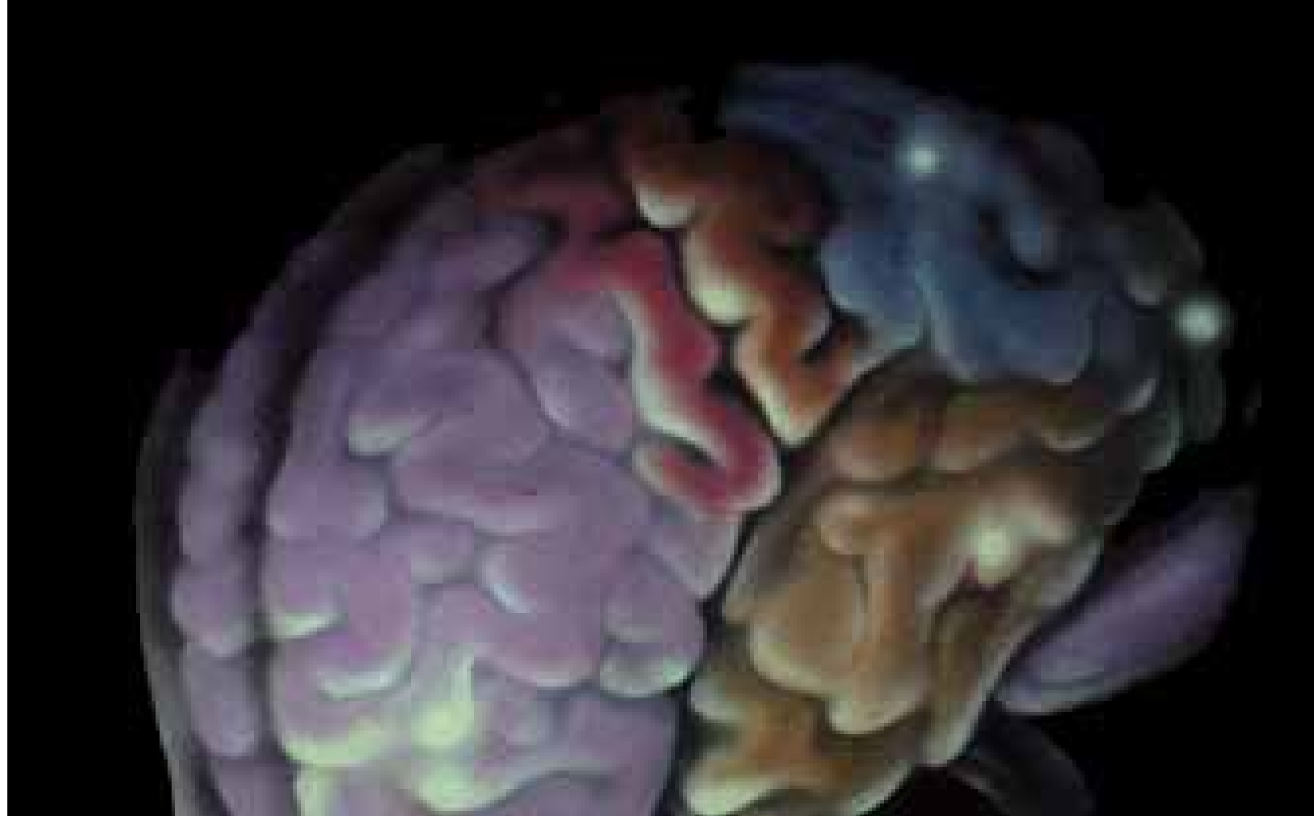
Blue Brain Project



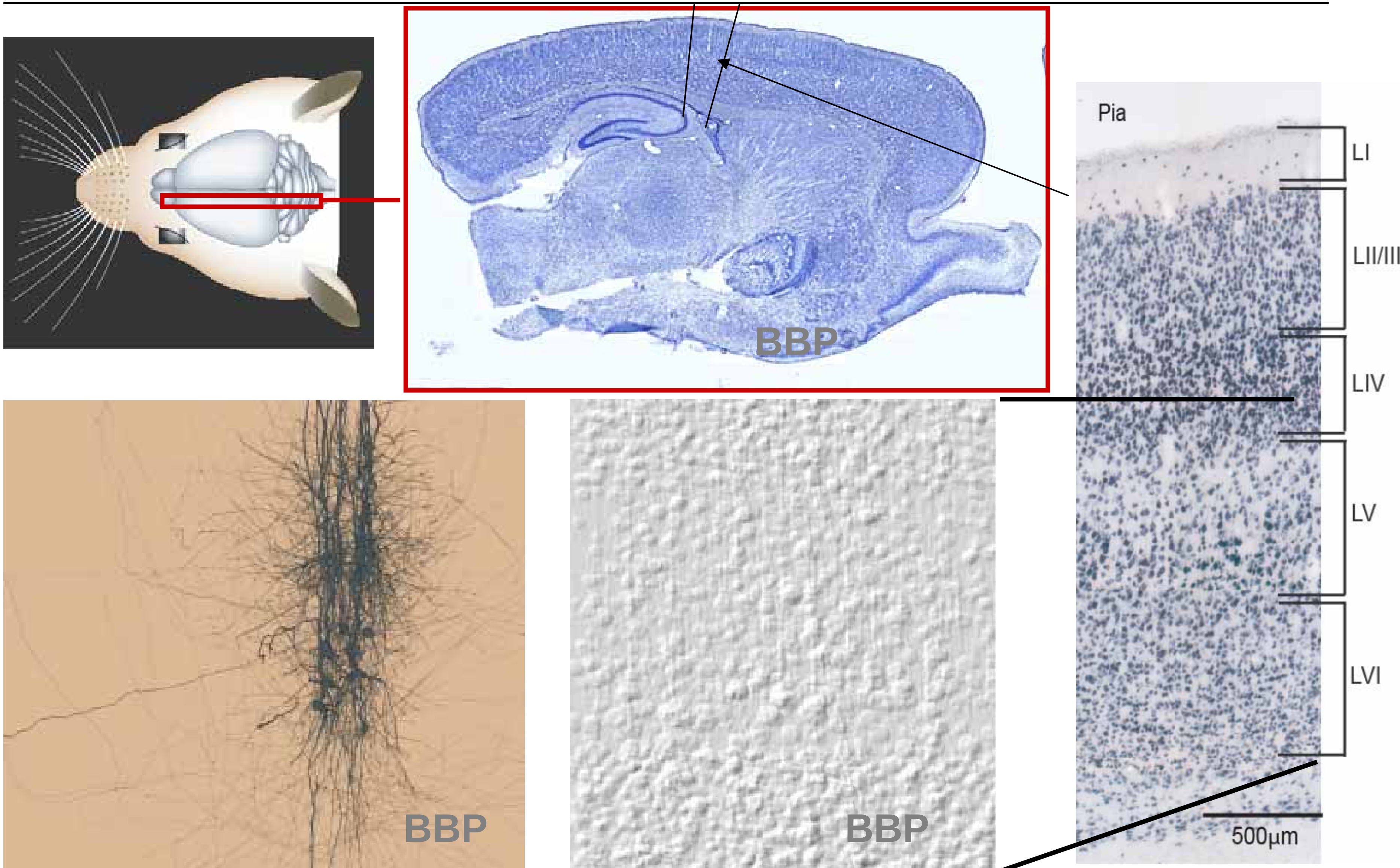
Prof. Henry Markram
Dr. Felix Schürmann
felix.schuermann@epfl.ch
http://bluebrainproject.epfl.ch

Reverse-Engineering the Brain

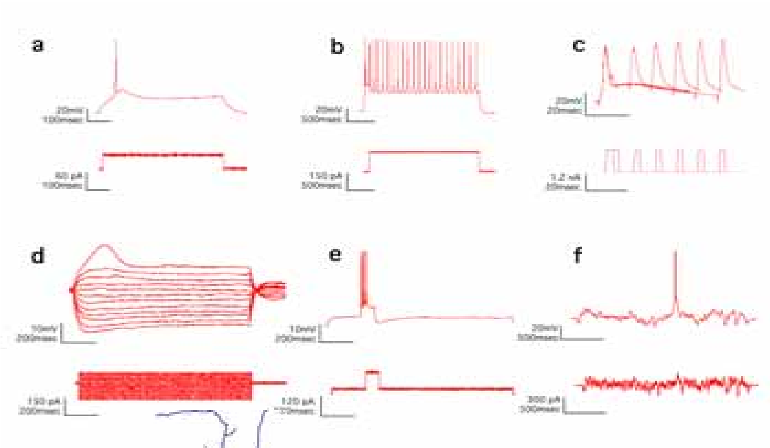
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
Brain Mind Institute

