The **FACETS** Consortium

Fast **A**nalog **C**omputing with **E**mergent **T**ransient **S**tates

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

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An Integrated Project in the 6th Framework Programme

Information Society Technology - Future Emergent Technologies

FP6-2004-IST-FETPI   Proposal Number 15879

FACETS in the 6th Framework Programme of the EC

6th Framework Programme (FP6) 2003 - 2006 (start dates) **: 15.6 Billion**

Integrating and Strengthening the ERA : 13 Billion

- **IST** (Information Science Technology) : 3.6 Billion
  - **FET** (Future Emergent Technology) : 300 Million
    - **Call 3** : 80 Million (only Integrated Projects and NoE)
      - Quantum Computing
      - Nanoelectronics
      - Ubiquitous Computing
      - **Bio-I3** : about 20 Million
        - Integrated Projects
          - CILIA
          - DAISY
          - **FACETS** : 10.5 Million

Extracts from the FET „Position Paper“ for Call 3 :

- Reverse engineer the brain
- Study Dynamics of large neuronal assemblies
- 1st research focus (out of 4) : “Study brain architectures as computational architectures”
  - static + dynamic
  - bridge dimensional scales
  - what is the information content of an assembly ?
  - plasticity is an aspect of “growing” or “self organisation”

FACETS : Past - Present - Future (or : 2 years from idea to reality ...)

- Idea developed out of SenseMaker project group
- Brainstorming Meeting at EPFL september 2003
- *FACETS name invented by Thierry Bal (CNRS, Gif-sur-Yvette)*
- Finalise „FACETS Core Document“ december 2003
- Consortium formed by june 2004
- Pre-Proposal submitted july 2004
- FACETS Project Proposal submitted september,22nd 2004
- Written referee reports and invitation for hearing november 2004
- Project presentation and hearing in Bruxelles november 2004
- Formal contract negotiations started march 2005
- Ethical review april 2005
- Project start september 2005
- Project duration 4 years

FACETS in Numbers

13 Institutions

EU funding 10.5 Million Euros (about 70% personell)

Substantial contributions from participating institutions

Project Duration 4 years

Average of 79 people (FTEs) working for the project full time

This is a small-medium *virtual research laboratory*

10 Workpackages

Contemporary IT systems

- Processor-memory based architectures with serial command execution (Turing)
- Predetermined algorithms define capabilies and performance (software)
- Based on well defined reproducible states and well defined reversible time evolution
- Electronics implementation of Boolean operators, high power consumption
- Extremely high yield requirements, little fault tolerance
- Limited by atomic distance scale in componets (nm) : component limited

WELL UNDERSTOOD

Neural computation

- Massively parallel, non-linear compting elements with large diversity
- Time correlations drive the dynamics
- Learning by internal self-organisation and strong interaction with environment
- Low power consumption and high fault tolerance
- Limited by degree of complexity : architecture limited

NOT UNDERSTOOD (listed as a major challenge for 21. Century science)

FACETS Goals as written in Project Proposal

- 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

- Use very large-scale computer based models to test the concepts and benchmarks developed in the project, develop a common data model for neural simulations

- Build and use large-scale hardware models based on the above results

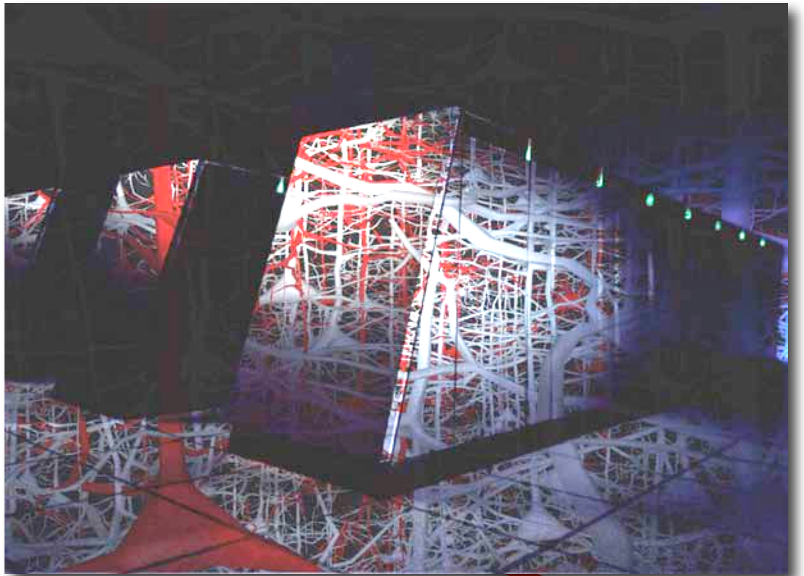
- Evaluate new computing paradigms using the FACETS benchmark problems in vision

