A first step towards in silico neuronal implementation of early-vision map.

SSD, Hammamet, 19-22 March 2007

O.Rochel, S. Chemla, P. Kornprobst, T. Viéville*
A. Daouzli, S. Saighi, C. Lopez, S. Renaud**

(*) Odyssee, INRIA Sophia Nice
(**) Laboratoire IMS, U. Bordeaux 1, ENSEIRB-CNRS
France

Outline

Context

Specification of a cortical map computation

Experimental validation on a HH network

Conclusion

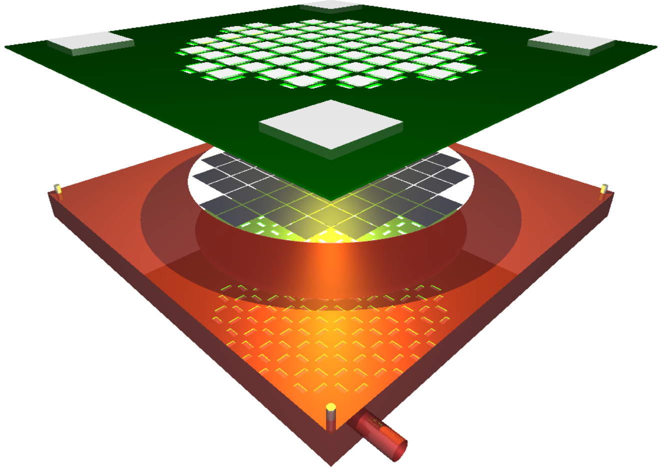
Context: the FACETS EU project

Neurobiology : Structural and Functional Investigation of the Neocortical Microcircuit

Modelling : A Virtual Microcircuit on State-of-the-Art Computers

Circuits : Emulation in analog and mixed-signal VLSI systems

TOOL Development



Common Goal : *Study non-classical universal computing solutions*

Benchmarking with visual tasks

FACETS framework

The multi-disciplinary consortium addresses the following research issues :

- 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 (e.g. IBM BlueGene at EPFL) and common 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 detailed and of large scale neural microcircuits
- Availability and further development of high level and low level **analytical models** of neural computations as a basis for novel computing paradigms.

A FACETS experiment

„emulate the dynamics of detailed and of large scale neural microcircuits“

„Benchmarking with visual tasks“

Context:

- High-level specification of how the **brain** represents and categorizes the **causes** of its **sensory inputs** is the link between:
  - “What is to be done?” (perceptuel task)
  - “How to do it?” (neural network calculation)
- Cortical map computations can be specified as optimization problems
- Optimization problems with regularization mechanisms can be related to neural networks dynamics, and implemented on Spiking Neural Networks

A FACETS experiment

„emulate the dynamics of detailed and of large scale neural microcircuits"

