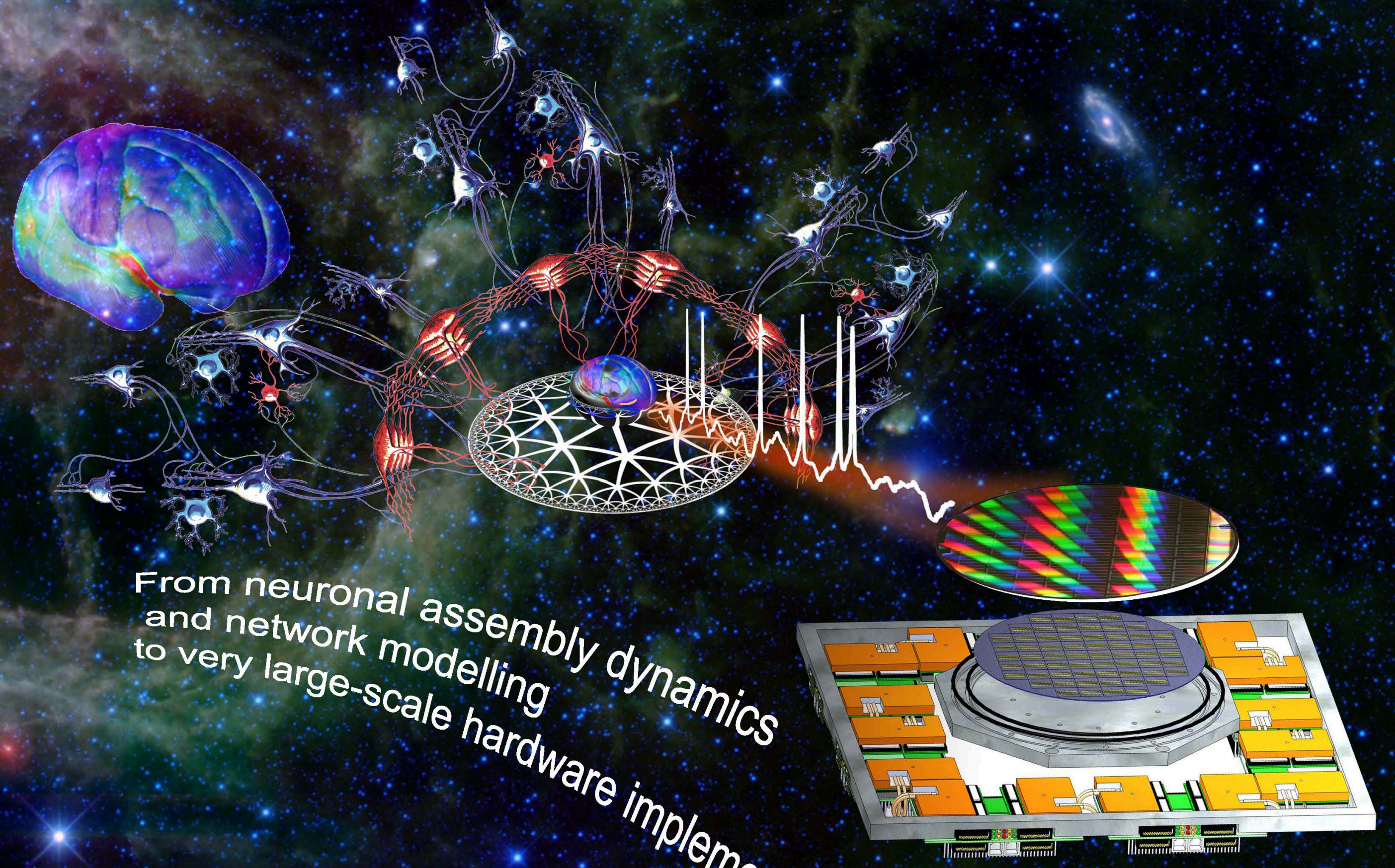
FRONTIERS IN NEUROMORPHIC COMPUTATION:

a Multi-FACETS Enterprise

3 - 4 JUNE 2010

Collège de France, Paris, France



From neuronal assembly dynamics
and network modelling
to very large-scale hardware implementation

Speakers include:

Gérard Berry
Alain Berthoz
Nicolas Brunel
Gordon Cheng
Andrew Davison
Alain Destexhe
Rodney Douglas
Olivier Faugeras
Yves Frégnac
Thomas Fritzsch
Wulfram Gerstner
Mark-Oliver Gewaltig
Achim Graupner
Jens Kremkow
Anders Lansner
Gilles Laurent
David Lester
Wolfgang Maass
Henry Markram
Guillaume Masson
Karlheinz Meier
Sylvie Renaud
Johannes Schemmel
Anteo Smerieri

More information and registration
(free of charge) at:
www.facets-project.org

IPSEN cost INAF Brain-i-Nets FACETS- ITN cnrs ITMO Neurosciences EU-FET

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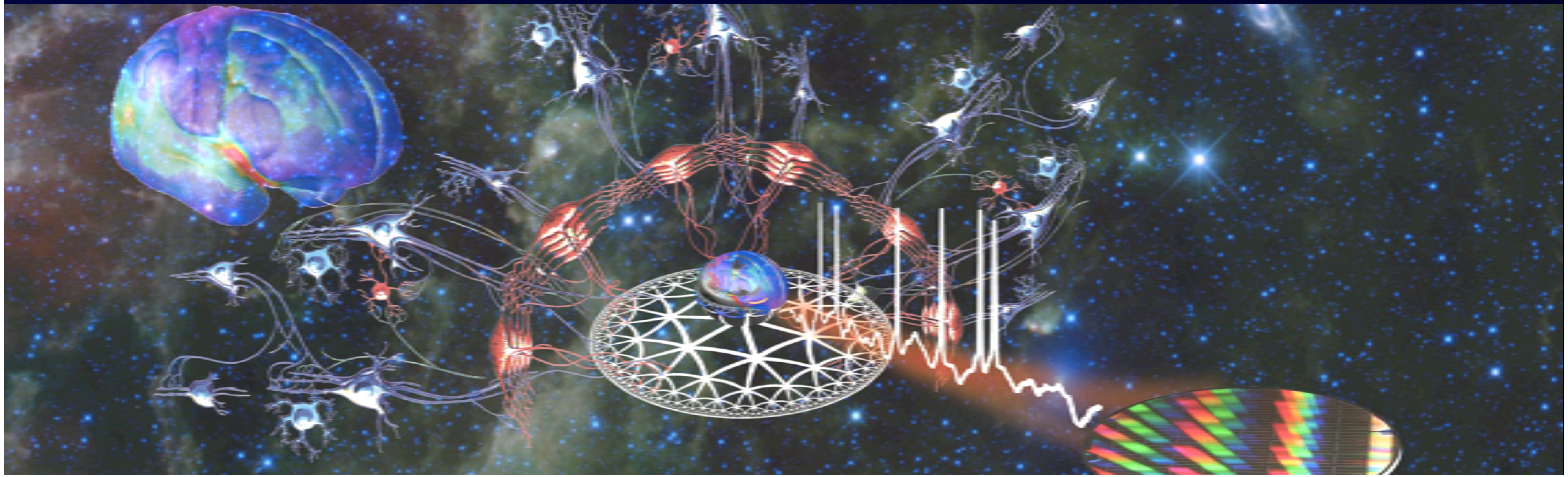
Welcome and Introduction - *Frontiers in Neuromorphic Computation*

