	FACETS ***FP6-2004-IST-FETPI 15879*** ***Fast Analog Computing with Emergent Transient States***

FACETS Project Presentation

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Report Preparation: Prof. Dr. Karlheinz Meier

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Partners: U Bordeaux, CNRS (Gif-sur-Yvette, Marseille), U Debrecen, TU Dresden, U Freiburg, TU Graz, U Heidelberg, EPFL Lausanne, Funetics S.a.r.l., U London, U Plymouth, INRIA, KTH Stockholm

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DELIVERABLES TABLE

Project Number: ***FP6-2004-IST-FETPI 15879***

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Title: ***Fast Analog Computing with Emergent Transient States***

Del. No.	Revision	Title	Type[1]	Classifi-cation[2]	Due Date	Issue Date
2	**1.0**	**FACETS project presentation**	**R**	**Pub**	**28 Feb 06**	**20 June 06**

1 *R: Report; D: Demonstrator; S: Software; W: Workshop; O: Other – Specify in footnote*

2 *Int.: Internal circulation within project (and Commission Project Officer + reviewers if requested)*
Rest.: Restricted circulation list (specify in footnote) and Commission SO + reviewers only
IST: Circulation within IST Programme participants
FP5: Circulation within Framework Programme participants
Pub.: Public document

3*: The FACETS website and sharepoint server is an intranet communication platform*

DELIVERABLE SUMMARY SHEET

Project Number: FP6-2004-IST-FETPI 15879

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FACETS

Fast Analog Computing with Emergent Transient States

Deliverable -D2-

Project Description

Introduction

Information science has been a major driving force of the economical and social development in the 20th century. Based on the ingenious concept of Alain Turings universal computing machine and the availability of semiconductor based transistors, the IT industry has been able to follow an aggressive roadmap of ever increasing performance according to power laws like the well known Moore's Law (see Figure 1). It appears to be a matter of time only until computers will eventually reach the capabilities of the human brain.

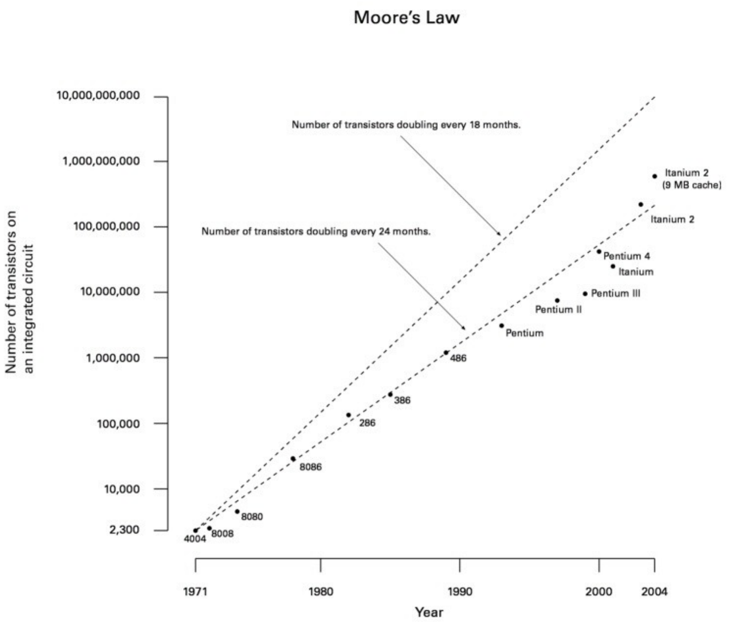

Figure 1 : Moores law represented by the number of transistors implemented in an integrated circuit on a logarithmic scale. The lines represent two different power laws.

Upon closer inspection, however, the brain is dramatically different from conventional computers. The differences are not only due to the use of biological tissue rather than silicon but also in terms of the computing architecture. The brain is not composed out of highly specialized and separated building blocks like a microprocessor but exhibits a rather uniform structure. It does not use Boolean logic like ANDs and ORs to perform operations on well defined stable states but involves the dynamics of transient (i.e. time-dependent) states to code and to process information. Maybe most importantly, there is no engineered software to deal with pre-defined situations. Instead, the brain is based on a huge number of truly massively parallel non-linear and diverse processing elements (neurons), a very high connectivity (synapses) and self-organisation (learning, plasticity).

