhan (ALUF) – Effect of single euron firing patterns on network dynamics

is now well established that the underlying networks of eurons form the functional basis for the working of the ain. Spikes, which are the result of the flow of ions due to e difference in the potential, emitted by the neurons erve as the medium of communication between these eurons in the network. Different statistical measures like e total number of spikes in a specified time interval, the nchrony between the spikes of neurons, the temporal gularity of the distribution of the spikes of each neuron able an overall measure of the state of the network. As n be imagined, it is possible that the properties of the ngle neurons like their morphology, the distribution of ion annels of different ions, the spiking pattern of the eurons could influence the overall state of the network. e wanted to study, the effect of such single neuron operties on the network dynamics during the course of e work.

our study, the excitatory neurons,which have a positive fluence on the probability of spiking of the subsequent euron, was kept as one type i.e., the spiking pattern of all e excitatory neons were the same. The inhibitory opulations, those neurons which have a negative fluence on the probability of spiking of the subsequent euron, was of two types. The proportions of the two types as changed and the effect of such change on the state of e network was studied. For mathematical simplicity, it is sual to assume the brain to be a random homogenous etwork and study the dynamics of such a network. In such ndom networks, we found that the two types of inhibitory eurons did not have a qualitatively different influence on e state of the network. The network was made less ndom with the presence of hubs (the hubs are neurons hich are more connected to other neurons). Even in such etworks, the state of the network was not qualitatively fected by the difference in the spiking pattern of the hibitory neurons. Even in other specifically connected etworks, the network state was not significantly affected the spiking pattern differences of the individual neurons.

n the other hand, we found that the local properties of the etwork like the overall burstiness (how frequently the spikes occurred in bunches of two or more) were affected by the global state of the network. Thus in the type of networks that we studied, the global state of the network influenced the local parameters but the differences in the local parameters did not qualitatively affect the global state of the network.

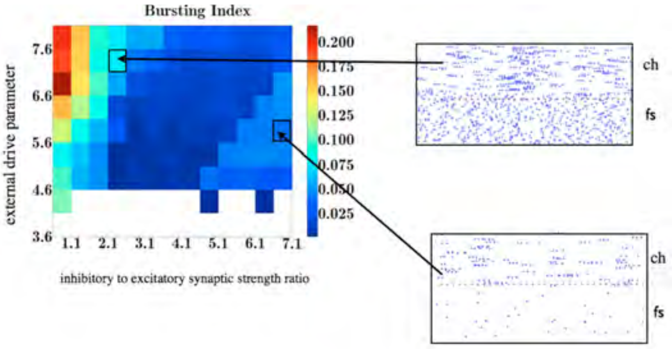


Figure: The external drive parameter determines the external input to the network. The inhibitory to excitatory synaptic strength ratio determines the proportional influence of the excitatory and inhibitory neurons on the network. In the figure above it can be seen that the change in these parameters changes the overall burstiness of the network. It especially makes one set of inhibitory neurons called the chattering neurons, more or less bursty. This is shown in the raster plots corresponding to the networks in different states. In the raster plots, the y-axis corresponds to the different neurons and the x-axis corresponds to the time.

Mina Khoei (CNRS INCM) - Predictive motion estimation: emergent visual computations in a probabilistic model

The most central question of this research is ‘How prediction in the visual system may ease processing of motion information’. Transfer of visual information from Retina to the cortex is accompanied with a neural delay in range of 100 ms. An object moving with high speed like a tennis ball can travel few meters during this period and then an important question is raised: whether we always see the moving scenes with this lag and behind their real position or not. Efficient performance of visual system in subtle tracking tasks suggests existence of a precise sensory information on the position and velocity of moving objects which is in conflict with existence of mentioned delays. For example a tennis player is able to hit the ball on time or some animals catch flying insects with appropriate actions and all these support the idea of having a compensating mechanism to overcome neural delays.

Prediction can be considered as one of the compensatory mechanisms. Our hypothesis is that visual system uses prediction as a large scale constraint to estimates the motion and predevelop according neural response before arrival of sensory input. We study predictive motion estimation in an abstract level in which motion is represented probabilistically. In a bayesian modeling framework motion is estimated by integration of prior knowledge on smoothness of trajectory and current measurement. We implement this probabilistic estimation as an internal model of expectation from visual world (position and velocity of moving object) and update it by observed information in a receptive field area.

With this internal representation of motion we are able to dissect prediction to its two components in position and velocity and explore their role separately. This approach is useful to study motion extrapolation, a mechanism of visual system to keep coherency of motion in spite of having frequent blank and occlusion resources. For example we found that by excluding position of stimulus from prediction tracking performance deteriorates, particularly in challenging tasks in which stimulus is moving in presence of high background noise or it is disappeared for a short period and then reappears. Consequently we found that efficient motion extrapolation in transient absence of stimulus updates internal representation of trajectory only when prediction is done in both position and velocity of stimulus. This modeling framework makes us able to simulate various experiments to address generic questions on motion processing computations with a predictive approach.