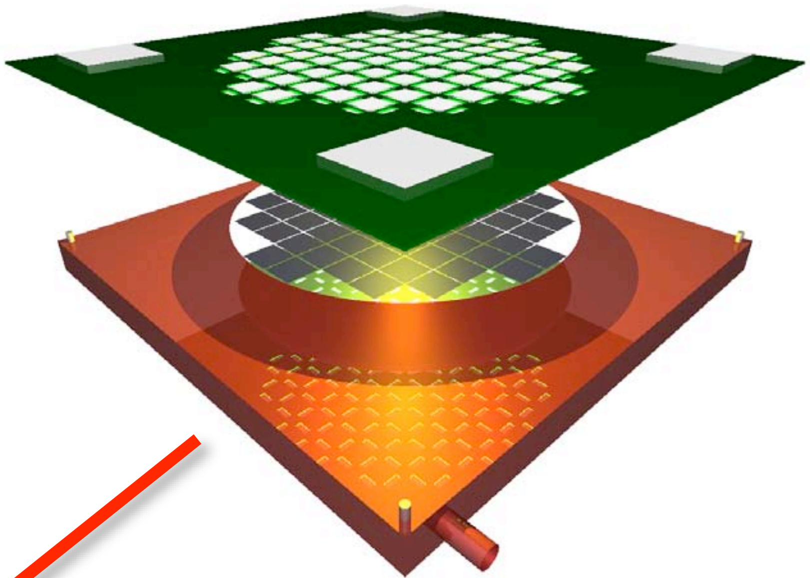
FACETS : Basic Idea, methodological approach and goals

Experimental Biology : Reverse Engineered Structural and Functional Blueprint of the Neocortical Microcircuit