The FACETS Consortium

The FACETS project aims to address the unsolved question of how the brain computes with a concerted action of neuroscientists, computer scientists, engineers and physicists. It combines a substantial fraction of the European groups working in the field into a consortium of 13 groups from Austria, France, Germany, Hungary, Sweden, Switzerland and the UK. About 80 scientists join their efforts over a period of 4 years, starting in September 2005. A project of this dimension has rarely been carried out in the context of brain-science related work in Europe, in particular with such a strong interdisciplinary component.

The following European institutions are members of the FACETS consortium

Ruprecht-Karls-Universität Heidelberg, Germany (coordinator)
University of Debrecen, Hungary
Ecole Nationale Supérieure d'Electronique, 'Informatique et Radiocommunications de Bordeaux, France
Technische Universität Dresden, Germany
Albert-Ludwigs-Universität Freiburg, Germany
Centre national de la recherche scientifique (UNIC), France
Centre national de la recherche scientifique (INCM), France
Technische Universität Graz, Austria
Ecole Polytechnique Federale de Lausanne (LCN), Switzerland
Ecole Polytechnique Federale de Lausanne (LNCM), Switzerland
Funetics S.a.r.l., Switzerland
The School of Pharmacy, London University, United Kingdom
University of Plymouth, United Kingdom
Institut National de Recherche en Informatique et en Automatique (INRIA), France
Kungliga Tekniska Högskolan Stockholm, Sweden

Motivation for the FACETS Project

Neuroscience is one of the main research topics of the 21st century. The human brain is said to be one of the most complex systems known to science and understanding how it works is as old a question as mankind. Most notably, the brain hides computational principles that exhibit such amazing properties like energy efficiency, fault tolerance, compactness to name only a few of them.

To understand the basic concepts behind these properties is essential for two reasons: The **life-science** point of view and the **information-technology** point of view.

- The first point of view has potential **medical applications** to cure brain and mind related diseases or even the longer-term goals to work towards neural prosthetic devices and artificial sensory organs.

- The second point of view could lead to **new computing devices** radically different from contemporary IT technology. Such devices could provide support for complex decision making processes like the one we are currently used to obtain only from human beings.

Aiming for a better understanding of biological nervous systems, there remains, however, one fundamental problem: A typical neural microcircuit in the human brain is a highly complex recurrent network (see Figure 2), composed of a huge number of neurons and synapses of diverse types that participate in equally diverse processes with time constants covering 13 orders of magnitude, from microseconds to years. These processes include, e.g, short term plasticity, long term learning, and development. Such neural microcircuits succeed in implementing massively parallel computations, where the inputs consist of multi-modal input streams generated by sensors recording a rapidly changing environment.

Given the complexity of the brain and its inherent dynamics, it is - at this time - still open whether our questions about the brain will ever be answered completely.

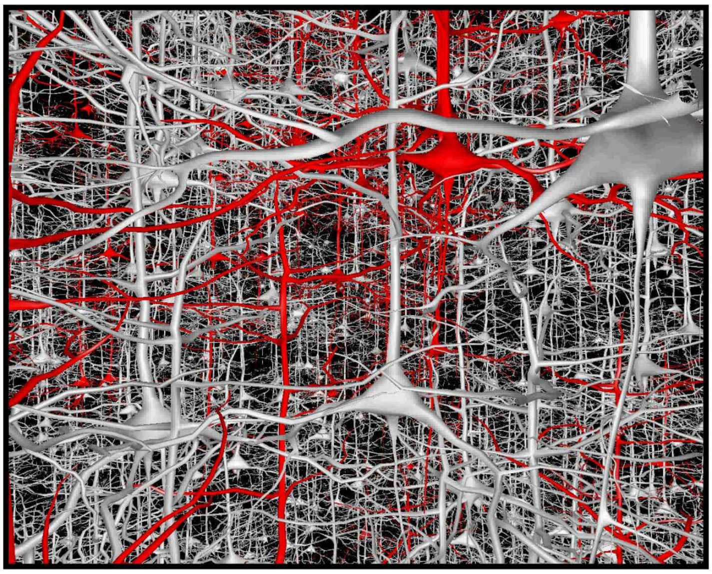

Figure 2: Computer Simulation of the Neural Microcircuit (Brain Mind Institute, EPFL Lausanne)