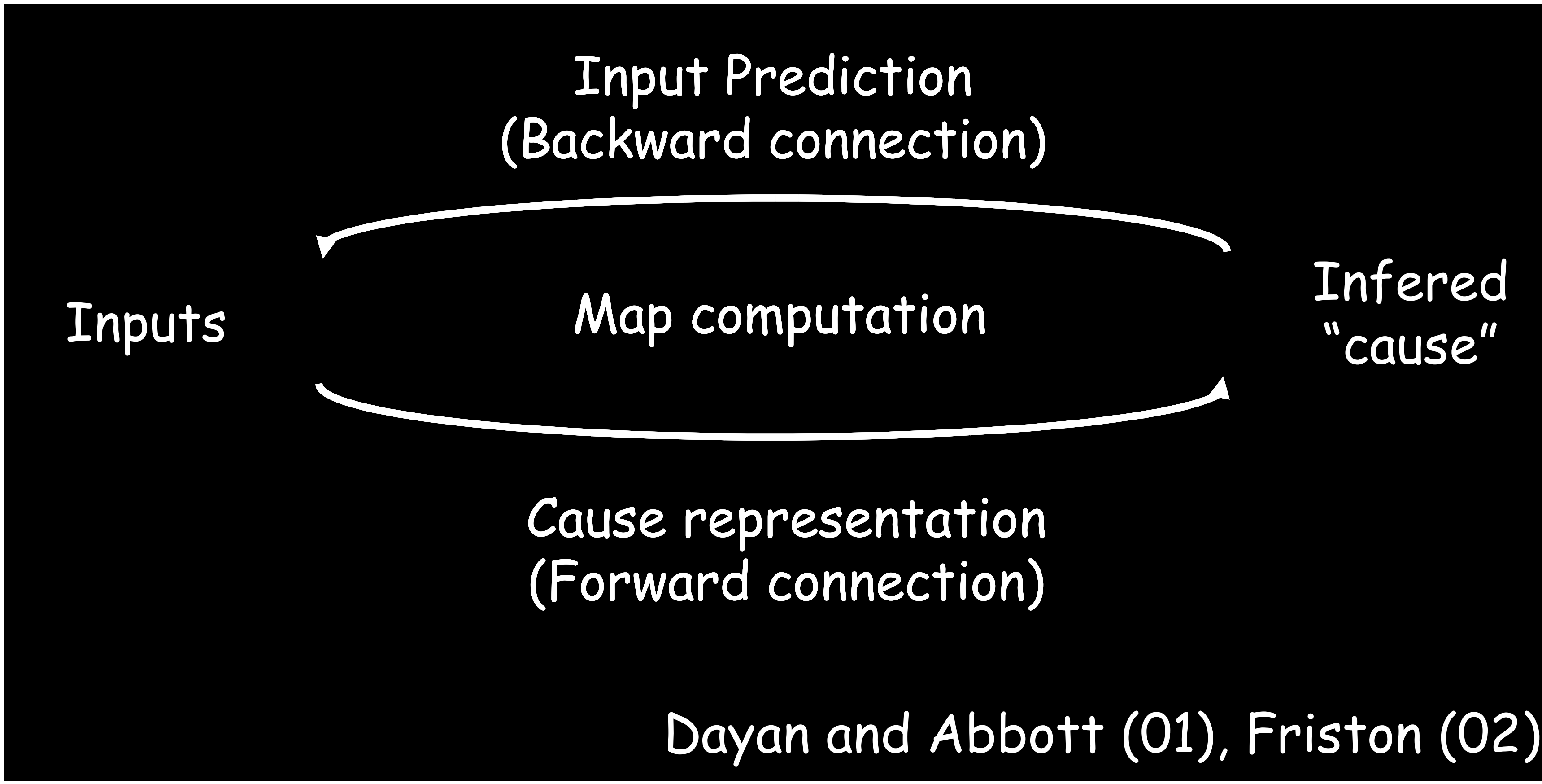
„Benchmarking with visual tasks"

a collaborative work between physicists and and computer scientists

- A general class of cortical map computations
  can be specified with variational approaches;
- How plausible is the related implementation
  with respect to biological networks is to be established;
- The available hardware platform (to simulate SNN) is a way to test it!