Modelling : A Virtual Microcircuit on a Computer

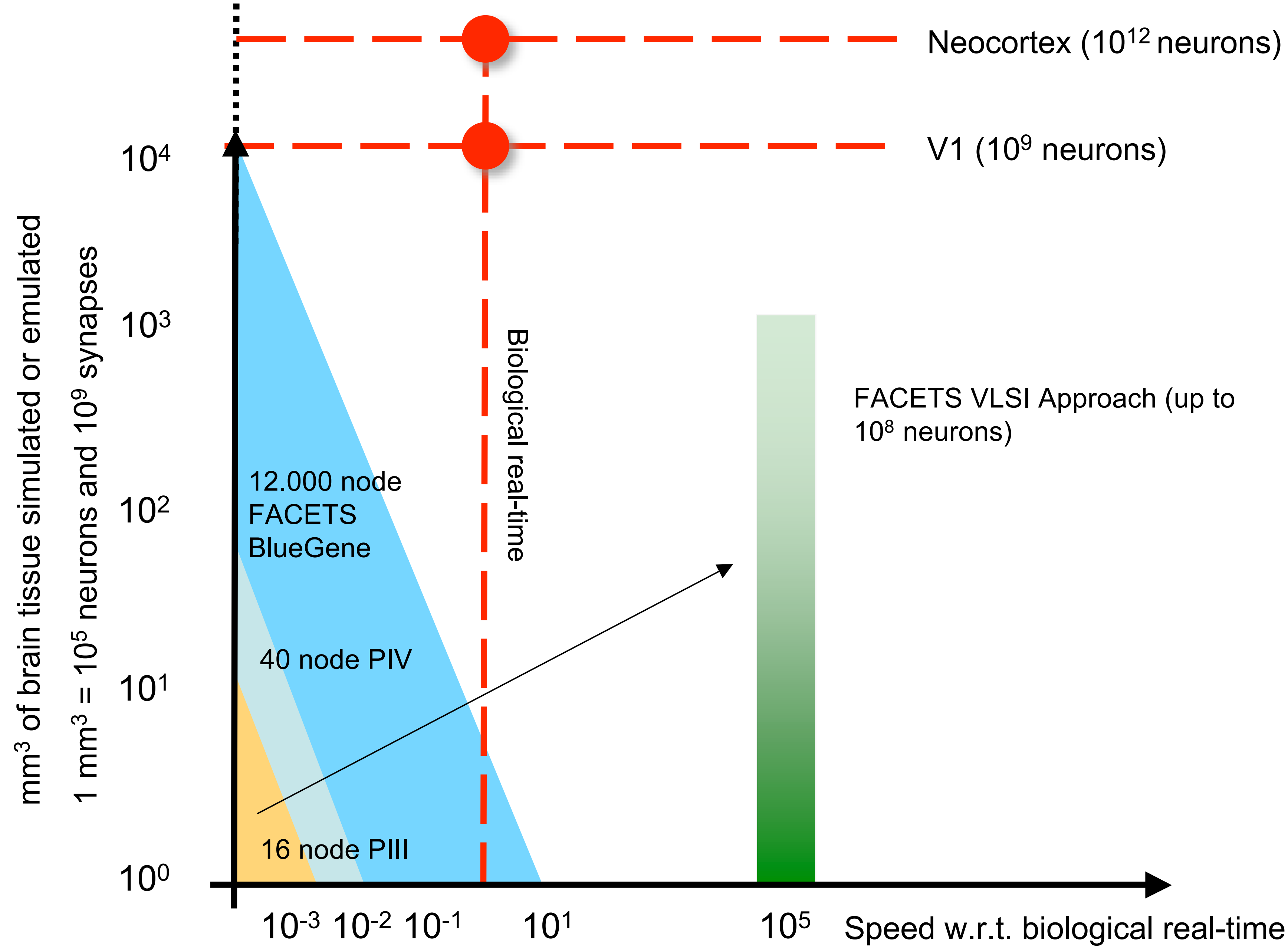
Circuits : Emulation in analog, fault-tolerant, scalable, high speed VLSI



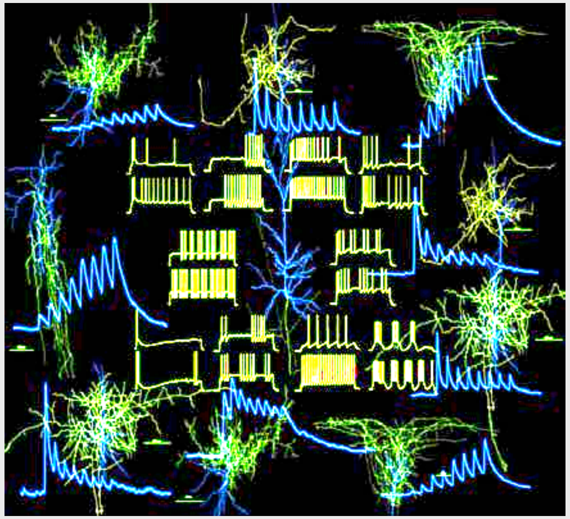


Common Goal : Study non-classical universal computing solutions

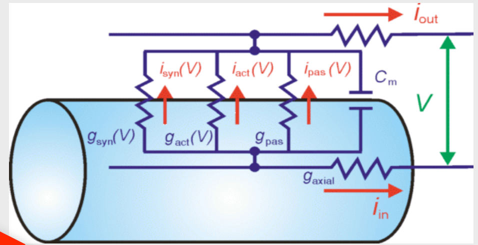
FACETS : Complementarity Supercomputers and VLSI - Complexity vs. Speed