Goals of the FACETS Project

The FACETS project aims at conceiving paradigms of computation that depart significantly from the Turing concept of contemporary IT systems and make instead use of the complex and ongoing dynamics seen in brain activity. Paradigms of computation will be studied, where the complexity is the determining part of the computational process rather than being something to be avoided. In particular, one goal is to show how diverse computational architectures can emerge from the dynamic succession of transient states of activity distributed across the network and constrained by the intrinsic connectivity.

To this end, the FACETS project works towards laying a theoretical and experimental foundation for the practical realisation of novel computing hardware, which exploits the concepts experimentally observed in the brain. Such novel hardware systems will be beneficial for a broad range of experiments ranging from tests of neuroscience models to experimental studies of novel concepts in information processing which exploit the complex dynamics, the diversity of computing elements and the plasticity of the biological example.

In summary, the goals of the project can be formulated as follows (see Figure 3):

- To provide biological input data from in-vivo and in-vitro measurements at cell and network level, set-up a large-scale computer data base for neural cell characterisation
- To use large-scale computer based models to test the concepts and benchmarks developed in the project, develop a common data model for neural simulations
- To build and use very large-scale hardware models based on the above results
- To evaluate new computing paradigms using the FACETS benchmark problems in vision

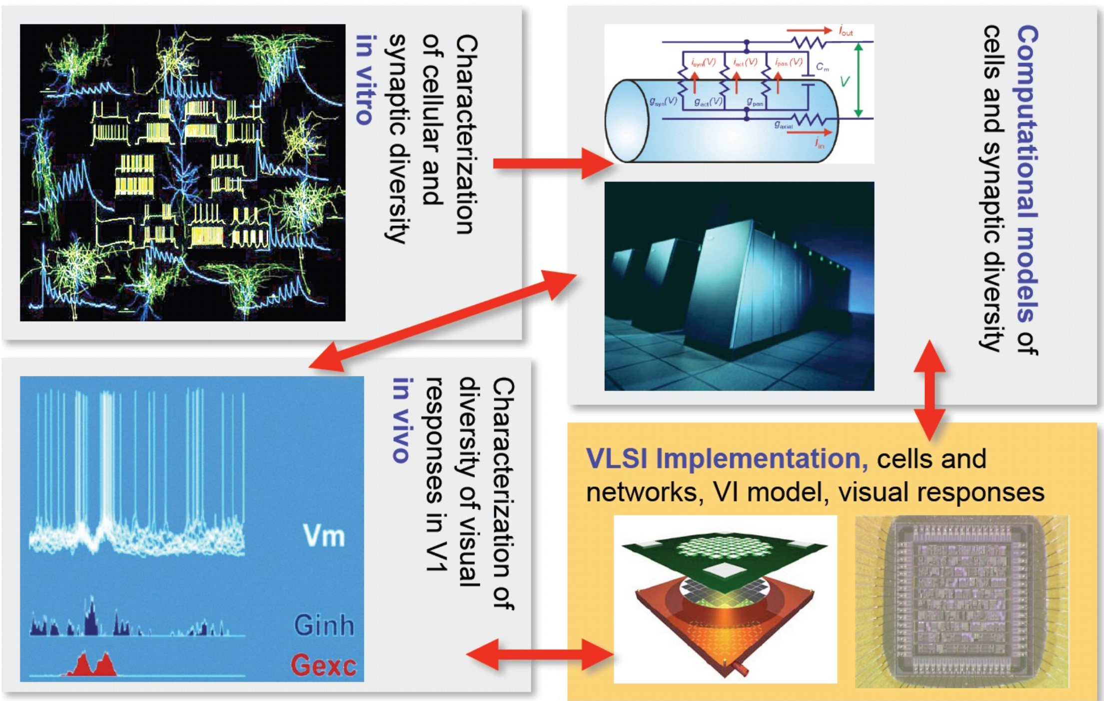

Figure 3: FACETS: Closing the Loop - Example for a Neuroscience Experiment

Modelling Approaches

Nearly all previous theoretical approaches for understanding biological nervous systems were based on models with simplified and homogenised neurons and synapses, simplified connection patterns and simple dynamics converging towards a set of point attractors. It is well known that the collective and complex behaviour of large populations of such units may lead to a distributed representation of information.

These now classic holographic theories have recently been the subject of renewed interest addressing the framework of complex dynamical systems, such as the dynamics-based computing, computing using neuronal diversity, or the liquid computing paradigms. From experimental studies, it is becoming increasingly clear that a diversity of functional assemblies are coexisting dynamically in the same anatomical network. The organisation of computations in neural microcircuits can only be understood on the basis of activity-dependent regulation and plasticity mechanisms that optimize such circuits for diverse tasks.