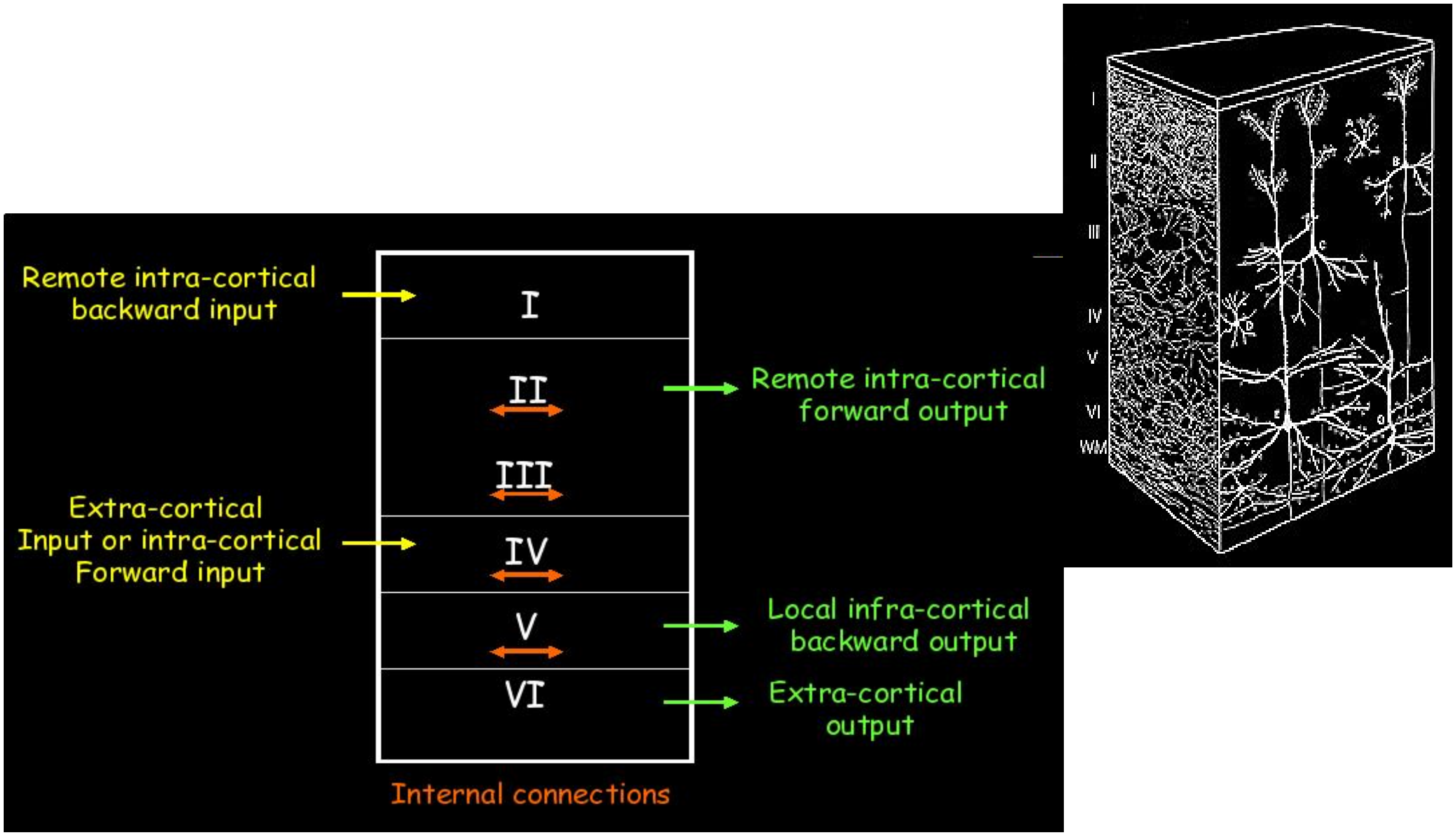
Position of the problem

How Brain finds causes from inputs?



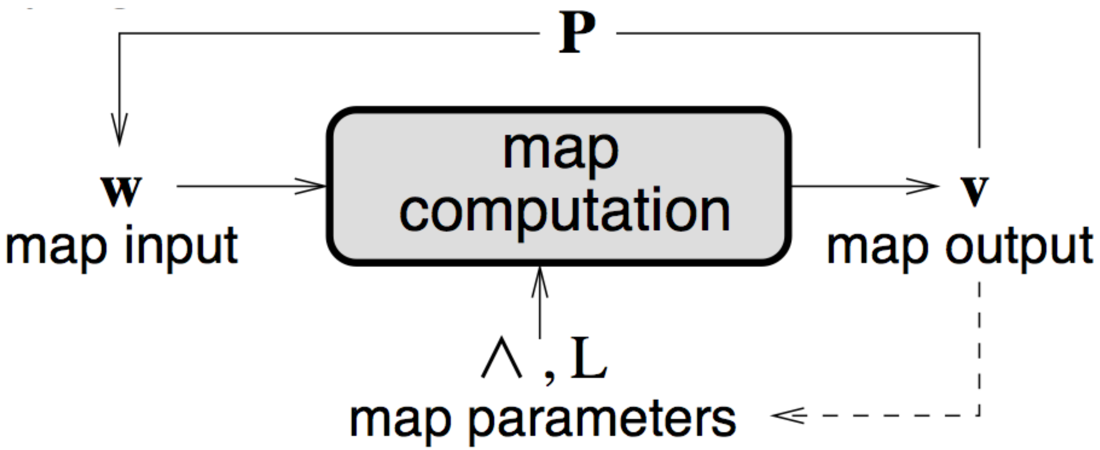
Biological plausibility

Cortical Hypercolumns functional model



Specification of a cortical map computation

Proposed model



Specification of a cortical map computation

Proposed model

Nonlinearities

$$\bar{\mathbf{v}} = \operatorname*{Argmin}_{\mathbf{v} \in H / \boxed{\mathbf{c}(\mathbf{v})=0}} \mathcal{L}(\mathbf{v}),$$