Karlheinz Meier



Morpheus by Jean-Antoine Houdon - Musée du Louvre

J. McCarthy, M. L. Minsky, N. Rochester, C.E. Shannon, 1956

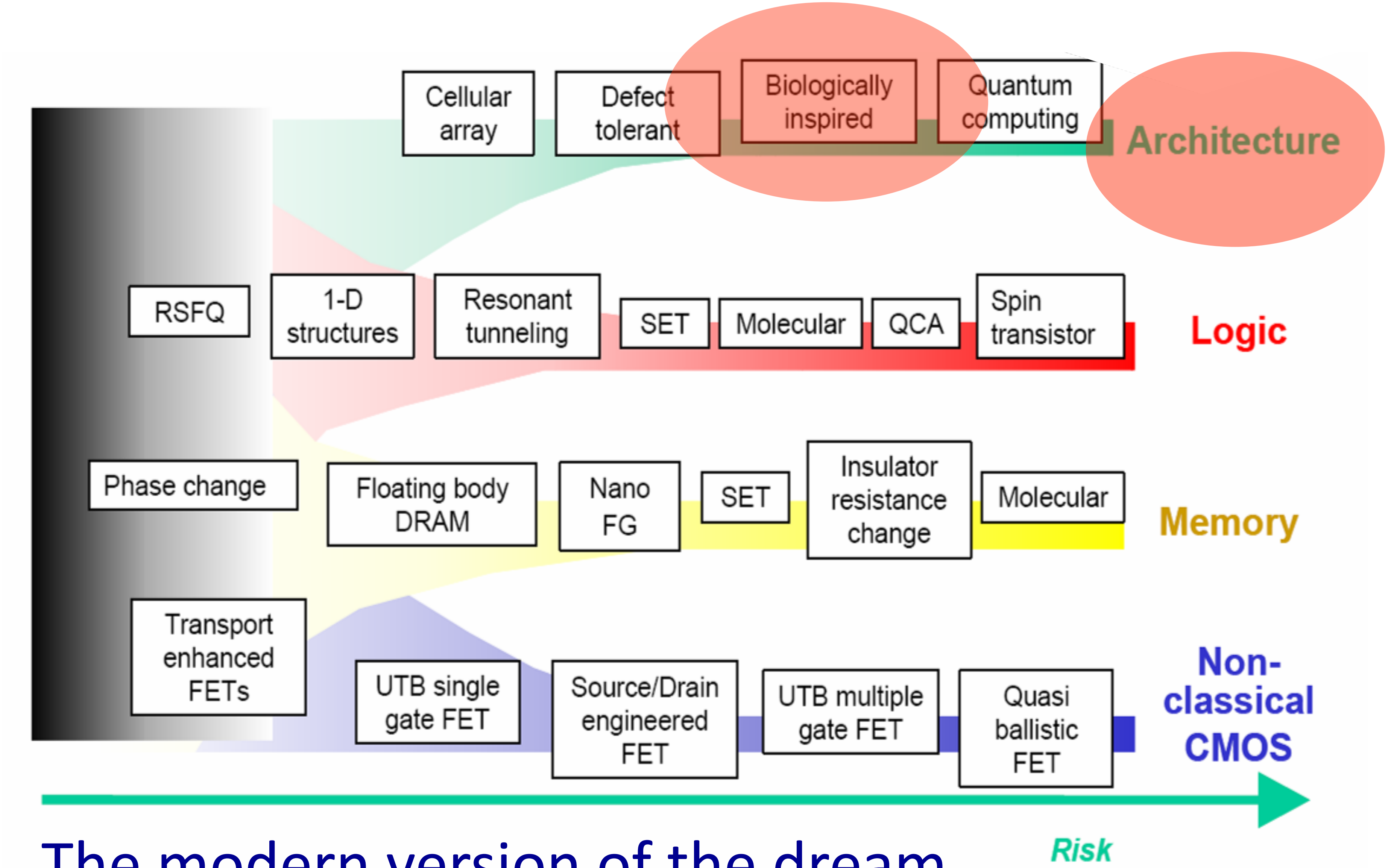
„We propose that a 2 month, 10 man study of artificial intelligence be carried out during the summer of 1956 at Dartmouth College in Hanover, New Hampshire.

The study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it. An attempt will be made to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves.

We think that a significant advance can be made in one or more of these problems if a carefully selected group of scientists work on it together for a summer"

- Machine ?
- Learning and Intelligence ?

International Technology Roadmap for Semiconductors



The modern version of the dream …

WHY ?

Contemporary IT Systems

- Processor-memory based architectures with serial command execution (von Neumann)
- Predetermined algorithms define capabilities and performance (Software)
- Reproducible states and reversible time evolution
- Electronics implementation of Boolean operators, high power consumption
- High yield requirements, little fault tolerance
- Limited by atomic distance scale in components (nm) : ultimately component limited