One reason for the relatively slow progress in the field of theoretical neuroscience is the difficulty of evaluating models with adequate test facilities. The invention of the digital computer has been a great improvement. Today, it is theoretically possible to test any model of neural function if it can be described by a mathematical formalism and if the resulting equations can be solved numerically. While this is in principle true for nearly all existing models, the computing time needed for this calculations becomes the limiting factor. Especially if plasticity, diversity and development are part of the model, the available computing power will be quickly insufficient to explore the timescales involved.

In order to solve the model equations, all digital simulations rely on the repeated execution of simple operations on data stored in some kind of memory. This is fundamentally opposite to the realisation in the human nervous system, where 100 billions of neurons and about 10^{16} synapses operate in parallel in continuous time. There is an enormous gap between nature and simulation, which reaches a complexity in the order of 10^3 neurons in real-time with a simple integrate-and-fire model and conductance based synapses on the fastest available microprocessors.

Neural Hardware Approaches

If the yearly performance gain of digital computers will be governed by Moore's law forever, it will take at least another half-century to reach the necessary computing power to simulate larger parts of the brain. If the model should include development, this simulation gap will widen even more. There is a strong need from the neuroscience community for systems that allow the modelling of moderately sized neural microcircuits including synaptic plasticity and cellular diversity. There are several approaches to fulfil these needs.

- Using parallel programming techniques on a computer cluster
- Developing a specialized digital system based on FPGA or ASIC technology
- Creating a physical VLSI model of the neural circuit under investigation

By creating specialized digital hardware processors it might be possible to gain an advantage over microprocessor-based systems. Still, it is unlikely that this will be more than an order of magnitude, since they are based on the same technology as microprocessors: The neural circuits remain to be realised with numerical solutions of differential equations. The biggest problem lies in the fundamentals of Moore's law itself: the scaling of process technology. In the current semiconductor roadmap the progress has already slowed down. The transistor density of high-performance microprocessors is likely to increase only by a factor of 25 from 2004 to 2018. A power consumption of 300 Watts is predicted for such a hypothetical chip while the on-chip operating frequency will be in the 50 GHz range.

Thus, the only possibility to get a significant gain in simulation speed within the current decade is parallelization of dedicated analog circuits, which implement directly the processes in nerve cells. Dedicated hardware like analog ASICs can be optimized for parallelization. In FACETS' very large scale neural network systems, the cell based calculations will be done using analog models and the communication across medium or long distances using digital (spike-time) coding. With this approach, the final system size is only limited by the available resources and not by physical (signal degradation) or timing limitations.