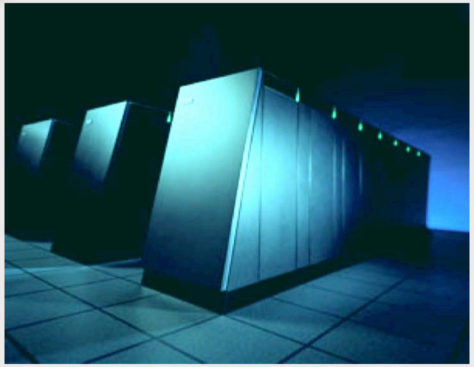


FACETS : Closing the Loop - Example for a Neuroscience Experiment

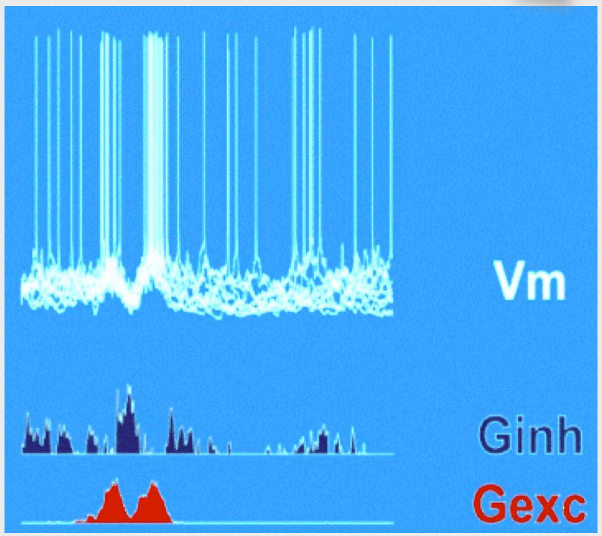


Characterization of cellular and synaptic diversity **in vitro**



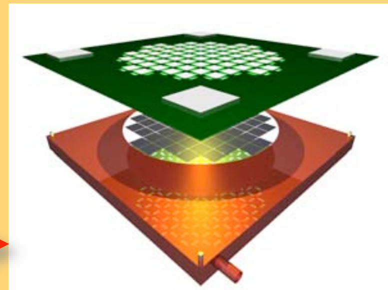


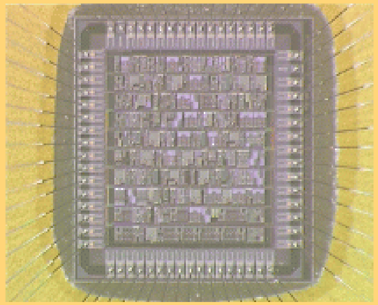
Computational models of cells and synaptic diversity