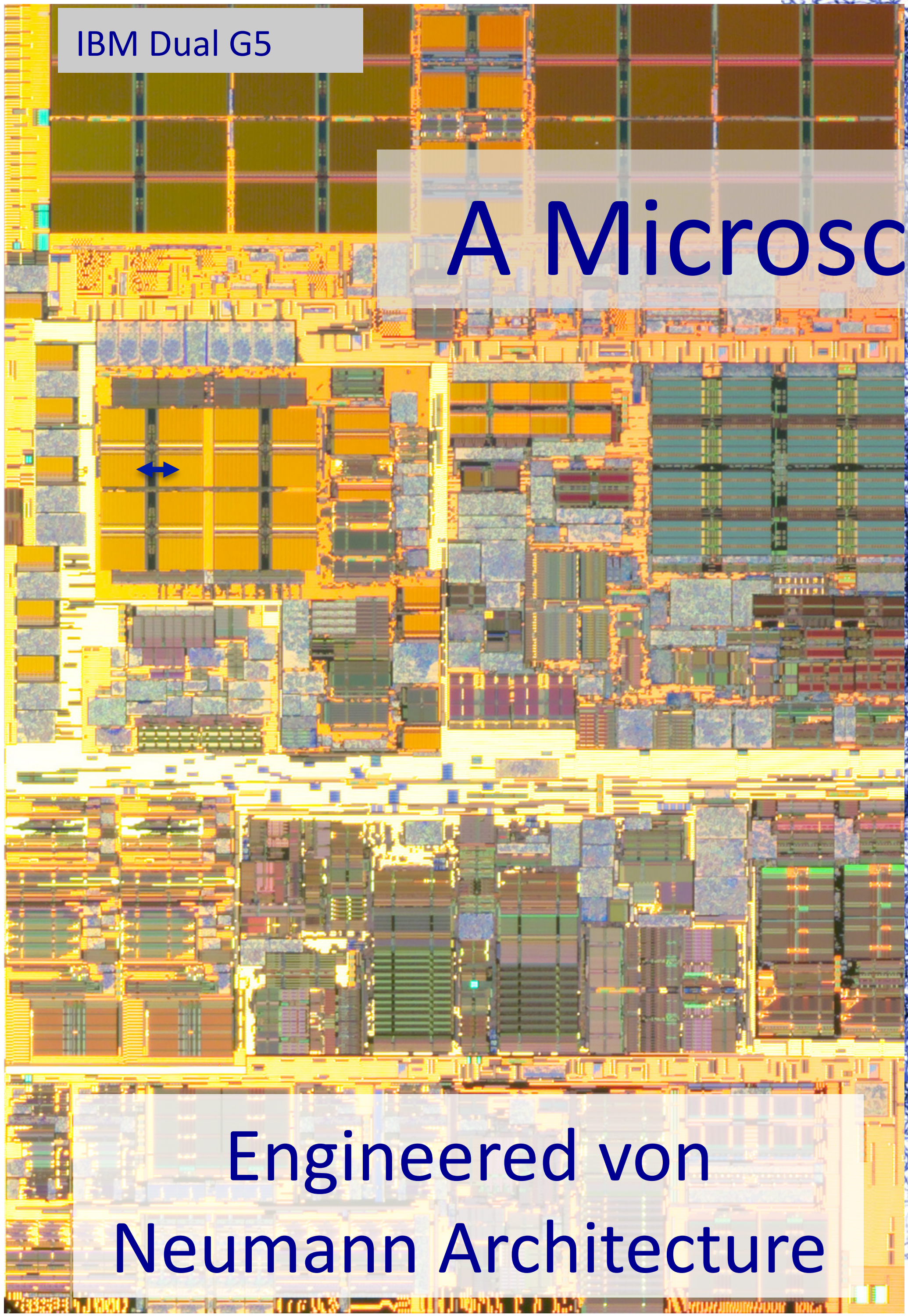
WELL UNDERSTOOD

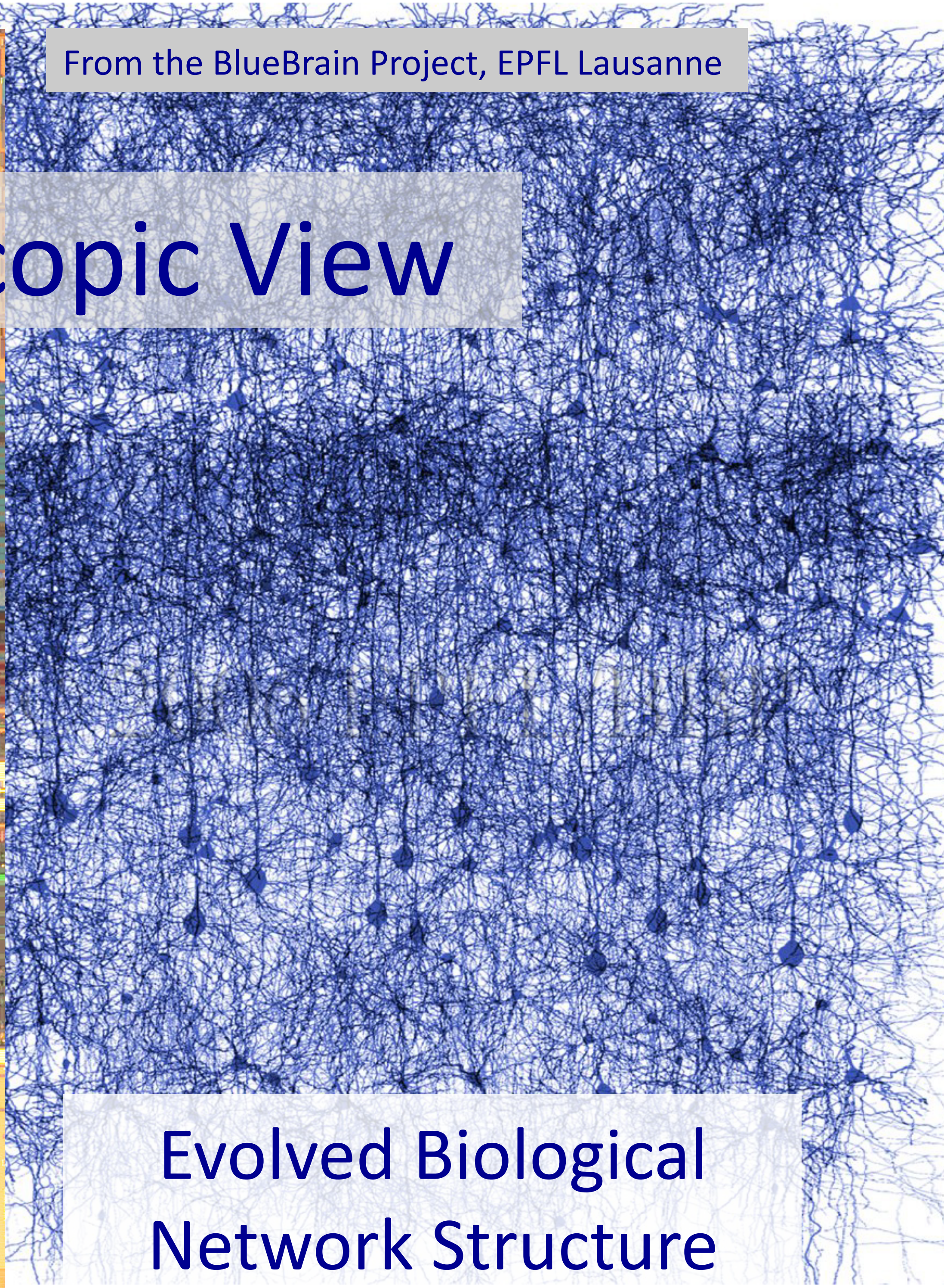
Neuromorphic Computation

- Maximally parallel, non-linear computing elements with large diversity
- Time correlations drive the dynamics (e.g. STDP)
- Learning by internal self-organisation and by strong interaction with environment
- Low power consumption and high fault tolerance
- Limited by degree of complexity : ultimately architecture/size limited

NOT UNDERSTOOD (major challenge for 21st century science)

A Microscopic View





Neuroscience Modeling Approaches

starting point: mathematical description based on biology

then:

- **analytical treatment**

  proof of general properties and limits

- **numerical solution (high performance computing)**

  flexibility, parallel objects not obvious

- **physical model (neuromorphic hardware)**

  artificial nervous system

  artificial parallel object = biological objects

- **biological model**

  “custom-made biological nervous system”

Essentials of Biological Neural Computation

Connectivity	10^{11} Neurons, 10^{15} Synapses in Neocortex
	10.000 Synapses per Neuron on average
Diversity	Categories and Parameters of Neurons
Plasticity	Long Term, Short Term, Local, Global
Timing	Time constants, delays, correlations

Essentials for Neuromorphic Hardware Systems

Connectivity	Efficient data protocols, 2D-3D connection technology
Diversity	Configurability (distributed memory)
Plasticity	Local and global dynamic and static memory
Timing	Control time constants, delays and time correlations
SCALABILITY	Learn from small systems – Approach large scales
	Bandwidth, delays, power, cost, fault tolerance

Future Emergent Technologies (FET) in ICT

„FET will explore radical interdisciplinary avenues, delivering proofs-of-concept for new options and demonstrating new possibilities. It will strengthen Europe's science and technology base in new and emerging areas, refine new visions to the point where they attract industrial investment, and establish new interdisciplinary research communities within European science and industry“

Especially :

“Recent advances in ICT and neuroscience enable a significant part of the human brain to be studied and modelled in-silico. This objective seeks to exploit such advances in order to better understand how the brain processes information and/or how it communicates with the peripheral nervous system (PNS), and to explore potential applications of this”

FACETS
Fast Analog Computing with Emergent Transient States

FACETS - From Neurobiology to new Computing Architectures

U Bordeaux, CNRS (Gif-sur-Yvette and Marseille),
U Debrecen, TU Dresden, U Freiburg, SCCH Hagenberg,
TU Graz, U Heidelberg, EPFL Lausanne, U London,
U Plymouth, INRIA Sophia-Antipolis, KTH Stockholm

An Integrated Project in the 6th Framework Programme
Information Society Technology - Future Emergent Technologies
FP6-2004-IST-FETPI

FACETS : Basic idea, methodological approach and goals

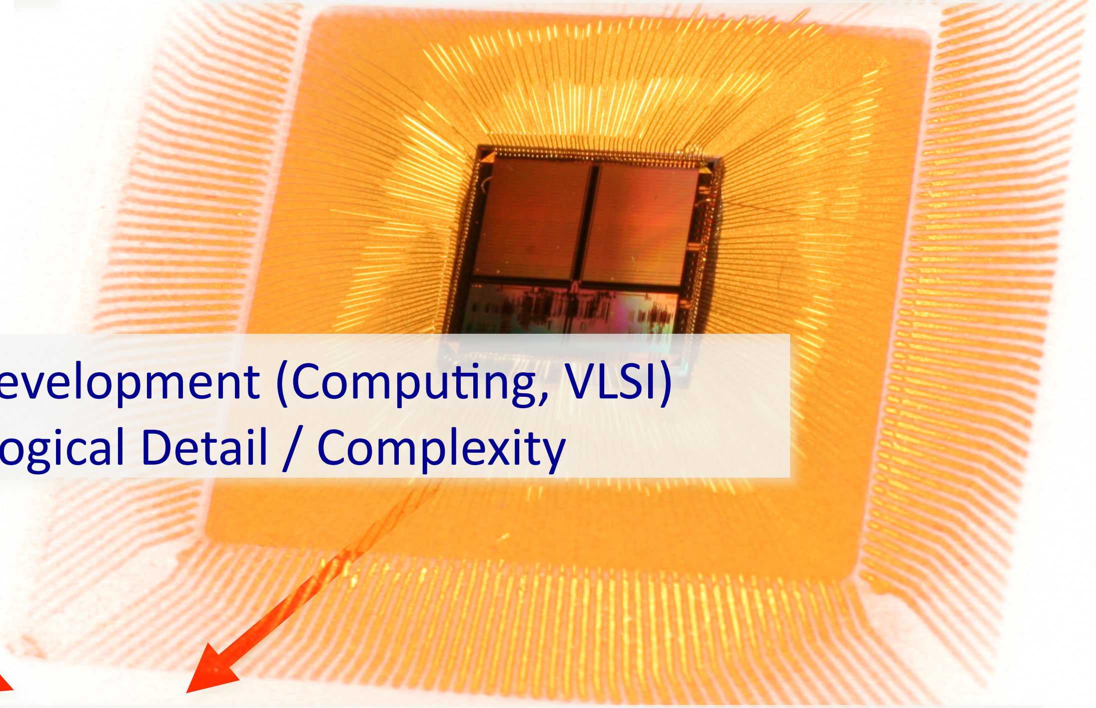
Neurobiology : Structural and Functional Investigation of the Neocortical Microcircuit and the Circuit Elements in-vivo and in-vitro

Modelling : Virtual Microcircuits on State-of-the-Art Computers

$$C\frac{dV}{dt} = -g_L(V - E_L) + g_L \Delta_T \exp\left(\frac{V - V_T}{\Delta_T}\right) + I - w, \quad (1)$$

$$\tau_w \frac{dw}{dt} = a(V - E_L) - w. \quad (2)$$

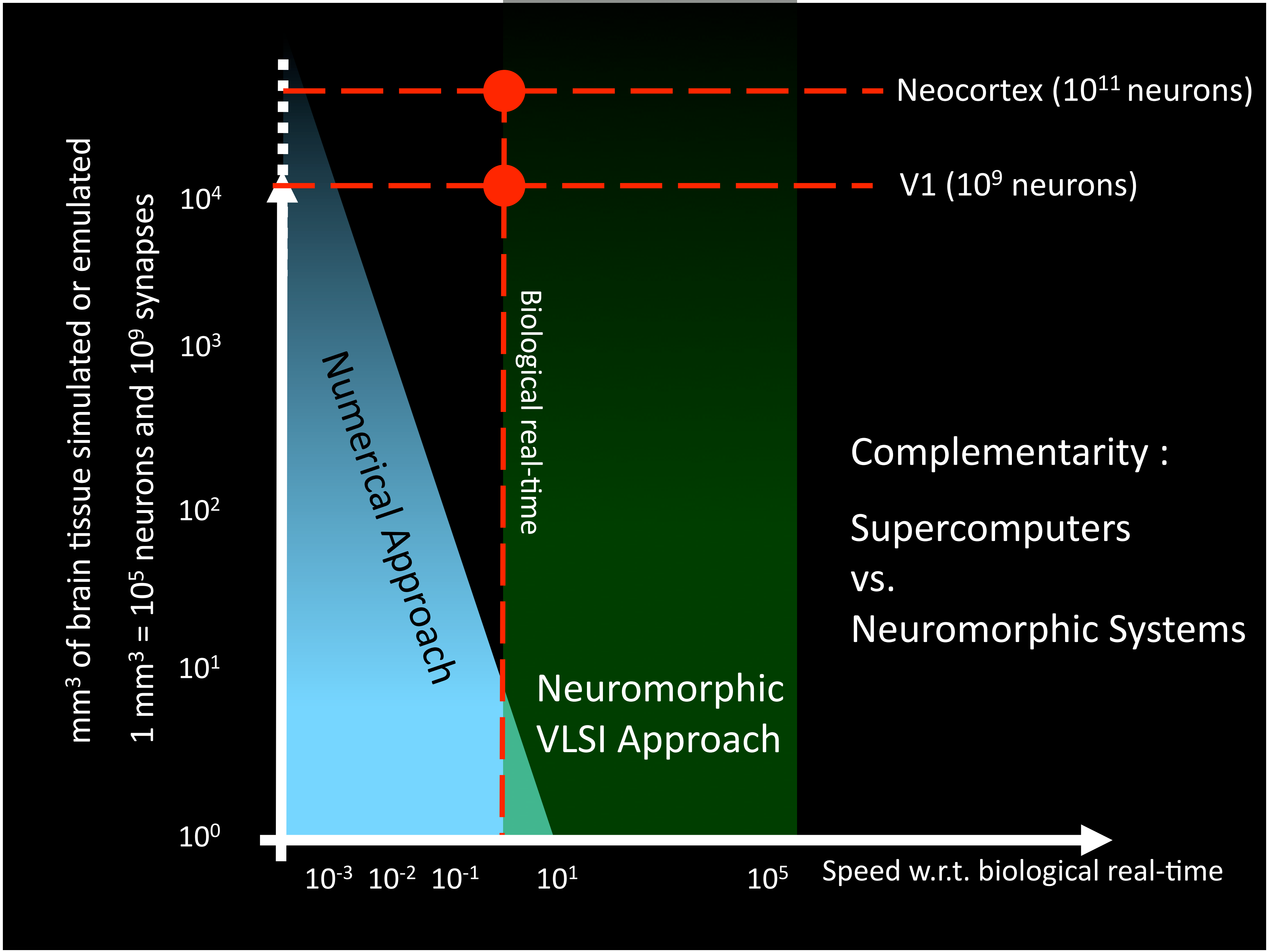
Hardware : Emulation in analog and mixed-signal VLSI systems