Control of the solution

with

$$\mathcal{L}(\mathbf{v}) = \boxed{\int_\Omega |\hat{\mathbf{w}} - \mathbf{w}|^2_{\mathbf{\Lambda}}} + \boxed{\int_\Omega \phi(|\nabla \mathbf{v}|_{\mathbf{L}})} + \boxed{\int_\Omega \psi(\mathbf{v})},$$

and

$$\boxed{\hat{\mathbf{w}} = \mathbf{P}\,\mathbf{v}}$$

Λ = Measurement information metric

L = Regularization metric

Inputs from outputs
Re-estimation

Dayan and Abbott, 2001

Specification of a cortical map computation

Implementation on SNN:

- we consider a regular spiking (oscillatory) mode

- the information is coded as the *instantaneous phase* P_i of the spiking neuron

For a neuron i, the map output is P_i ; the cortical map constraints are implemented by:

$$\frac{dP_i}{dt} = -e_i(P_i)P_i + \sum_j s_{ij}(P_i)P_j + k_i I_i$$

Specification of a cortical map computation

Implementation on a Spiking Neural Network

$$\frac{dP_i}{dt} = \boxed{-e_i(P_i)P_i} + \underset{j}{} s_{ij}(P_i)P_j + k_i I_i$$

P_i = instantaneous phase of V_{mem}
V_{mem} from HH model

$$C_{mem} . \frac{dV_{mem}}{dt} + \Sigma I_i + I_{syn} + I_{leak} = 0$$

Specification of a cortical map computation

Implementation on a Spiking Neural Network

$$\frac{dP_i}{dt} = -e_i(P_i)P_i + \boxed{\sum_{j} s_{ij}(P_i)P_j} + k_i I_i$$

σ_i = synaptic weight (j to i)