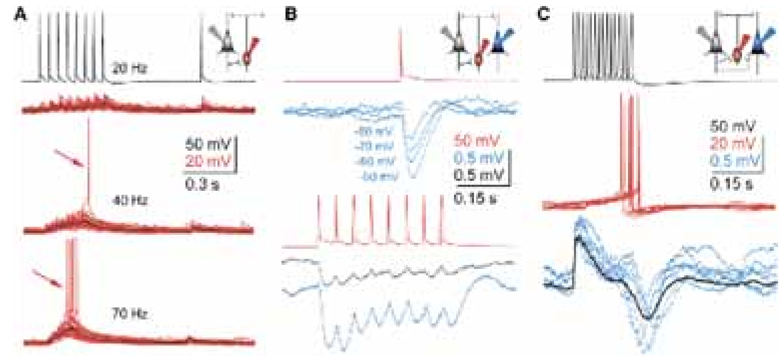
IBM®

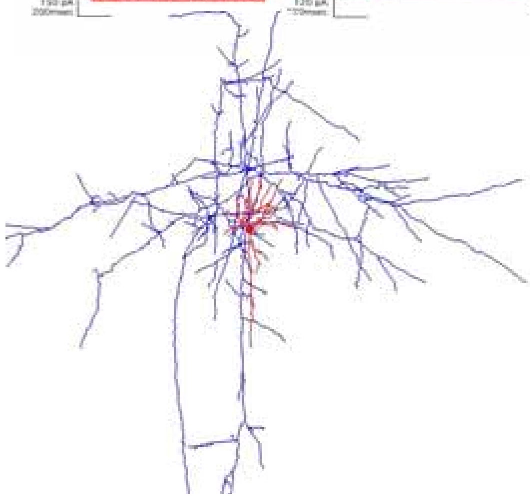
The Electrophysiologist's View

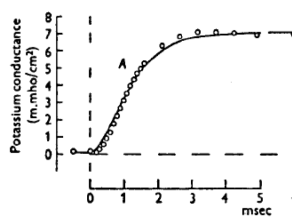


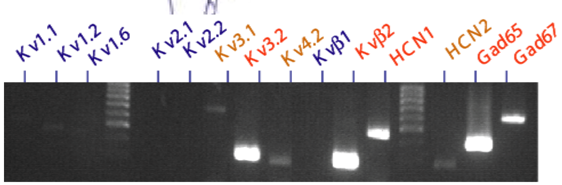
Accurate Models that Relate to Experiment

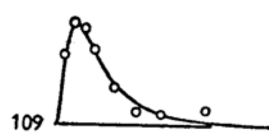


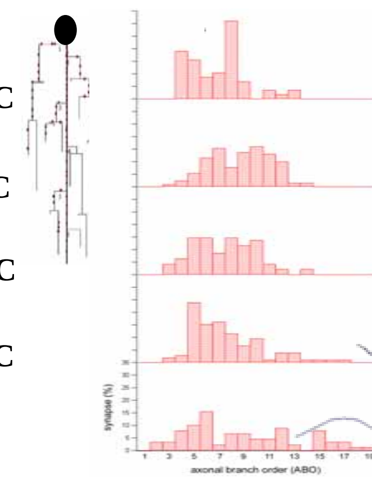


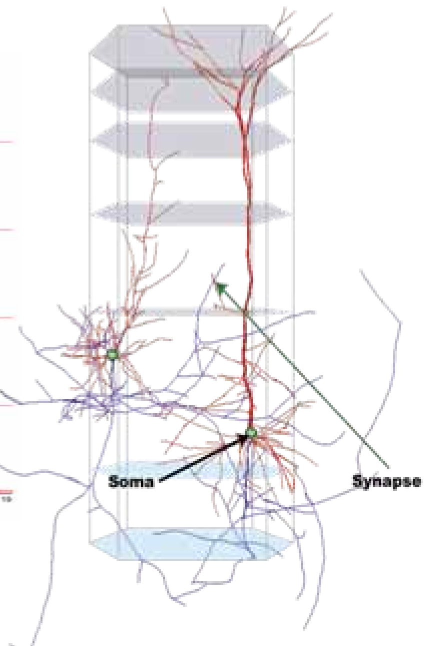








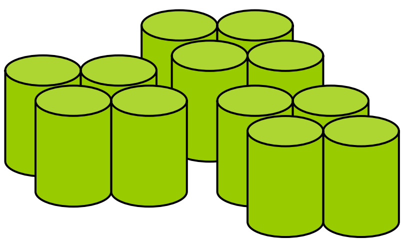




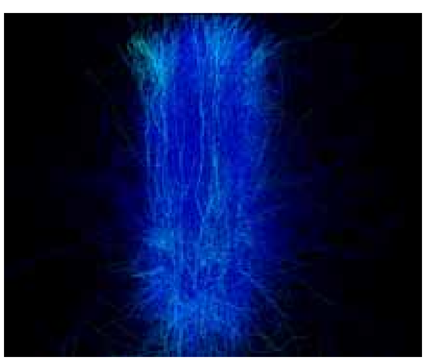
BBP Phase I: Neocortical Column

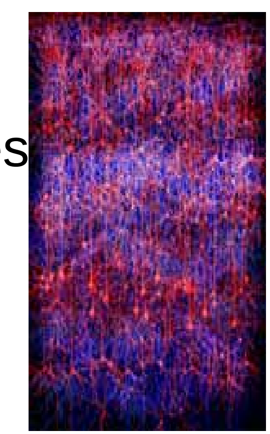
Create a faithful “in silico” replica at cellular level of a neocortical column of a young rat by the means of:

- **reverse engineering the biology components**
- **forward constructing functional mathematical models**



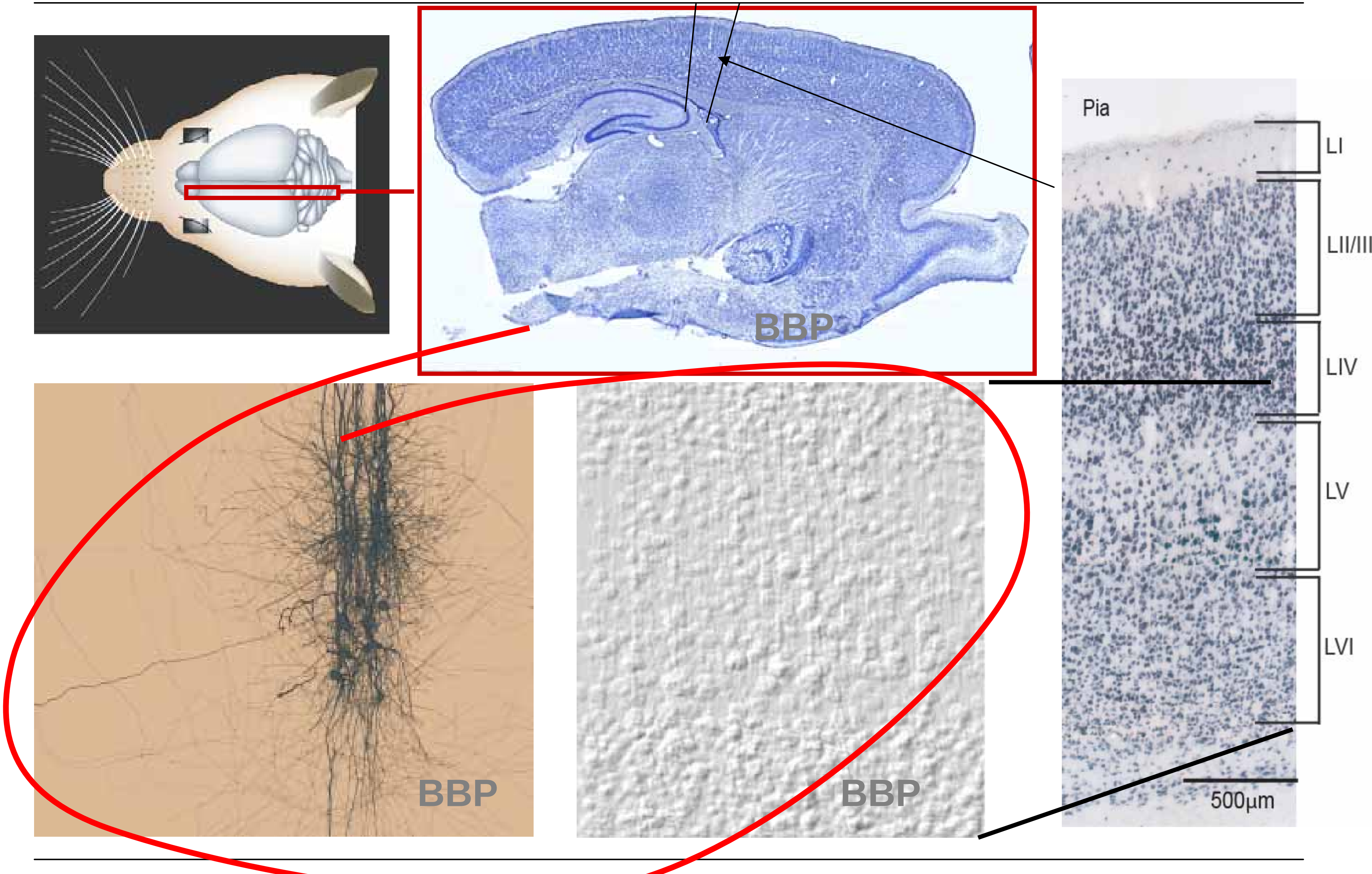
- **Building**
  10,000 morphologically complex neurons
- **Constructing**
  a circuit with 30,000,000 dynamic synapses
- **Simulating**
  the column close to real-time