The FACETS hardware will be implemented as very large-scale VLSI-based neural circuits that emulate substantial fractions of the brain (see Figure 4). As such, it will be based on a novel computing paradigm radically different from the Turing approach which forms the successful basis of contemporary IT systems. The new paradigm makes use of the massively parallel, complex and ongoing dynamics observed in brain activity. Thus, a detailed structural (connection pattern, neuronal diversity) and functional (dynamic states of activity, plasticity) characterization of cortical circuits is a prerequisite to establish theoretical models of the computing concepts realized in the brain that can in turn be transferred into requirements for the hardware realization. Figure 5 shows a hardware design study.

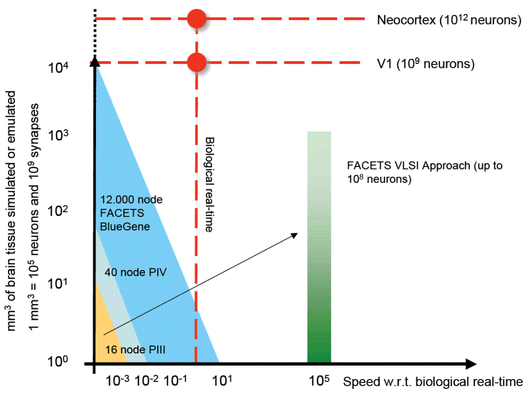

Figure 4: Supercomputers and VLSI - Complexity versus Speed

The proposed hardware system will feature a high degree of configurability, the possibility to read-out and monitor ongoing activity, and a high operation frequency. In particular, this will allow to study experimentally the very different time domains from individual spike generation over short term plasticity to long term learning, development, and possibly even evolution.
The speed of the hardware will permit to bridge the huge time gap between the above mechanisms (milliseconds to years): A relative speed-up of 100.000 can be achieved and will compress time-scales of a year to a few minutes (Figure 4). Therefore, this hardware is expected to serve as a valuable and flexible future research tool for neuroscience. Among other things, artificial systems of this kind will help to reduce the need for experiments carried out with living neural tissue.

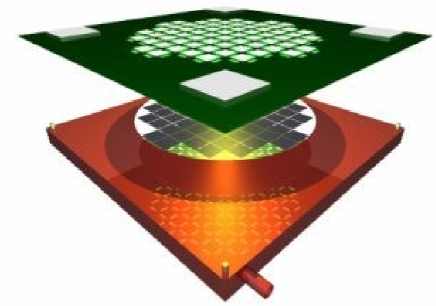

Figure 5: Design Study of a Neural Network Hardware Using Wafer Scale Integration

Structure of Research Activities

Four major lines of research have been defined, which closely follow the project goals described in the previous paragraph :

- The experimental characterisation of cortical cells and networks in-vivo and in-vitro
- The study of theoretical and computer based models of cells and networks
- The design, construction, and operation of VLSI circuits emulating the biological example
- The study of mechanisms for changes and adaptation on all 3 above levels

Beyond that, a very essential aspect of the work to be carried out within the project is the necessary integration of the results and demonstrators produced in the above lines of research. To this end, the performance of software models and hardware systems will have to be assessed in realistic scenarios.

In order to focus the computational analysis on realistic tasks for this new approach to computing, the benchmark applications for the project will concentrate on computational problems that arise in vision, in particular on problems involving rapidly changing visual input where there is a particular need for novel computational ideas and corresponding circuit designs.

The implementation of the FACETS scientific, training, demonstration and management goals is organised into 10 workpackages (WP). Here, 8 scientific workpackages are complemented by 2 workpackages handling the aspects of management (WP 1) and outreach and dissemination (WP 10), respectively. An organisational chart of the FACETS workpackage structure and their interdependencies is given in Figure 6.