Biologically plausible
Short-term adaptation

Specification of a cortical map computation

Implementation on a Spiking Neural Network

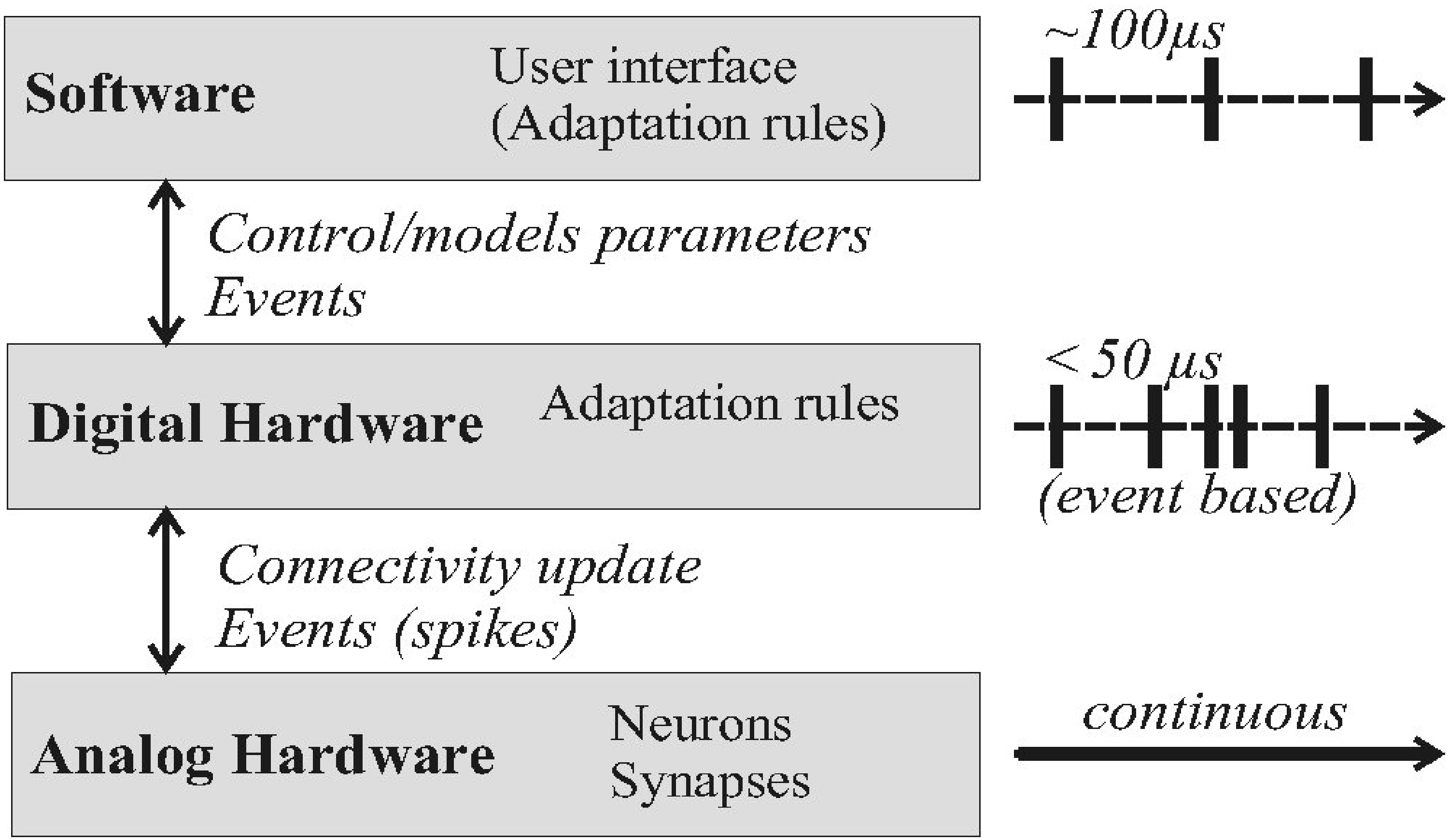
$$\frac{dP_i}{dt} = -e_i(P_i)P_i + \sum_j s_{ij}(P_i)P_j + \boxed{k_i I_i}$$