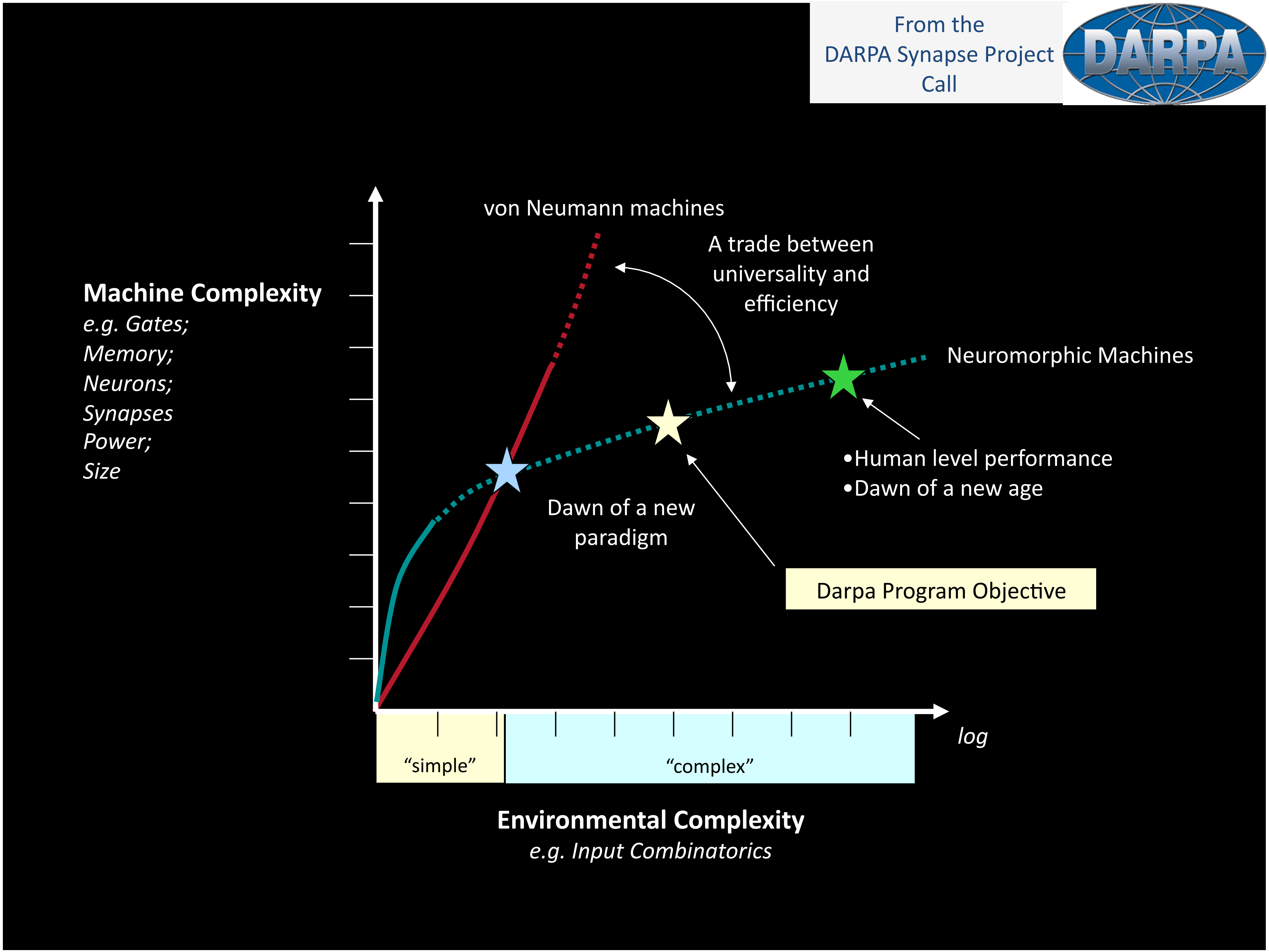
Methodology : Tool Development (Computing, VLSI)
Reduction of Biological Detail / Complexity

Common Goal : Study non-classical universal computing solutions

Verification (Biology vs. Modelling vs. Hardware with visual tasks in VI)



mm³ of brain tissue simulated or emulated
1 mm³ = 10⁵ neurons and 10⁹ synapses
10⁴
10³
10²
10¹
10⁰
Neocortex (10¹¹ neurons)
V1 (10⁹ neurons)
Numerical Approach
Biological real-time
Neuromorphic VLSI Approach
Complementarity :
Supercomputers
vs.
Neuromorphic Systems
10⁻³ 10⁻² 10⁻¹ 10¹ 10⁵
Speed w.r.t. biological real-time



From the
DARPA Synapse Project
Call
DARPA
Machine Complexity
e.g. Gates;
Memory;
Neurons;
Synapses
Power;
Size
von Neumann machines
A trade between
universality and
efficiency
Neuromorphic Machines
Dawn of a new
paradigm
•Human level performance
•Dawn of a new age
Darpa Program Objective
log
"simple"
"complex"
Environmental Complexity
e.g. Input Combinatorics

?