Characterization of diversity of visual responses in V1 **in vivo**

VLSI Implementation, cells and networks, VI model, visual responses

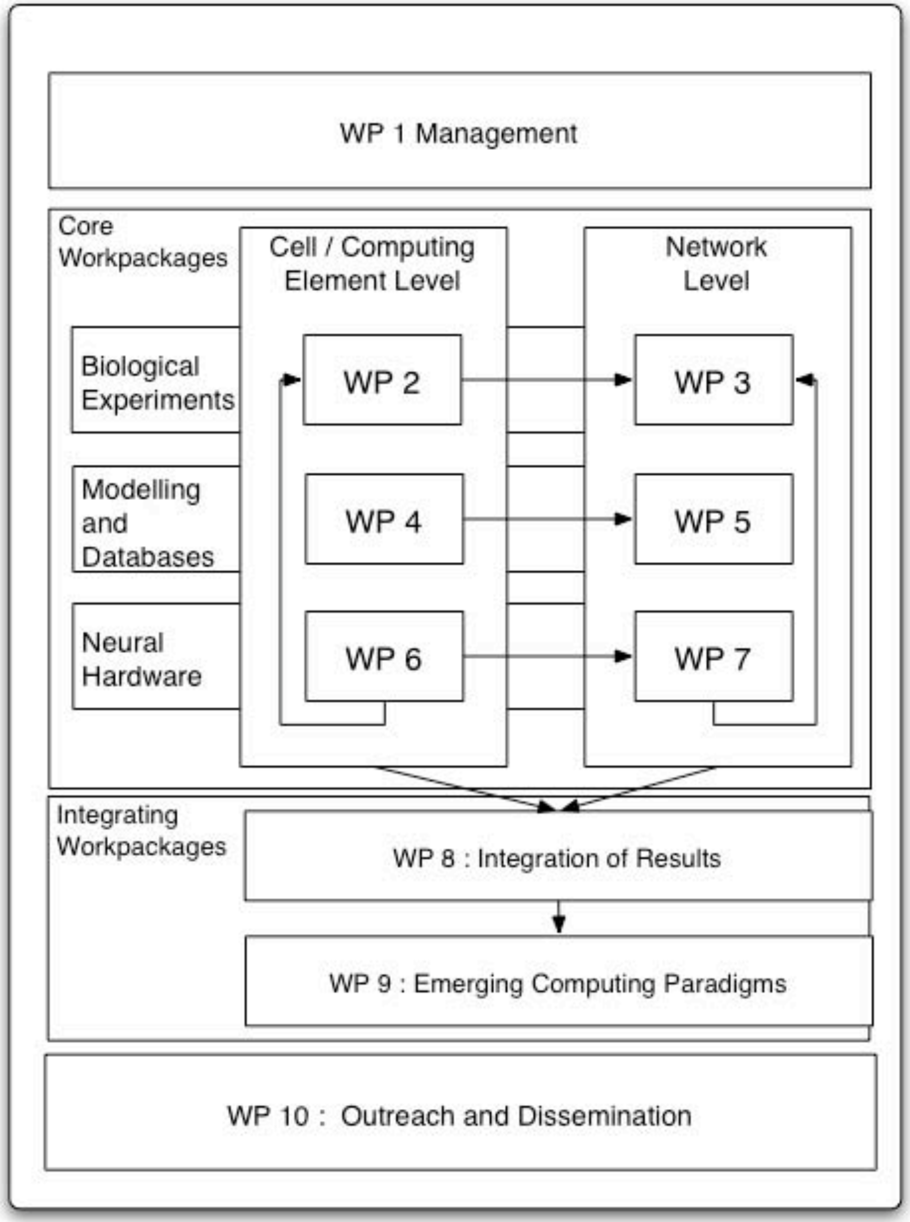




The consortium combines competence and long time experience in the following research areas :

- Concerted and organised effort to collect a detailed and large statistics **database** of neural cell and network properties from high statistics in-vitro measurements.
- Availability of state-of-the-art hardware (IBM BlueGene at EPFL) and software tools to **simulate** the dynamics of very large scale neural microcircuits.
- Access to state-of-the-art analog and mixed-signal VLSI technologies to **emulate** the dynamics of large scale neural microcircuits at speeds up to 100.000 times faster than the biological example.
- Availability and further development of high level and low level **analytical models** of neural computations as a basis for novel computing paradigms.