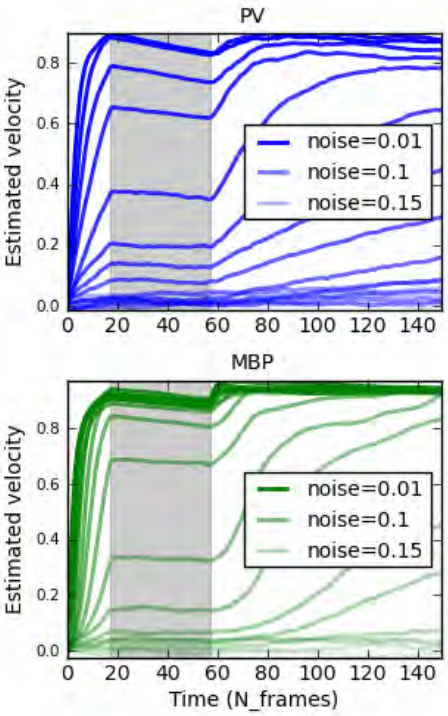


Figure: Motion extrapolation for a noisy stimulus moving in a blanked trajectory: Stimulus is a horizontally moving dot with u=1 which includes a blank as shown with shaded area. In addition there is a sensory noise and colors from dark to light correspond to noise levels increasing linearly between 0.01 to 0.2. (Top) Estimated velocity of model under PV configuration while motion estimation only benefits from predictions in velocity space. (Bottom) Estimated velocity of motion-based prediction (MBP) configuration, where estimation is predictive in both position and velocity of motion. In both configurations, increasing of noise corrupts tracking performance and after blank response converge only for noise values under a threshold and then enters to no tracking state. This threshold for PV and MBP configurations are 0.05 and 0.11 respectively. Note that the quick catch up after reappearance of stimulus never appears in PV but only in MBP in the cases in which a tracking state stabilized before blank.

Pierre Berthet (KTH) - Computational model of reinforcement learning and action selection in the basal ganglia and their different pathways

I work on a computational model of the basal ganglia, a central group of nuclei in the brain involved in the attribution of resources (motor or cognitive) to complete different tasks. This distribution is based on how good the outcome has been in previous experience, and the predicted reward associated with the current possible options. This system can thus learn which option should give the best result in a given state. We believe that the neurons, via their synaptic connections, encode the probabilities of occurrences of the various options and that serves as the basis for selection. The level of dopamine, a neurotransmitter, in this system is believed to code for the discrepancy between the expected and the actual reward, and thus to be critical in the modification of the connections between neurons, for example to increase the probability of repeating something that has led to a positively rewarded outcome, when in the same situation.

Our model features the three main pathways of these nuclei (direct, indirect and reward prediction) and we can change the configuration of the system in order to include in the selection process information from any combinatio of these pathways. This has led to a first publicati investigating the performance of these different selecti modes.

In recent years, with the development of optogenetics, technique where light can modify the activity of vira infected neurons in vivo, it has been possible to alt animal behaviours by selectively targeting neurons of nucleus in the basal ganglia. We were able to reprodu these experimental results by simulating optogene stimulation in our model (see figure 1). We have al looked at the dynamics of the changes in the differe interconnected, pathways that can lead to a simil selection bias. The reward pathway can be involved both the selection and in the modification of the connection Our model predicts that a stimulation affecting the err signal would have a significant impact on the selectio However, the resulting bias in our simulations is not simil to the one observed in rats. We thus suggest that t activity of the neurons targeted by the stimulation might n be critical for the modification of the connection at the ti of the dopamine release coding the error signal. T support the Actor/Critic hypothesis where the former directly involved in the selection and the latter has predict and inform the Actor about the outcome. The Act has been commonly associated with the dorsal part of t striatum, which is the location of the infected neurons in the biological study.

A next step is to implement spiking neurons in the mod and to interface it with other computational models, f example with the visual system or with a more detail model of the nuclei of the basal ganglia.