Cells

Circuits

Systems

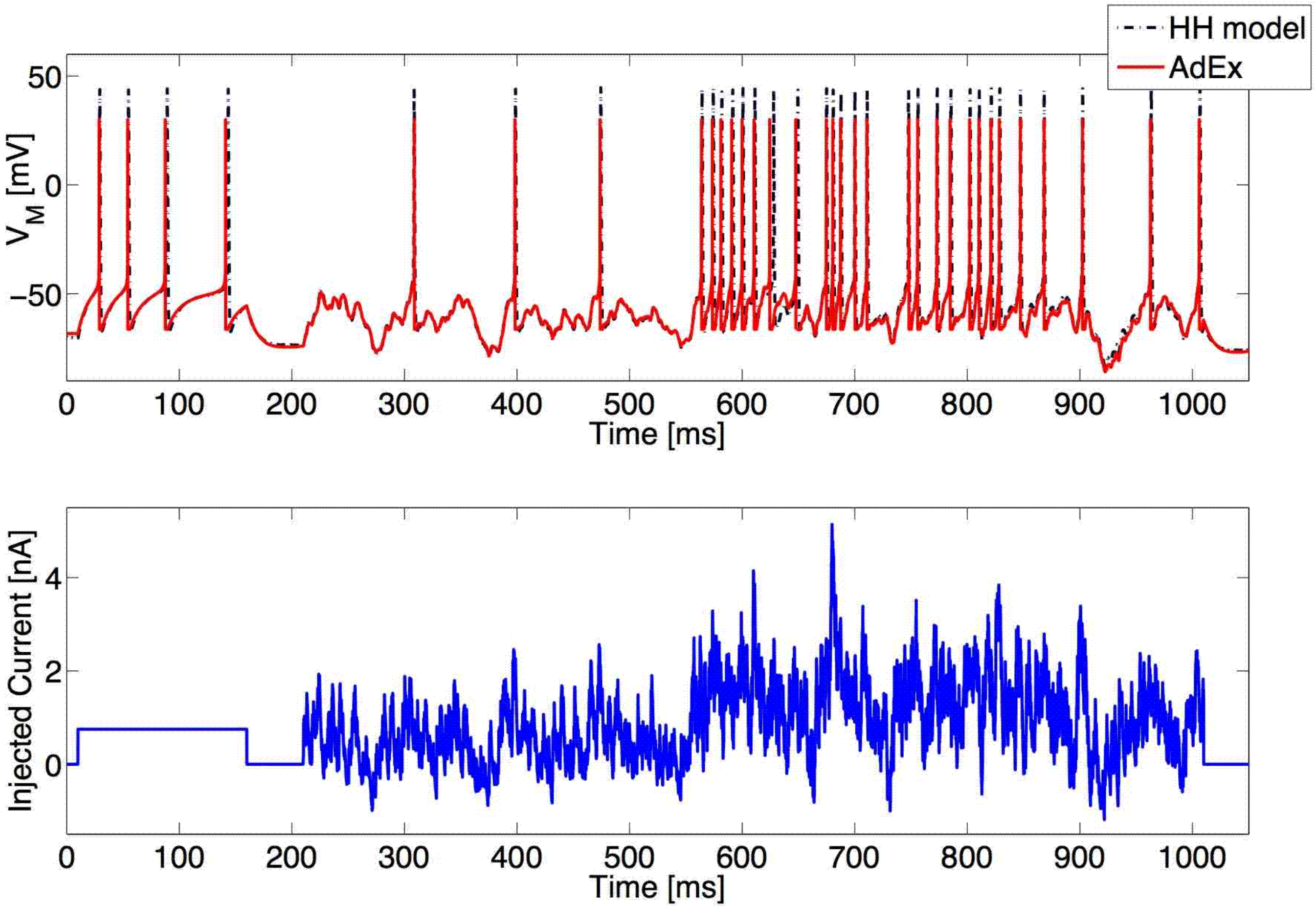
Networks

Experiments

Cells : The FACETS Adaptive-Exponential IF Neuron Model

$$-C_m \frac{dV}{dt} = g_l(V - E_1) - g_l\Delta_t \left(\frac{V - V_t}{\Delta_t}\right) + g_e(t)(V - E_e) + g_i(t)(V - E_i) + w$$

$$-\tau_w \frac{dw}{dt} = w - a(V - E_l).$$

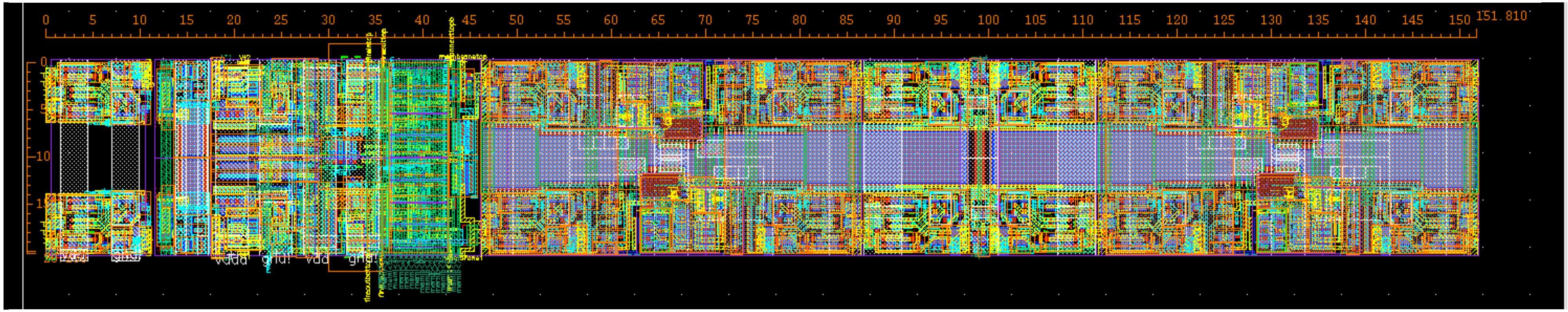


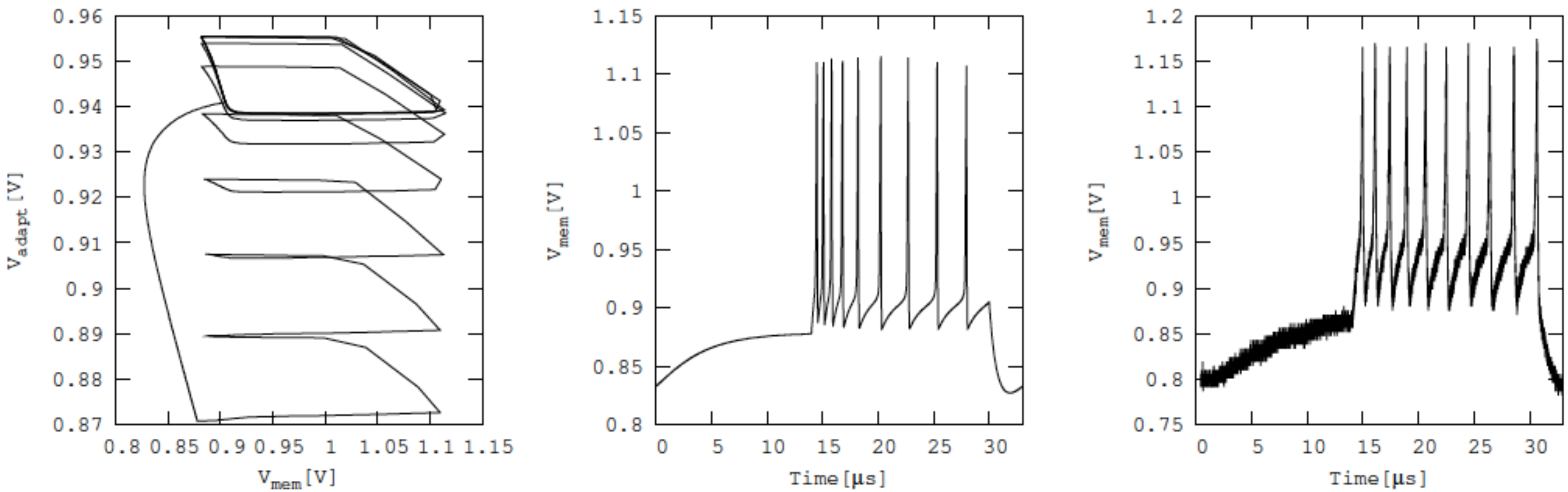
Brette, Gerstner, Adaptive Exponential Integrate-and-Fire Model as an Effective Description of Neuronal Activity, *J Neurophysiol 94: 3637-3642, 2005*

Circuits : Single AdExp Neuron : Analytical –Layout – Simulation - Measurement

$$-C_m \frac{dV}{dt} = g_l(V - E_1) - g_l \Delta_t \left(\frac{V - V_t}{\Delta_t} \right) + g_e(t)(V - E_e) + g_i(t)(V - E_i) + w$$

$$-\tau_w \frac{dw}{dt} = w - a(V - E_l).$$





Systems : Neural Processing Unit, up to 200.000 AdExp Neurons, 50.000.000 Synapses Separation of Neural Circuits and Monitoring/Readout/Control

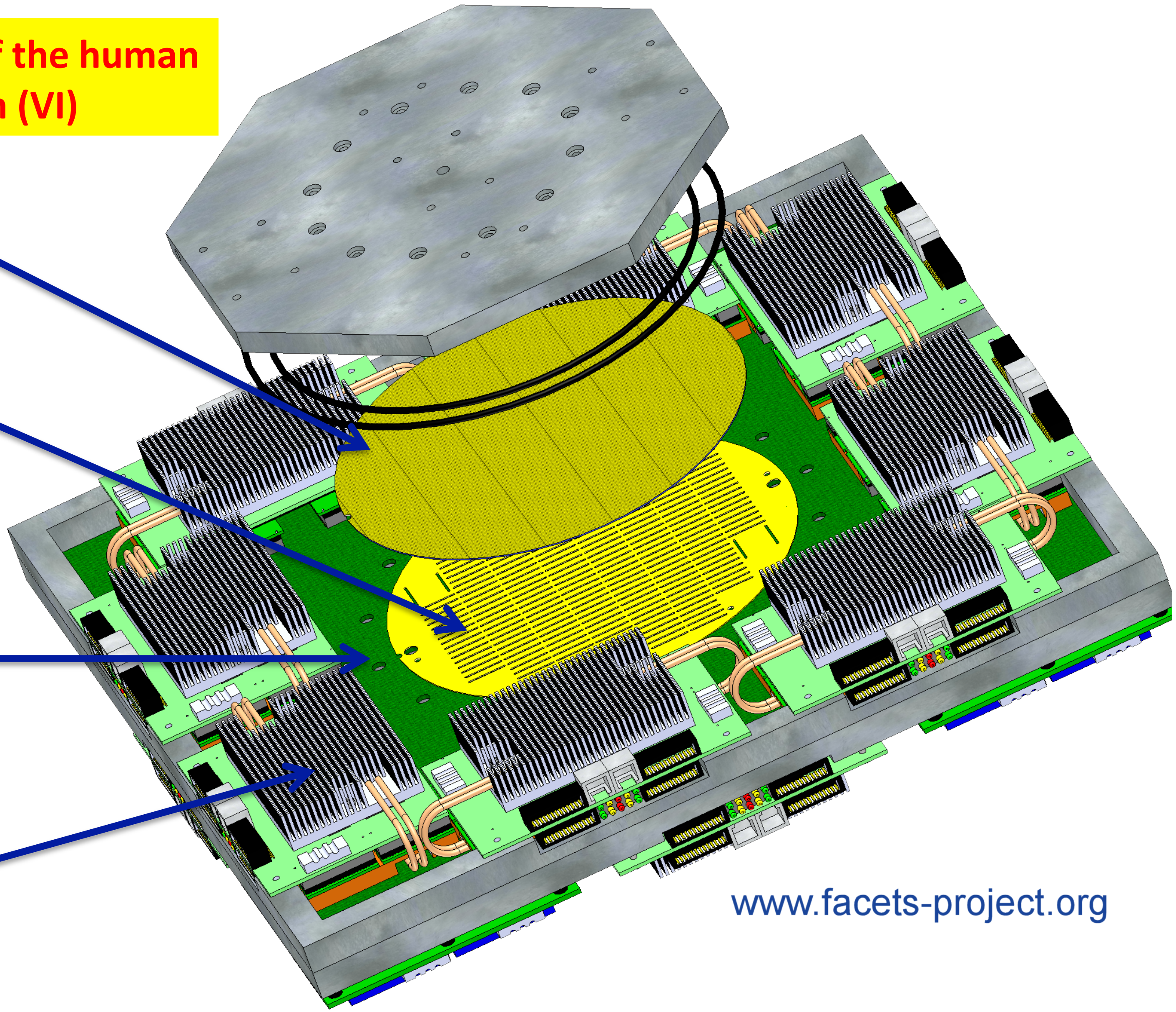
Approx. 1/10.000 of the human visual system (VI)