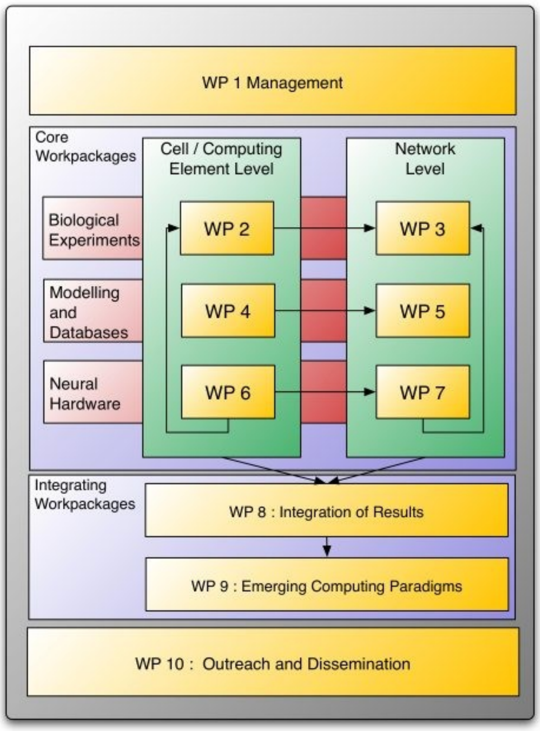

Figure 6: FACETS workpackage organisation

The basic concept of the implementation plan is to create 6 small size, scientifically focused, and rather autonomous subgroups which work on well defined fields providing the specific knowledge required to reach the overall project goal.

These 6 subgroups work on the 6 "Core Workpackages" (CWs) WP 2 - WP 7. In the spirit of autonomous operation, the day-to-day collaboration within the CWs will be very intense and they organise scientific exchange, ad-hoc meetings, workshops, and training activities according to their own specific needs.

The 6 Core Workpackages address the following topics:

- WP 2 : Biological Experiments at the Cell Level
- WP 3 : Biological Experiments at the Network Level
- WP 4 : Modelling and Database at the Cell Level
- WP 5 : Modelling at the Network Level
- WP 6 : Neural Hardware at the Cell Level
- WP 7 : Neural Hardware at the Network Level

Beyond those CWs, a dedicated WP 8 takes care of integrating the individual results. This WP is of particular importance to make best use of the unique interdisciplinary power assembled in the FACETS project. Furthermore, a major scientific goal of the FACETS projects is to apply the accumulated knowledge in biology, modelling, and hardware design to explore and exploit emerging new computing paradigms. WP 9 is dedicated to this challenge. WP 8 and WP 9 are called "Integrating Workpackages" (IW).

Finally, WP 10 is organised to spread the knowledge available and acquired within the consortium internally, in the scientific community, and to the public. Among other activities, it is planned to organise within the FACETS community 4 annual workshops to ensure that scientists (especially young scientists) have access to cross-disciplinary training. This is necessary to promote communication within the consortium and to improve in-depth understanding of partners' approaches. Furthermore, the FACETS partners will organise annual meetings which are open to the scientific community.

While every single workpackage integrates the concerted effort of multiple participants, each is coordinated by a dedicated workpackage leader from one of the participating institutions. The workpackage leaders are:

- WP 1 Björn Kindler, Ruprecht-Karls-Universität Heidelberg, Germany
- WP 2 Henry Markram, Brain-Mind Institute, EPFL Lausanne, Switzerland
- WP 3 Yves Fregnac, CNRS-UNIC, Gif-sur-Yvette, France
- WP 4 Wulfram Gerstner, Brain-Mind Institute, EPFL Lausanne, Switzerland
- WP 5 Alain Destexhe, CNRS-UNIC, Gif-sur-Yvette, France
- WP 6 Sylvie Renaud, Ecole Nationale Supérieure de Bordeaux, France
- WP 7 Johannes Schemmel, Ruprecht-Karls-Universität Heidelberg, Germany
- WP 8 Thierry Viéville, INRIA, Sophia-Antipolis, France
- WP 9 Wolfgang Maass, TU Graz, Austria
- WP 10 Kirsty Grant, CNRS-UNIC, Gif-sur-Yvette, France

Contact and Information about the project

The project has an extensive internet which is continuously updated with the latest results obtained :

http://www.facets-project.org

The coordination office in Heidelberg will also be available to provide information about the project.

FACETS Coordinator	**Project Administrator**
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