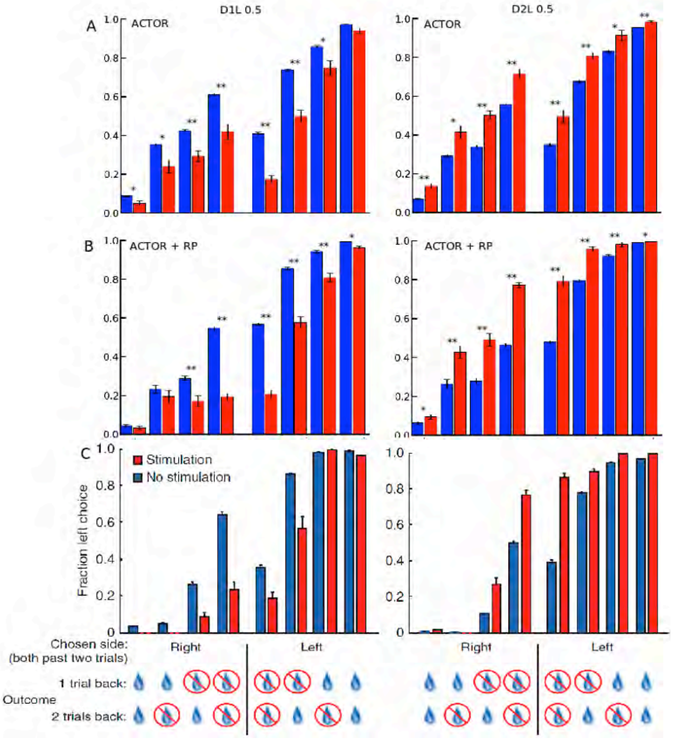
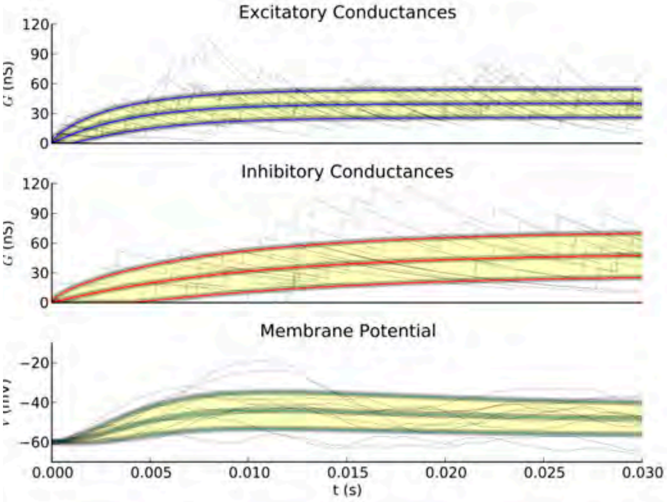


Figure: Effect of the stimulation on the left/right selection ratio for differe previous experience: action selected and reward obtained for the previo two trials. A and B are simulation results and C are experimental resu from rats. Left and right column represent respectively the results o stimulation of the direct and indirect pathway of the left dorsome striatum (responsible of the right hemibody). Actor is the combination the direct and indirect pathway, Actor+RP adds the reward predict system in the selection. ** and * denotes respectively a significa difference of $p<0.001$ and $p<0.05$ between condition with and with stimulation. Error bars represent s.e.m.

larco Brigham (CNRS UNIC) - Stochastic nalysis of the membrane potential activity in onductance-based models

om the standpoint of a single neuron, pre-synaptic :tivity may be considered random in terms of activated 'napses and arrival times. The main subject of my thesis :plores the time evolution of a simplified neuron model ıder random pre-synaptic activity. The model is without ›iking mechanism in order to focus on membrane ›tential evolution but takes into account biologically levant elements such as post-synaptic conductances. ıe key result is an analytical solution for time evolution of embrane potential moments under shot noise ›nductances."



jure: Individual realizations of excitatory and inhibitory synaptic nductances (top and middle) and membrane potential (bottom) in a uron under in vivo conditions. Statistical means and standard deviation grey, their exact estimations in colour.

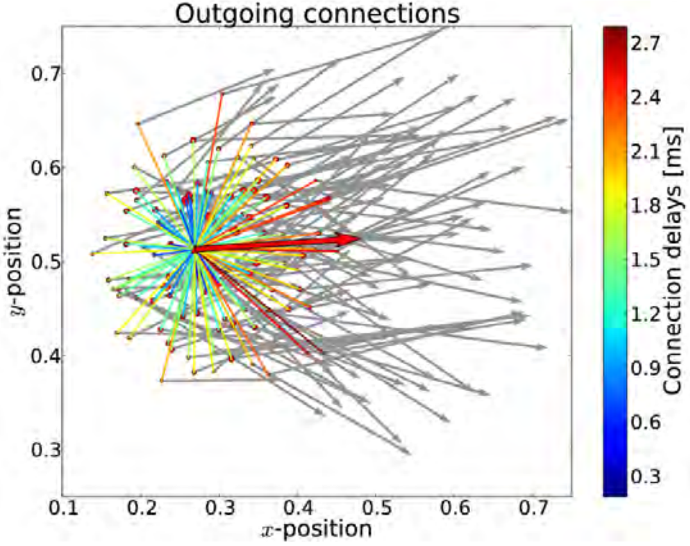
ernhard Kaplan (KTH) – On connectivity and ınction in the visual and olfactory system

ıe focus of my work lies in modeling neural systems that ›lve a specific task. In these functional models, we are udying the question how connections between neurons groups of neurons should be set up to achieve the given sk. For example, in a collaboration with colleagues from NRS-INT in Marseille we developed a neural network that able to predict the trajectory of a moving dot stimulus ıen the dot is hidden behind an obstacle. In the future, ə will study how the connections in the network could ›velop by themselves, i.e. based on a learning rule and e network activity driven by the stimulus.

another project I have developed a model of the first ree stages of the olfactory system and have shown that is system is able to learn 'artificial smells' and to cognize them, hence this works like a self-organizing ıttern recognizer.