FACETS : Project Structure



Flow of Work

6 rather autonomous core workpackages

Biology - Modelling - VLSI Hardware

Each on : Cell Level - Network Level

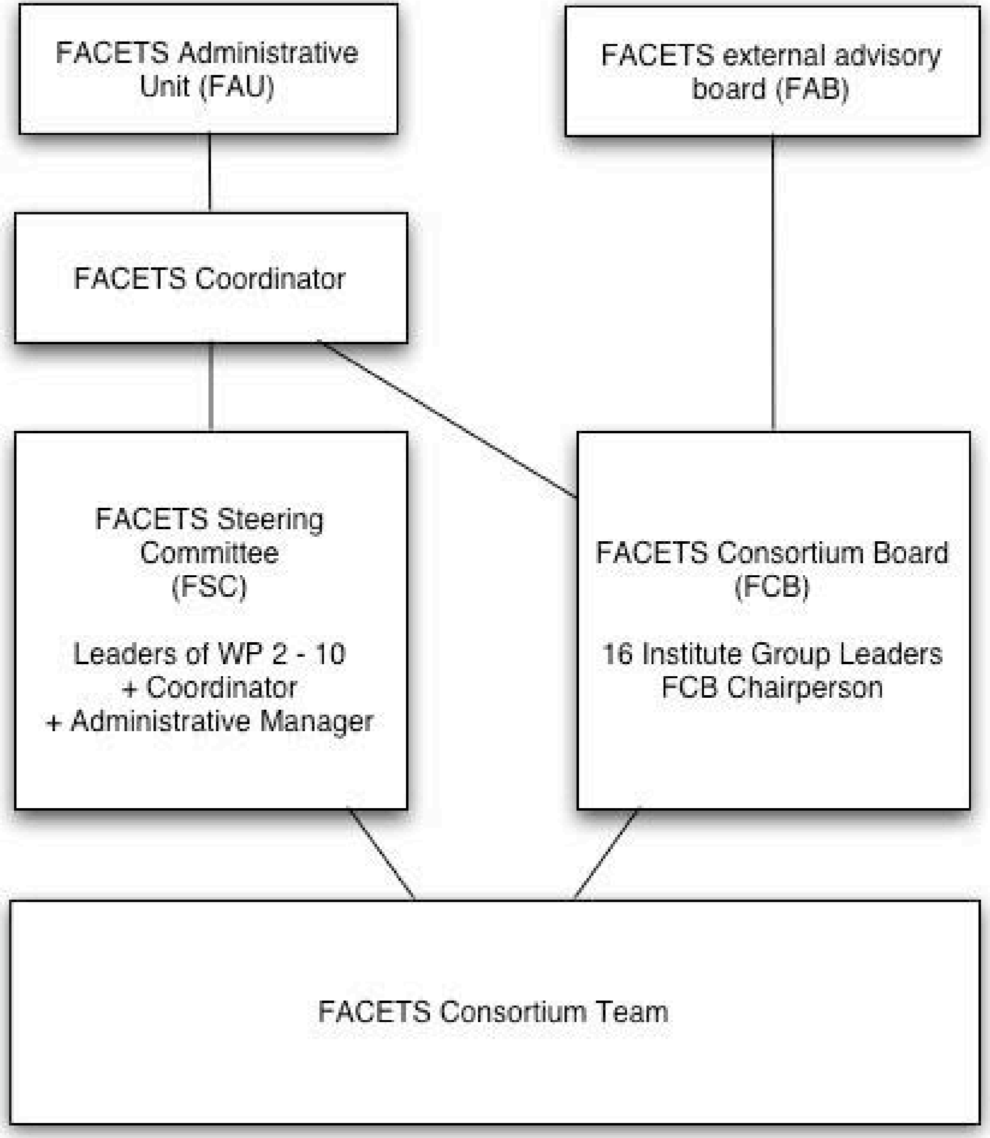
Major Efforts on

integration of results

and

study/implementation of new computing paradigms

WP1 . Administrative Structures



WP 2 : Biological Experiments on the Cell Level (Henry Markram)

This work package aims to deliver a thorough cellular and synaptic breakdown of the neocortical microcircuit at the anatomical, physiological, pharmacological, and gene expression level as well as rules for synapses learning. This workgroup will therefore provide the cellular and synaptic parameters to model

a) single neurons
b) synaptic transmission between different types of neurons
c) networks of neurons
c) synaptic learning using biologically realistic parameters.

All data existing data detailing the microstructure of the neocortical microcircuit as well as data obtained during the course of this grant, will be entered into a database located at the Brain Mind Institute in Lausanne. A preliminary database has been constructed and is located at http://microcircuit.epfl.ch. The database will be modified to accommodated the specific data formats of each workgroup to include *in vitro* and *in vivo* data from different brain regions.

WP 3 : Biological Experiments at the Network Level (Yves Fregnac)

“The sensory neocortex is considered here as a context-dependent reconfigurable computing machine”

The WP is organized as a series of biological studies in the slice and in the intact organism which aim at

1) providing a mechanistic understanding of the genesis of high-conductance states and dynamic attractors during sensory processing
2) validating self-organizing principles of synaptic plasticity which have been initially studied in simplified preparations
3) relating the diversity of the computational and functional repertoire of sensory cortex with the diversity in anatomy and electrical signatures of cortical circuits
4) providing benchmark paradigms for the study of V1 cortical mechanisms involved in low-level (non-attentive) perception.

WP 4 : Modelling and Databases at the Cell Level (Wulfram Gerstner)

This workpackage uses experimental data on single neurons and synapses collected in WP2, and additional data on synaptic plasticity in vivo from WP3.

The overall goal of the workpackage is to develop efficient models of single neurons and synapses that include all important aspects of single-neuron behaviour while being suitable for the large-scale simulations of WP5 and WP9 and the hardware implementations of WP6 and WP7.