Post-Processed Neural Network Wafer (8 inch)

Vertical High Speed and Power Connection Matrix

Control and Communication Board with digital communication ASICs

Control and Communication FPGAs



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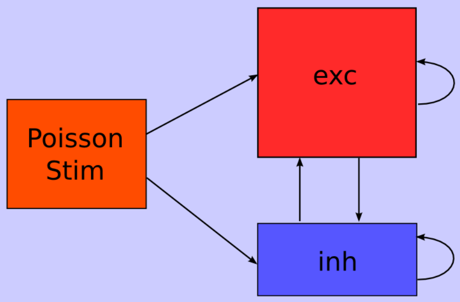
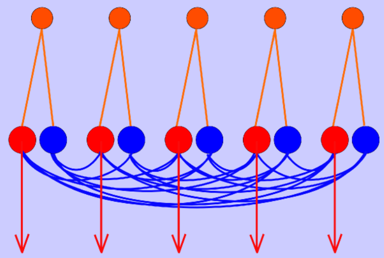
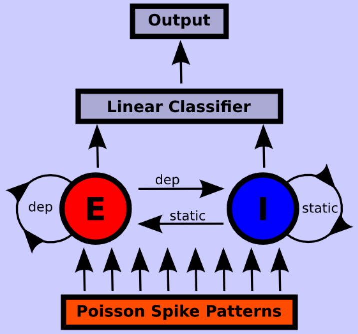
Cortical Volume Model