I_i the inputs, k_i a gain

Network inputs

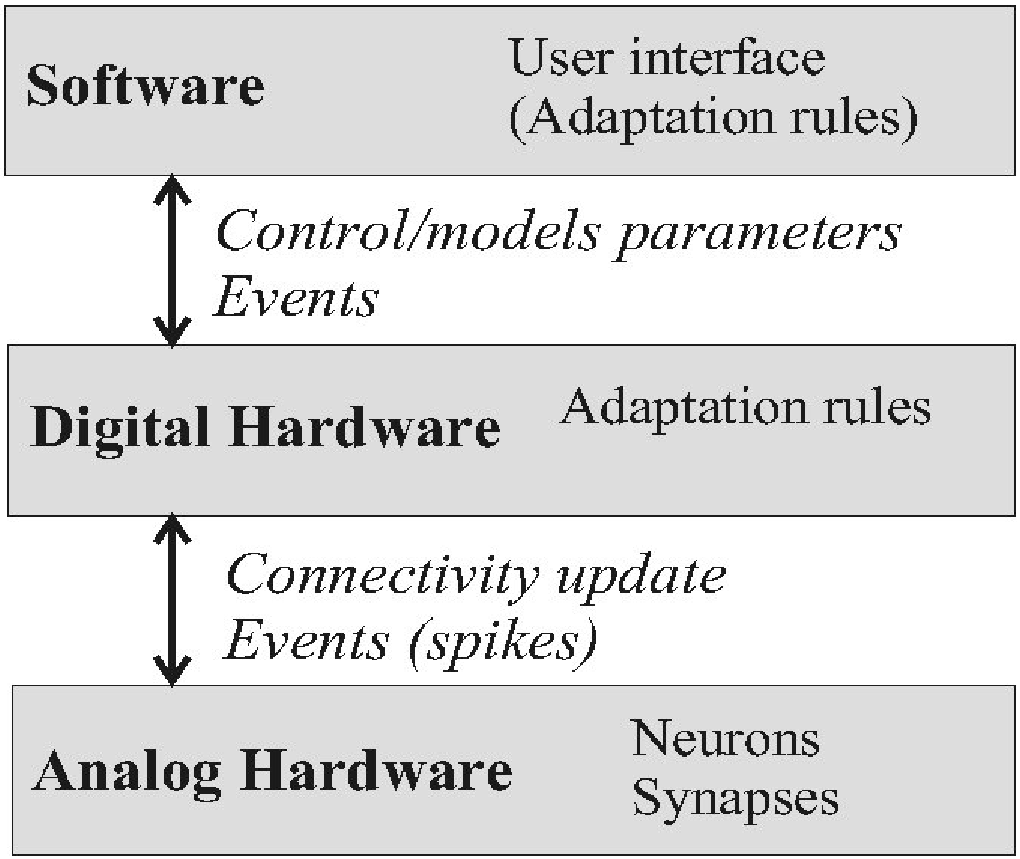
Experimental validation on a HH network

The hardware set-up



Experimental validation on a HH network

The hardware set-up



Stimulation inputs

STDP rules for
Synaptic connections

HH neurons
Synaptic inputs

Experimental validation on a HH network

$$\frac{dP_i}{dt} = \boxed{-e_i(P_i)P_i} + \boxed{\sum_{j} s_{ij}(P_i)P_j} + \boxed{k_i I_i}$$

Software — User interface (Adaptation rules)

Control/models parameters
Events

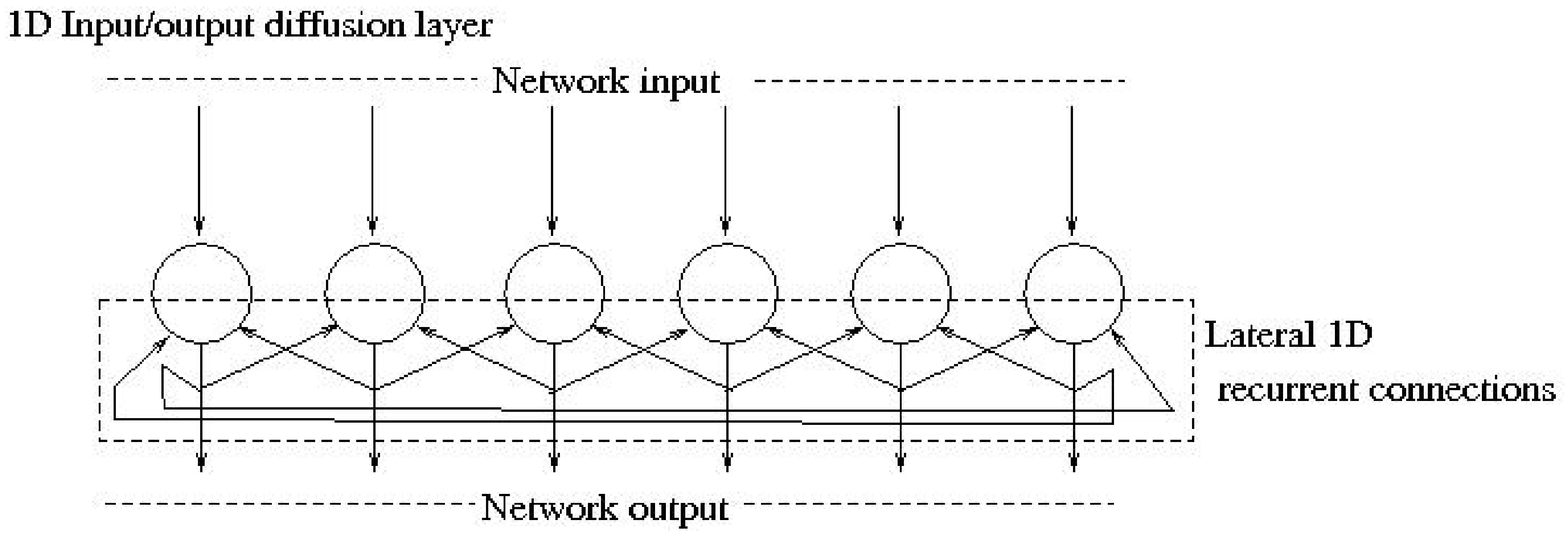
Digital Hardware — Adaptation rules

Connectivity update
Events (spikes)