The specific aims of the workpackage are to make experimental single-neuron data accessible in a data base; to develop detailed conductance based models of each neuron type in the data base; to reduce the detailed models to simplified models suitable for large-scale software simulation and large-scale hardware integration; and to develop efficient models of synaptic dynamics on short and long time scales.

WP 5 : Modelling on the Network Level (Alain Destexhe)

The main goal of WP5 is to bridge the gap between experimental data at the network level (see WP3), and modelling approaches, so that the results from *in-vivo* experiments can be directly addressed using hardware approaches (WP6, WP7).

This workpackage consists in building network models of the sensory neocortex, including top-down influences coming from higher cortical areas to V1 and from V1 to thalamus, and explore low-level biological paradigms such as the genesis of states of activity consistent with *in-vivo* measurements, and the emergence of functional selectivity in receptive fields of V1 cells.

The models developed here will be passed to other workpackages (WP9) to investigate high-level computational paradigms.

WP 6 : Neural Hardware at the Cell Level (Sylvie Renaud)

Design and exploit specific VLSI circuits of high biological relevance in order to simulate at the level of single cells or small networks the models developed in WP2-WP5.

The real-time properties of the VLSI circuits that implement the conductance-based neuron models identified in WP4 will allow a systematic and detailed exploration of parameter space.

Furthermore, the physical and analogue aspects of the hardware simulations of this WP will provide input for the development of neural hardware at the network level of WP7.

WP 7 : Neural Hardware at the Network Level (Johannes Schemmel)

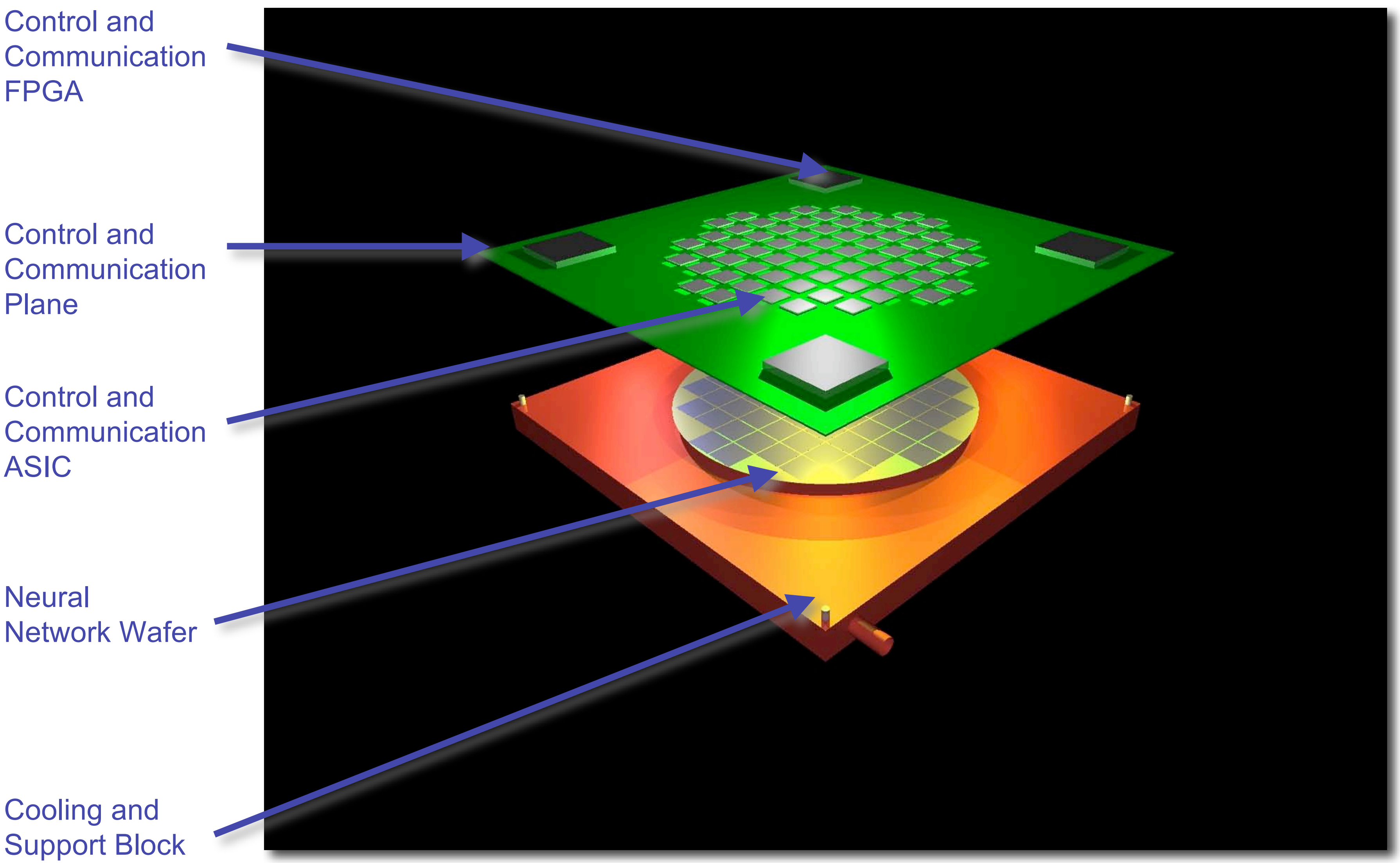
Hardware design of very large-scale hardware neural network systems