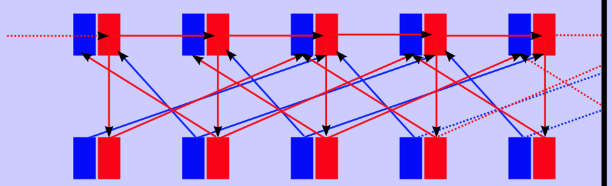
Insect Glomeruli Model



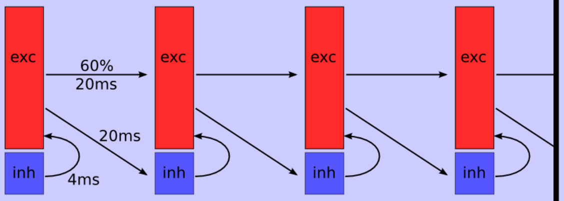
Liquid State Machine



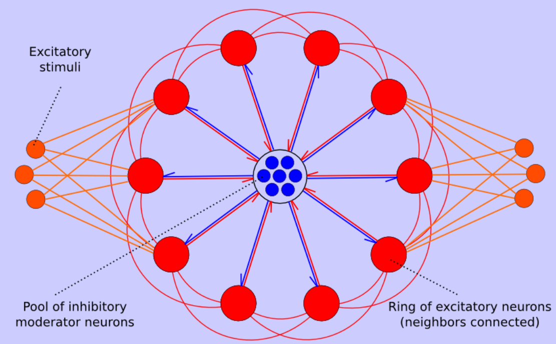
Population Chain



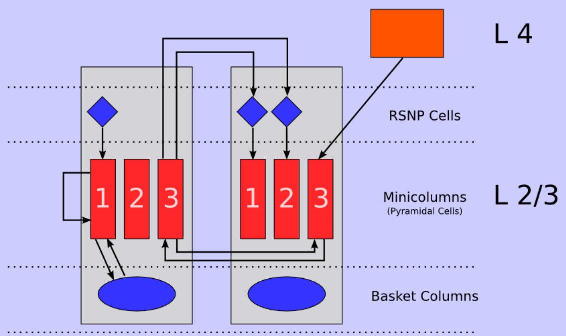
Synfire Chain

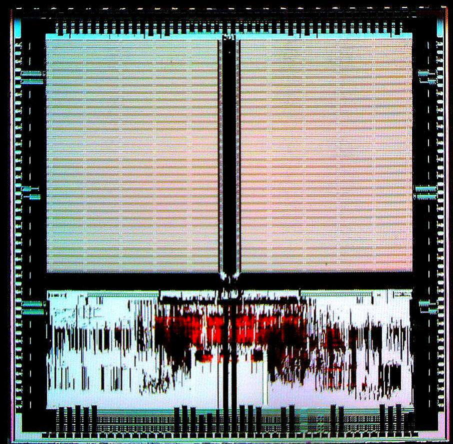


Winner-Take-All Ring



Layer 2/3 Attractor Model

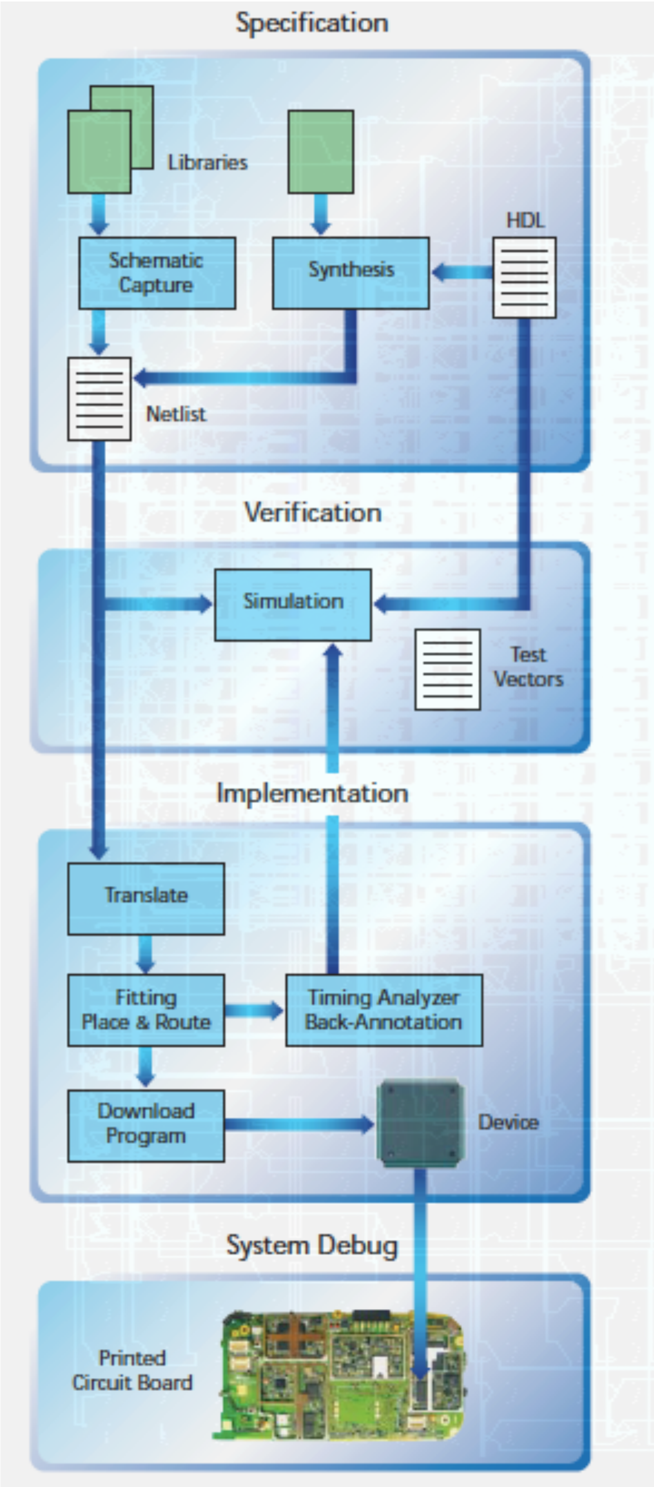


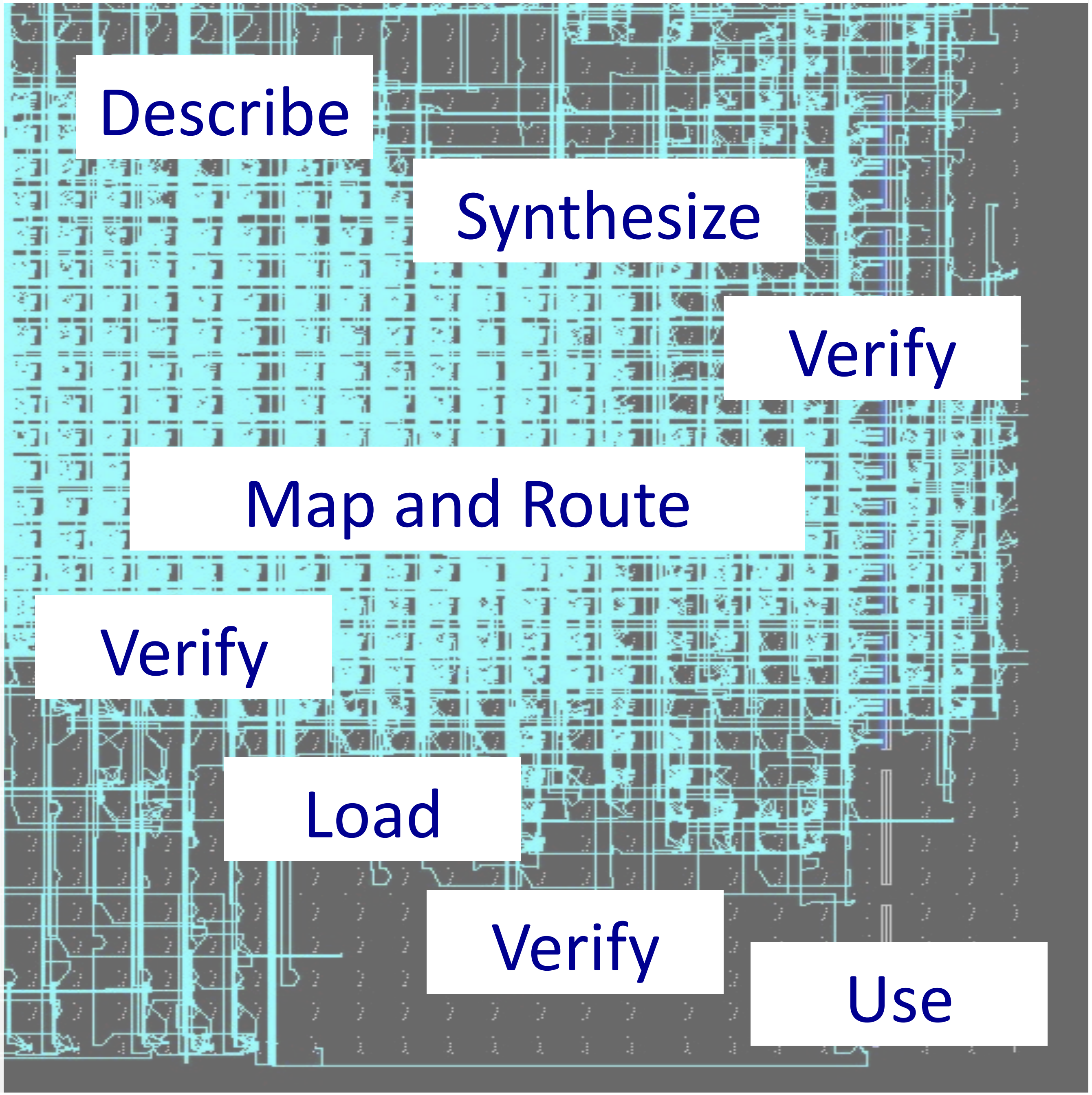


Networks : Generic and Biologically Inspired

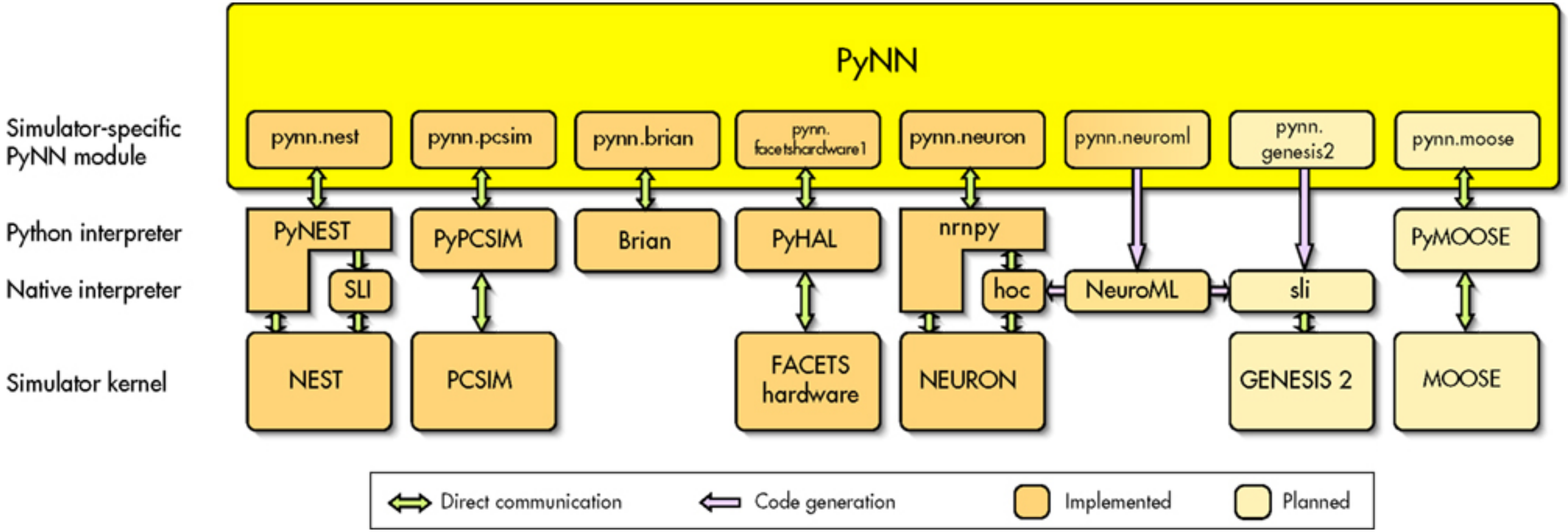
EXPERIMENTS ?