Analog Hardware — Neurons, Synapses

Experimental validation on a HH network

The 1D network architecture:
M neurons for M processed points

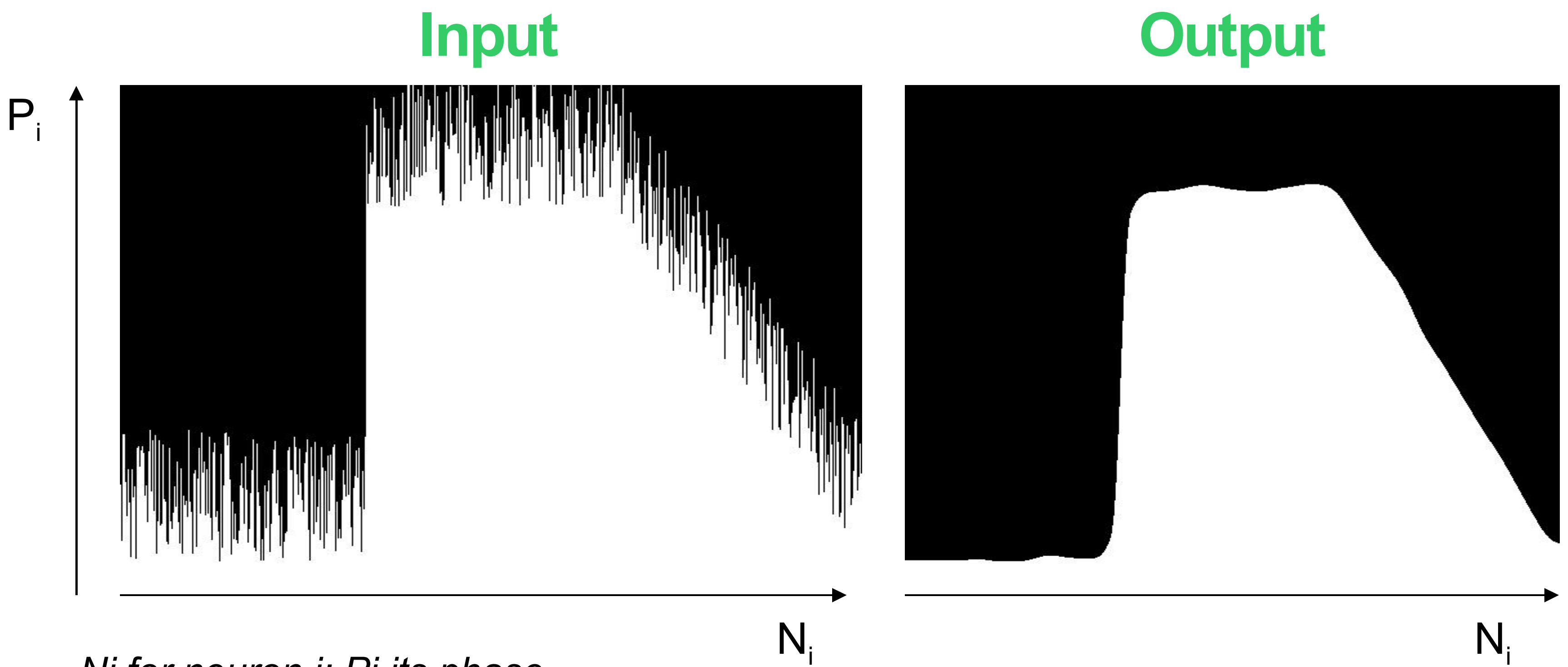


- local recurrent connection for adaptive diffusion
- input / output : temporal representation

Experimental validation on a HH network

An example of software simulated result:

A noisy input is applied; after running the adaptive SNN, the output converges to a smoothed state



Ni for neuron i; Pi its phase

Conclusion

- We propose to map variational approaches in cortical computation maps onto a biologically-plausible network
- We implement such a network on SNN, using a mixed A/D hardware platform optimized to run real-time simulations on configurable SNN.
- Next step is to apply it to 2D problems and implement decision/discrimination functions in SNN
- Such an implementation is a support/analysis tool for biologists and computational scientist who study network functions in the visual cortex