ırthermore, I'm trying to understand how the activity of or ›uron network models should be interpreted, or 'decoded' the context of the given task.

ıe purpose of this modeling work is to link the network's sk, e.g. pattern recognition or motion prediction, to the echanisms responsible for the given function and to ovide hints and theories how real neural systems could ›ssibly achieve these tasks. The models I work with are ›rtainly unrealistic in many ways because we have to mplify the enormous complexity of real neural systems (e.g. network size, biophysical detail), but the components and principles we apply are plausible and are inspired by those found in real systems.



The figure shows the connectivity pattern we hypothesize to be crucial for a motion prediction system. The red arrow shows the preferred direction of an example cell, the colored lines show the outgoing connections of this example cell to its network neighbors and the gray arrows show the preferred direction of those target cells.

The idea behind this connectivity pattern is the following: Normally, movements follow a smooth trajectory which should be resembled by the network connectivity. That is, cells that preferably respond to certain trajectories, e.g. movements from left to right at a certain speed, should transmit the detected motion information on to their network neighbors in a similar way in order to prefer the percept of smooth trajectories.

Diego Fasoli (INRIA)

In my thesis I worked on analytic and numerical methods for the calculation of the correlation between rate or spiking neurons for many different synaptic connectivity matrices. In fact, according to the Theory of Complexity, it may be more relevant to use realistic connections, which describe the way the neurons interact with each other, than adopting biologically realistic models for the soma. A typical example that comes from the Theory of Complexity is represented by flocks of birds, where, assuming simple interaction rules, i.e. flying in the same directions of the neighbors, with the same speed and avoiding obstacles or to bump into other birds, it is possible to recreate the flocks' ability to form stable and complicated patterns and to rejoin when the group is split. This elucidates the importance of the interactions, compared to a single interacting element (i.e. a neuron or a bird in these examples). For this reason in my thesis I focused on the synaptic connectivity of the neural networks, trying to quantify its role in the behavior of the system, with special emphasis on the correlation structure between the neurons. I also determined the finite size effects of the network, for a generic number of neurons, extending the previous results obtained with the mean-field approximation, namely for infinitely many neurons (see for example).

The techniques developed in my thesis are listed below:

- mean-field theory;
- Mayer's cluster expansion;

- perturbative theory for neural networks with special symmetries;
- perturbative theory for weak synaptic weights.

Moreover, once the probability density of the network is known, it is possible to evaluate its information processing capabilities in terms of information transfer, storage, modification and encoding. In particular, I focused on information encoding, which is quantified by the Fisher information of the neural network. In the thesis I evaluated the Fisher information numerically and analytically, proving in many ways that the common belief of a better information encoding performed by independent neurons is generally incorrect.

Javier Baladron (INRIA) - Exploring the neural codes with parallel hardware

The aim of this thesis is to understand the behavior of large interconnected populations of neurons. The method we use to reach this objective is a mixture of mesoscopic modeling and high performance computing. The first allows us to reduce the complexity of the network and the second to perform large scale simulations. All the simulations presented in this work are performed on a Graphic Processing Unit cluster. A set of techniques are proposed to simulate the models fast enough on this kind of hardware. The speedup obtained is equivalent to that of a huge standard cluster.

In the first part of this thesis a new mean field approach for realistic model neurons is used to study numerically the effects of noise on extremely large ensembles of neurons. This is done by solving a set of partial differential equations that describe the evolution of the probability density function of the network. The simulations have shown that the law governing a large population of neurons may converge faster to a stationary probability density if the levels of noise are high. Also, the same approach is used to create a model of one hyper-column from the primary visual cortex where the basic computational units are large populations of neurons instead of simple cells. The numerical experiments have shown that the model is able to compute the correct orientations.