Will depend on the work emerging from the three lines of research addressing the characterization of cortical circuits (WP2, WP3), the construction of theoretical models (WP4, WP5) and the studies of hardware on the cell level (WP6).

2 Step approach : Discrete distributed system - Wafer Scale Integration

Feature	Description
Scalability	Clearly defined “stackable” building blocks, no size or distance dependent communication quality, capability to build superstructures
Complexity	Approach the number of computing elements (neurons, synapses, connections) of a cortical area (e.g. VI)
Mixed-Signal	Analogue computational elements (neurons and synapses), direct short range spike transmission, digitally coded, event-based medium and long-range data transmission of action potentials
Massively Parallel	Exploit the same concepts of parallelism as the biological example
High Speed	Time compression factor of 100.000 beyond biological real-time. Possibility to study all biologically relevant dynamics in convenient laboratory time scales. 1 ms corresponds to 10 ns, 1 year corresponds to 5 minutes
Configurability	User configuration of neuron and synapse parameters to implement, configuration of medium and long range connectivity, on-chip storage und update of synaptic weights based on *STDP* rules
Fault Tolerance	Ability to operate with faulty components on all network levels (computing elements and connections) imposed by imperfections of the semiconductor production process. Use of wafers without detailed pre-testing
Biological Basis	Based on inputs from biological measurements and corresponding models at the level of computational elements as well as network structure

FACETS :A Neural Processing Unit (NPU) with $5x10^5$ Neurons and $2x10^9$ Synapses



WP 8 : Integration (Thierry Vieville)

In the "Core Workpackages" the competences in the areas of biological experiments, modelling and hardware design are focused in order to ensure scientifically focused collaboration in smaller groups without formal communication procedures.

For the final goal of improving the understanding of neural signal processing and working towards possible applications in novel computing architectures the strength of the FACETS project lies in its broad interdisciplinary background and the capability of communication.

The task of WP8 is to collect the results from the "Core Workpackages" and to distribute them for use either in other "Core Workpackages" or for the development of emergent computing paradigms in workpackage 9.

WP 9 : Emerging Computing Paradigms (Wolfgang Maass)

The aim of this workpackage is to develop new computational paradigms on the basis of the results of the other workpackages. In particular it will

characterize the functional properties of biological neural networks investigated in WP3 and corresponding neuronal network models constructed in WP5, and use this characterization as guide for the refinement of structural parameters in network models.

examine computational properties of the models of neural circuits constructed in WP3 and WP5, and produce specific computational goals for the hardware-oriented WP6 and WP7.

investigate whether theoretical predictions of novel non-Turing computational properties of dynamic neural circuits hold true for detailed and realistically scaled software and hardware models of neural microcircuits, and develop new theoretical models that capture computational advantages of the biologically realistic models for cortical circuits produced by the other WPs

develop new paradigms for anytime computing on complex sensory input streams.