Implement Custom Digital Circuits : A Success Story For Configurable Hardware



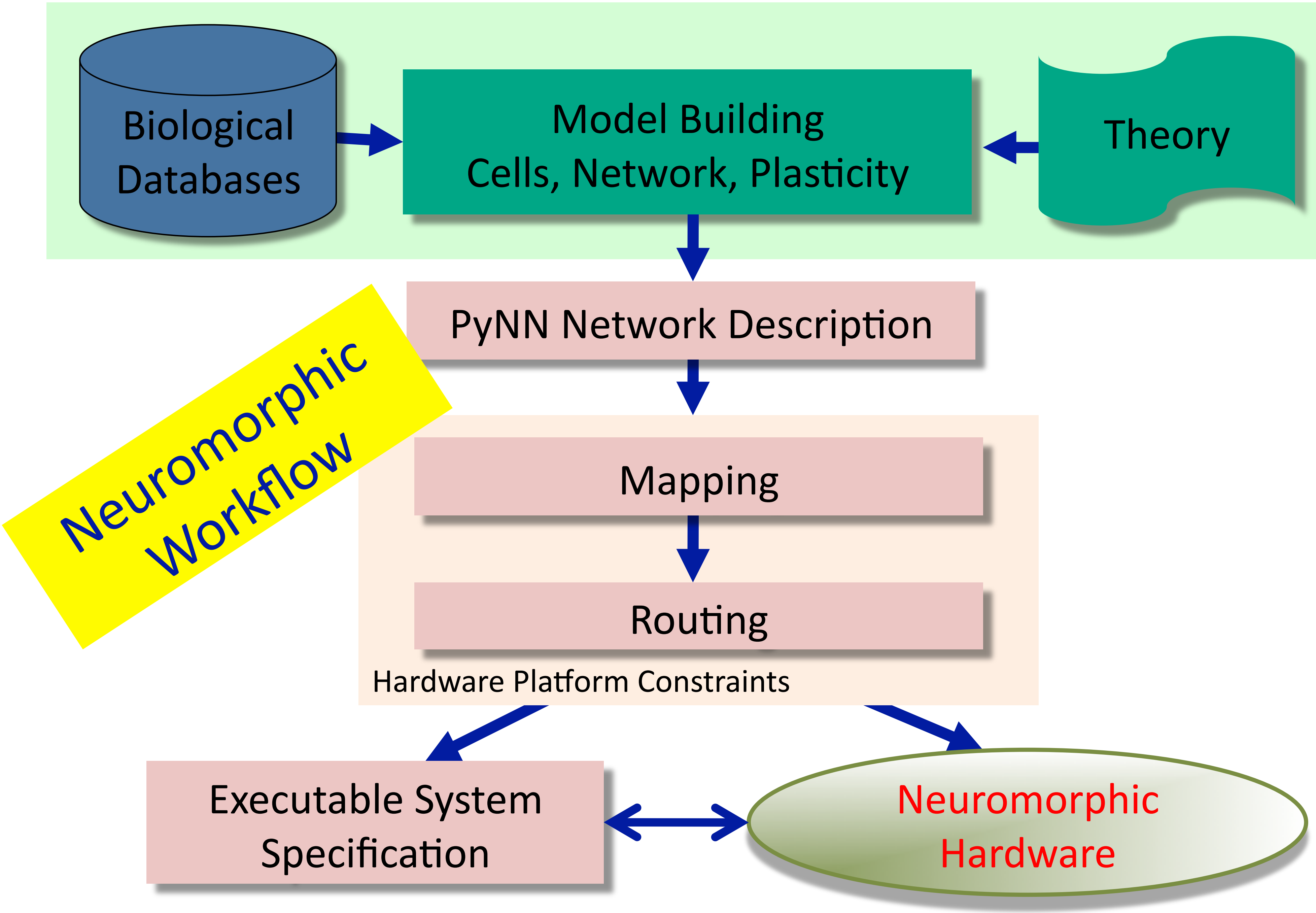


PyNN : A Platform independent Description Language for Neural Circuits

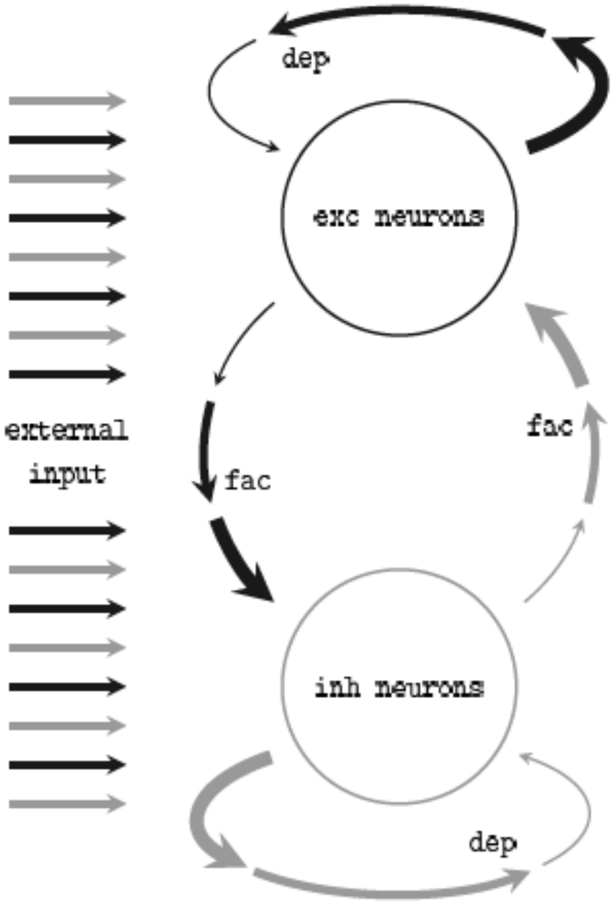


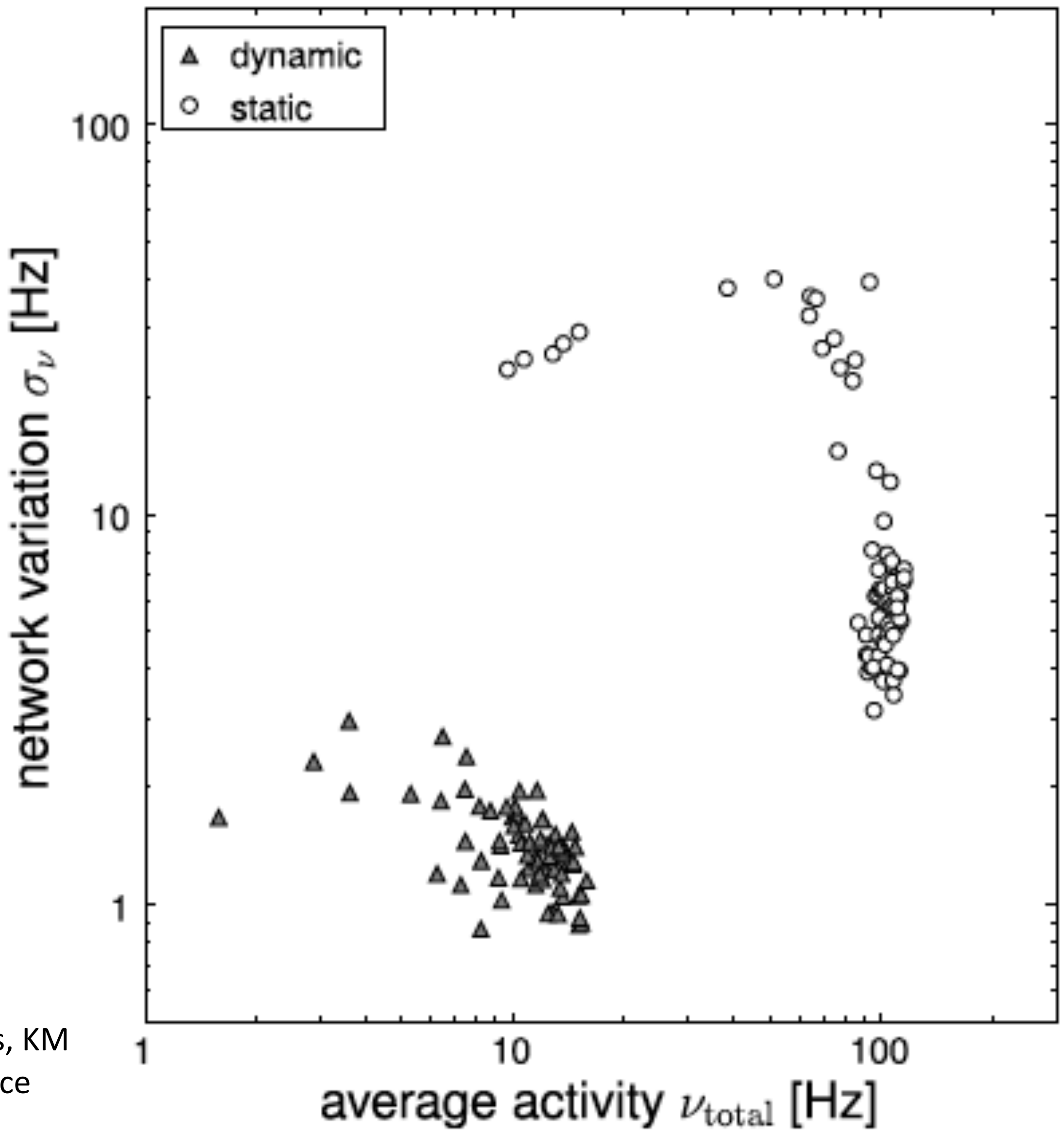
Integrating and widely accepted toolset for a generic (i.e. simulator independent) access to neural simulation

Bringing new computer architecturs (i.e. neuromorphic systems) to th non-mexpert neuroscience user


Biological Databases
Model Building
Cells, Network, Plasticity
Theory
PyNN Network Description
Neuromorphic Workflow
Mapping
Routing
Hardware Platform Constraints
Executable System Specification
Neuromorphic Hardware

Essential Difference : Circuit changes after initial Configuration – Dynamical systems !





J. Bill, K. Schuch, D. Brüderle, J. Schemmel, W. Maass, KM
submitted to Frontiers in Computational Neuroscience

The Merits of accelerated (here : 10^5) neural VLSI

	Biology	Electronics
Precision of spike based learning	10^{-04} s	10^{-09} s
Short term synaptic plasticity	10^{+00} s	10^{-05} s
Development	10^{+07} s (4 months)	10^{+02} s (1.6 min)
Learning	10^{+09} s (3 years)	10^{+04} s (2.8 h)
13 Orders of Magnitude		
Evolutionary Processes	10^{+12} s (3000 years)	10^{+07} s (115 days)
16 Orders of Magnitude		

Access to > 10 Orders of Magnitude in Time in an artificial System with a spatial complexity of >> 10^5 !?

A Telescope for complex adaptive Network Science

An Essential FACETS Success : Graduate Students

Strong interest in the research subject : FACETS is a Ph.D. Factory !

> 100 Ph.D. students with thesis either finished or under way

12 FACETS Training Workshops for Graduate Students :

Neuromorphic Electronics (I)	Bordeaux	2006
Hands-On-Biology workshop (I)	Debrecen	2007 (2x)
The Brain and the Turing Machine	Freiburg	2007
Modeling for Beginners	Sånga-Säby	2007
Biology	Debrecen	2008
Learning	Freiburg	2008
Using Python for computational neuroscience	Freiburg	2008
FACETS Databases	Leysin	2009
Hands-On-Biology workshop (II)	Freiburg	2009
Neurpmorphic Electronics (II)	Dresden	2010
Hand-On-Biology workshop (II)	Gif-sur-Yvette	2010

Hands-on :

Using Python for Computational Neuroscience. Freiburg 2008

Pre-Conclusion (wait for tomorrow ..)

Through FACETS neuromorphic computer architectures have made a first step from the research and development labs to the non-technical-expert scientific user

The well working interdisciplinary collaboration among neuroscientists, engineers, physicists, computer scientists has been (and will be even more in the future to come) a prerequisite for this work cost

IPSEN
Innovation for patient care

INSTITUT DE NEUROBIOLOGIE
Alfred Fessard

cnrs
dépasser les frontières

MARIE CURIE ACTIONS

Thanks !