In the second part of this thesis a numerical study of two neural field models of the primary visual cortex is presented. The main focus in both cases is to determine how edge selection and continuation can be computed. The difference between the two models is in how they represent the orientation preference of neurons, in one this is a feature of the equations and the connectivity depends on it, while in the other there is an underlying map which defines an input function. Using both models we have shown how edge selection may be possible with a connectivity that only depends on the distance between elements and also how edge continuation may be produced

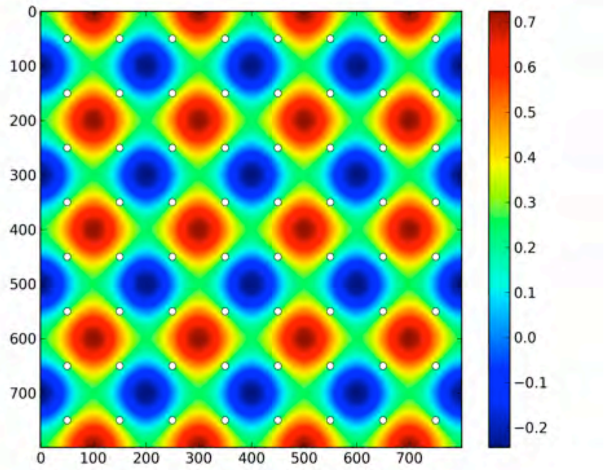


Figure: Pattern of activity of a neural field model when an edge w orientation pi/4 is presented.

Area III Neuromorphic Hardware

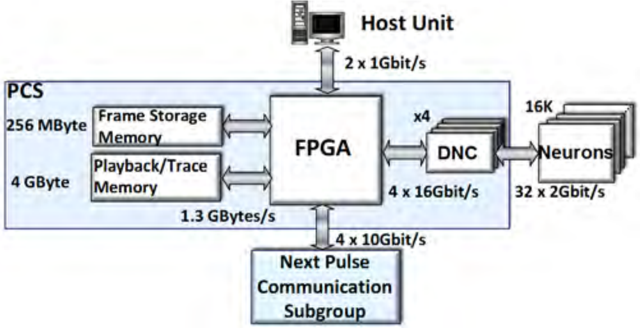
Vasilis Thanasoulis (TUD) – Analysis and development of a communication infrastructur for a waferscale neuromorphic system

This thesis achieved to design and implement an efficie high-speed and packet-based communication platfor capable for the external configuration, control ar stimulation of a large-scale neuromorphic system. T proposed design provides the communication from a ho unit, via an FPGA (Field Programmable Gate Array) boa and digital network chips (DNC), towards silicon neuro and then backwards, via the same design, to the host u (Figure1). The system allows, via a tree-like structure, f the fast configuration, control and stimulation of multip individual neuron-synapse blocks. All the design decisio have been made for the support of high-speed links and a efficient throughput of 1.46 Gevents/sec.

The proposed system includes also a Playback/Tra storage level, which allows for long-term neural stimulati with time accurate spike trains and the recording of t resulted neural activity. This is an important step forwa for the execution of learning experiments and for t emulation of neural networks that include spike-timin dependent plasticity (STDP). The Playback/Trace stora level by having capacity of 50 million pulses, allows f instance the stimulation of 1000 neurons (at 10 Hz) for hours real time (corresponding to 4,6 sec in t accelerated system). With a bandwidth of 742 Mevent/s f read and 589 Mevent/s for write, it is a very importa feature for the accelerated neuromorphic computation, as circumvents the throughput bottleneck of the slower ho communication.

Several neural benchmarks from the computation neuroscience have been applied in order to stu repercussions of different frame-based routing i plementations with respect to neural behavior. T parameters have been investigated: the pulse transmissi latencies and losses via the physical communication link A verification methodology of the implemented co munication has been developed, involving statisti studies of the applied and traced spike trains. Simulatio of neural networks have been carried out, in order tract the firing rates of the activity and histograms of their stribution. The application of the same networks on the plemented system and the acquired results show the gibility of the proposed design for neuromorphic plication.

routing logic on FPGA has been developed based on the stem of the Figure below, allowing for source-based uting of the events, controlled long-range delays (axonal) d multi-wafer connectivity. Future plans include the plementation of a Multi-FPGA system and effective cket routing methodologies for the support of the inter-afer communication. The results from here are vital for e implementation of the multi-wafer scale system.



gure: The architecture of the high-speed and packet-based network, ich allows for fast configuration, control, stimulation and monitoring of a ge-scale neuromorphic system.

larc Olivier Schwartz – Reproducing iologically Realistic Regimes on a Highly-ccelerated Neuromorphic Hardware System

tificial neural networks have many applications, from ttern recognition to robot navigation. However, it is efficient to simulate those networks on a typical mputer, as they are massively parallel systems by ture. Over the past decade, the field of neuromorphic gineering emerged to solve this problem by plementing analog circuits that emulates the behavior of ural networks.

ese neuromorphic chips have several advantages over mputer simulations: they are usually faster, more energy ficient and fault-tolerant. However, compared to purely gital systems, analog hardware is subject to transistor ze mismatches. For neuromorphic systems, and in rticular for the circuits emulating neurons, this means at there will be neuron-to-neuron variations on the chip, sulting in a different behavior for each hardware neuron. is is why a calibration step is necessary to compensate ese variations, and guarantee a correct operation of all uron circuits.

is thesis presents a software framework to automatically nvert the parameters of a neuron models written in a scription language, PyNN, to parameters which will be ed to configure the hardware system, while making sure at the hardware neurons behave in the same way that eir theoretical counterparts. After a theoretical analysis, is framework is applied both on transistor-level level mulations of the hardware as well as on the hardware stem itself. Finally, the software framework is used to mulate some simple neural networks on the uromorphic hardware system.

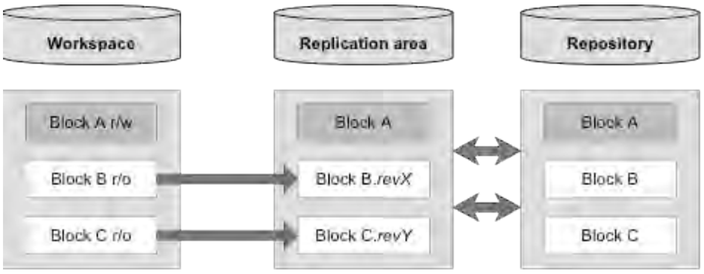
adoslav Prahov (ZMDI) - Description and nplementation of a Design Data Management

Methodology for Neuromorphic and Mixed-Signal Systems

An aspect of primary significance in neuromorphic integrated circuit (IC) design is configuration management (CM) of design data, i.e., the task of keeping a project comprising a multiplicity of revisions well organized. This is an especial challenge encountered by large teams of developers when they simultaneously contribute to the data. Over half a century since its establishment, there are now two fundamental architectures and a wide diversity of automated tools supporting and facilitating CM application by managing revisions of documentation, source code, and a wide variety of files, and automating storing and retrieving revisions. This thesis presents and evaluates these architectures and the top five CM tools in terms of market share, offer reasons for switching from one architecture to another in the context of software development and qualify their relevance from the perspective of integrated circuit design. We show detailed measurements comparing the two primary representatives of centralized and decentralized CM tools: Apache's Subversion(r) and Git (GPL). The analysis is based on both theoretical benchmarks and a real-world data set.

During the measurements we observe that Subversion often exhibits a performance deficit when it handles an immense amount of managed data. In order to further investigate this, we present a performance study conducted on a typical industrial platform. We identify the large quantity of files and directories as being the pivotal performance bottleneck of Subversion—as the number of files and directories increases, performance deteriorates further. We analyze the impact of the reformed meta-data structure in release 1.7 on the efficiency and contrast it to the previous revision 1.6. We also examine how the performance is affected by the hardware configuration and suggest measures for improvement that facilitate higher efficiency.

Since Subversion provides insufficient support for IC projects consisting of large numbers of managed items, we address this problem by introducing, discussing, and demonstrating several approaches that improve the performance of Subversion when handling a vast amount of files and directories. Our approaches are division of the working copy into smaller pieces with a decent granularity, conversion of the working copy into a single tarball file, and implementation of a referred central working copy. Each method is incorporated into the configuration management flow through a lifecycle of IC development, which offers the opportunity to compare and validate each technique. Our foremost approach is the referred central workspace for read-only access. For an industrial IC design project, during day-to-day work, we could observe an acceleration of up to 360 times the execution time for Subversion operations. For larger projects, the acceleration could be even higher.



Love Cederstroem (ZMDI) – Synthetic Synapses in Electrical Systems

Within electronics design there are two main different functional signal domains: digital and analog. The analog domain deals with signals where the exact level within a range has meaning. The digital domain on the other hand deals with signals where defined ranges are mapped to one certain value, e.g., voltages are interpreted as either a one or a zero. When the two signal domains are present in the design of system this referred to as mixed-signal. There are also two main different physical domains: integrated circuit and circuit board. Traditionally a system is constituted by several packaged integrated circuits (chips) on a circuit board, over the last decade technological advances have enabled miniaturization and we have seen the birth concepts like “system on chip” and “system in package.“

Because all of these domains present different challenges to the designers different software and modeling approaches are used, which has resulted in difficulties to transcend the domains during development as they originally were treated separately. From a top down perspective this work first describes how to battle the issues arising from designing and simulating mixed signal test systems in the mixed physical domain. Secondly this work addresses how the issues can be attacked from a bottom up approach in the context of the emerging memristor technology for synthetic synapses in electrical systems.

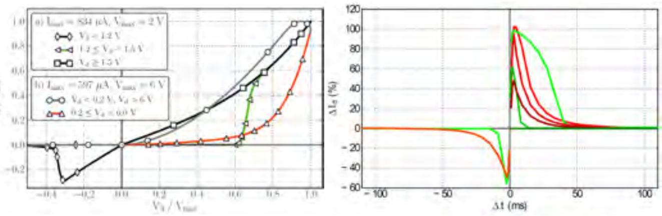


Figure: left: Simulations showing the different hysteresis characteristics for a device with rapid switching (green) compared to a model for a device with gradual resistive switching (red). To the right: This comparison points out the advantage of a more gradual switching when the device is used as a synapse under the spike timing dependent plasticity computing paradigm since it provides a more predictable behaviour and a wide region of operation.

Filippo Grassia (IPB) - Silicon neural networks: implementation of cortical cells to improve the artificial-biological hybrid technique

This work has been supported by the European FACETS-ITN project. Within the framework of this project, we contribute to the simulation of cortical cell types (employing experimental electrophysiological data of these cells as references), using a specific VLSI neuron circuit to simulate, at the single cell level, the models studied as references in the FACETS project.

These silicon neurons are based on the Hodgkin–Huxley formalism and they are optimized for reproducing in biological time scale a large variety of neuron behaviors thanks to tunable parameters. By comparing them with experimental electrophysiological data of these cells, we show that the VLSI neurons can reproduce the main firing features of cortical cell types (as an example, see Figure for the intrinsically bursting (IB) neurons).

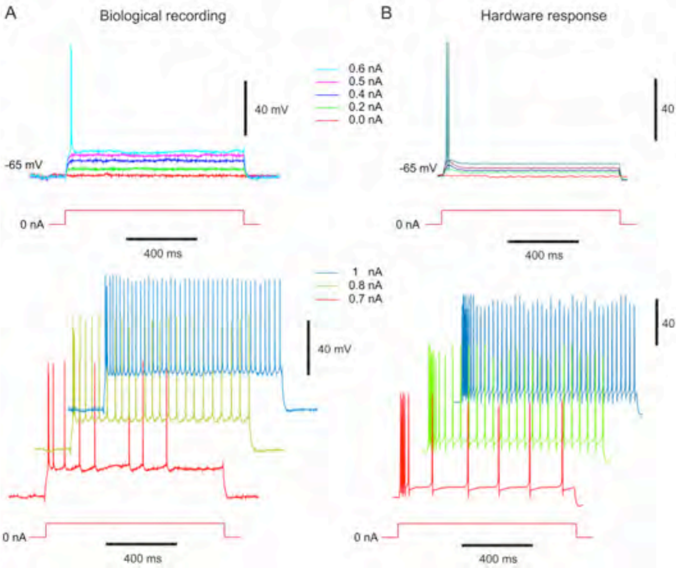


Figure Membrane voltage of “Intrinsically bursting” neurons. (Intrinsically bursting (IB) cell from guinea-pig somatosensory cortex *vitro* modified from Pospischil et al., 2008; experimental data from C Monier and Yves Frégnac, CNRS). Response to different depolarizi current pulses. **(B)** Measurements of the IB hardware neuron at sa depolarizing current pulses.

Moreover, this hardware and software platform based Hodgkin–Huxley conductance models and real-tim processing at the sample level will be helpful to improv the hybrid technique also called “dynamic-clamp,” th consists of connecting artificial and biological neurons study the function of neuronal circuits.

The second goal of this work was to contribute to th design of a mixed hardware-software platform (PAX specifically designed to simulate spiking neural networks.

The tasks performed during this thesis project included: the methods used to obtain the appropriate parameter se of the cortical neuron models that can be implemented our analog neuromimetic chip (the parameter extracti steps was validated using a bifurcation analysis that show that the simplified HH model implemented in our silico neuron shares the dynamics of the HH model); 2) the fu customizable fitting method, in voltage-clamp mode, tune our neuromimetic integrated circuits using metaheuristic algorithm; 3) the contribution to th development of the PAX system in terms of software too and a VHDL driver interface for neuron configuration in th platform.

Area IV Computational Principles, Learning and Plasticity

Johannes Bill (TUG) - Probabilistic models of computation and self-calibration in recurrent networks of spiking neurons

With my research at TU Graz, I aim to deepen o understanding of computation in the brain by studyi recurrent spiking network dynamics and the role of neur plasticity from a Bayesian perspective of informatio processing. The approach is motivated by recent studie from cognitive psychology and neurobiology which sugge that the way mammals integrate sensory information ar form memories during behavioral experiments can be w described by means of Bayesian methods. This is citing finding because akin learning theories became emendously successful during the last decade in state-of-e-art information technology for processing large nounts of complex data streams: for instance in itomated image recognition or email spam filters. For udying cortical network dynamics from this computational rspective, my work particularly revolves around the iestion whether and how neurons and synapses, the key iilding blocks of the brain, can naturally carry out the athematical operations and algorithms required for ayesian information processing.

ie work sets out with the notion, that humans and iimals seem to establish and maintain a model of their ivironment, or more technically speaking, to identify iaracteristic features in their sensory input and to scover relations among these features. Bayesian asoning exploits such a comprehensive model to draw nclusions about hidden causes that underlie partial or oisy observations, and, even more importantly, weighs e level of (un-)certainty of different potential solutions. iring my PhD studies, I contributed to developing a eoretical framework that explains how recurrent networks spiking neurons can embed complex probability stributions in their connectivity structure and in the namical properties of their constituents. More ecifically, this study showed how the transient spike sponse of recurrent networks can be interpreted as a stributed Markovian sampling process from a well-efined Bayesian posterior distribution (see figure). In irticular, our theory conceives ubiquitously observed ienomena, such as the apparent trail-to-trail variability in uronal population responses, as an integral part of an igoing computation. In a complementary line of research, and my colleagues investigated how sampling networks tegrate spiking input streams and how they can learn to entify characteristic features in the input statistics. In this ork, we showed analytically and in computer simulations w the interplay of synaptic and intrinsic plasticity can tablish a probabilistic model of spiking input streams in a atistically optimal fashion. More precisely, we proved that mpetitive network architectures with STDP-like synaptic id homeostatic intrinsic plasticity can implement iriational probabilistic inference and posterior-constrained lline Expectation Maximization learning.

ongoing work, I combine the above theoretical proaches to examine the computational function of a iquitous network motif found in superficial cortical layers ross many species. Interestingly, the analysis of network namics points towards an essential role of local inhibition support synaptic plasticity during learning. This study uld contribute to establish Bayesian spiking network odels as a useful research methodology for derstanding the complex, distributed dynamics of rtical networks within a comprehensive theory of mputation.

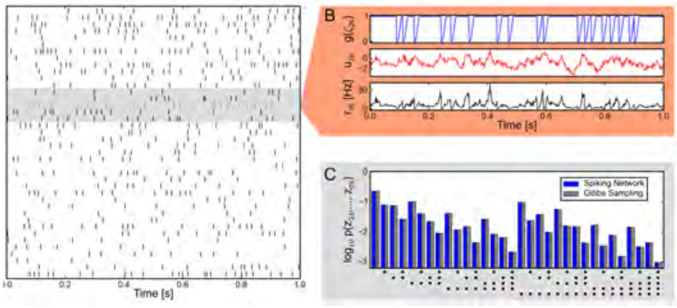


Figure: Sampling from a Boltzmann distribution by a recurrent spiking neural network. (A) Spike raster of the network. (B) Traces of internal state variables of a neuron. The rich interactions within the network give rise to rapidly changing membrane potentials and instantaneous firing rates. (C) Joint distribution of 5 neurons (gray shaded area in A) obtained by the spiking neural network and Gibbs sampling. The columns list all 32 possible states of the 5 neurons, active states are indicated by a black dot. The tight match between both distributions suggests that the spiking network represents the target distribution with high accuracy. [Figure taken from: Buesing, Bill, Nessler, Maass. Neural Dynamics as Sampling: A Model for Stochastic Computation in Recurrent Networks of Spiking Neurons. PLoS Computational Biology, 2011.]

Carlos Stein (EPFL LCN) – Theory on neuron and synaptic plasticity models that can learn to see

As easy as it may seem, recognizing a fellow human's face is a miraculous accomplishment of our brain, not yet reproduced by our best artificial intelligence. It involves a series of processing steps, including categorizing the "pixel" information, arriving at the retina, in edges, then shapes and finally objects. All this is not wired up, but actually learned through experience in our first months of life.

We studied the development of the visual cortex, modelling the ways neurons connect to each other, known as plasticity rules. With the right model, when the first layer of neurons is presented with outdoor pictures, the second layer spontaneously adapt its connections to detect edges in the images, reproducing what our visual cortex does.

The theory predicts if a given selection of neuron properties, plasticity rule and input images, will develop the expected detection capabilities and why. This generalizes known models to a single simple framework and hints on how to design new ones. Moreover, as many possible systems give similar positive results, evolution may have been free to converge to one based on additional constraints.

Friedemann Zenke (EPFL LCN)

Learning and memory in the brain are thought to be mediated through Hebbian plasticity. When a group of neurons is repetitively activated together, their connections get strengthened. Later, this can cause co-activation even in the absence of the stimulus that triggered the change originally. To avoid run-away behavior it is important to prevent neurons from forming excessively strong connections with each other. This is thought to be achieved by regulatory homeostatic mechanisms that constrain the overall neuronal activity. In this project we studied how fast homeostasis has to react to be able to guarantee stable activity in plausible models of recurrent neural networks where excitatory synapses are subject to physiological Hebbian learning rules. The most important finding is that the activity of such networks is unstable unless there is regulatory control on a very short timescale of seconds to minutes. Since this timescale is incompatible with most known forms of homeostasis, there has to be yet another rapid regulatory mechanism. We hypothesized that this role could be taken by Hebbian plasticity at inhibitory synapses, or else there has to be a rapid and yet unknown mechanism affecting excitatory synaptic plasticity directly.