BBP

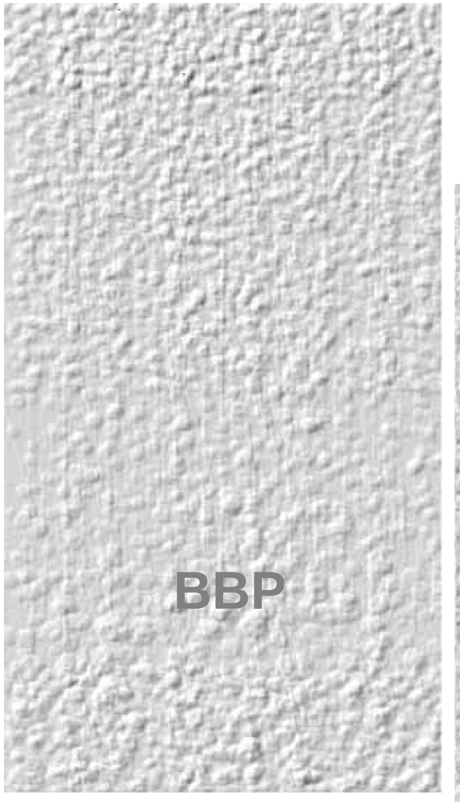
The Electrocphysiologist's View - Revisited



BBP Phase I: « in vitro » vs. « in silico »

in silico

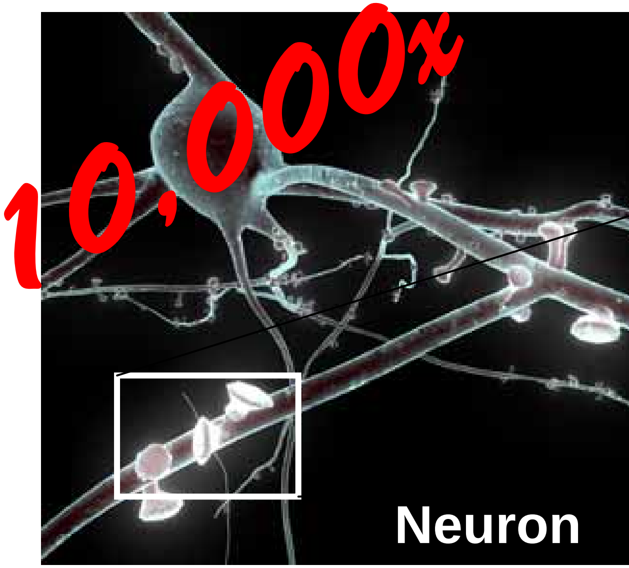
in vitro



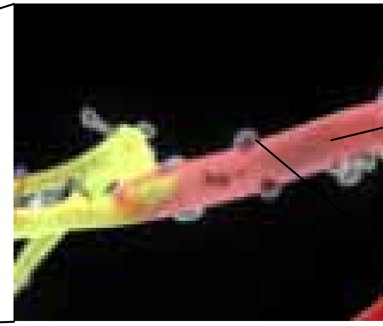
in silico

in vitro

Level of Detail

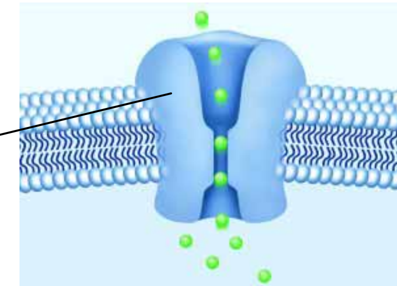


Compartment



~350compartments/neuron

Channels



~20HH style channels/compartment

Synapses

~3,000/neuron

A Rat's Neocortical Column:

- ~1mm^3
- 6 layers
- > 50 morphological classes
- ~340 morpho-electrical types
- ~200 types of ion channels
- 10,000 neurons
- 18 types of synapses
- 30,000,000 synapses

IT Challenge:

- 3,500,000 compartments
  - passive (cable, Gauss Elimination)
  - active HH style channels
- 30,000,000 synapses
  - dynamic

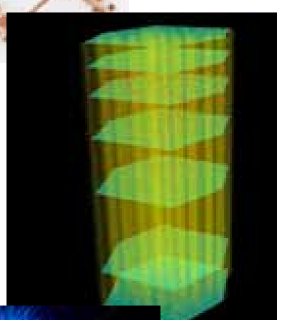
- → reporting 1 value/compartment → 140GB/biol sec

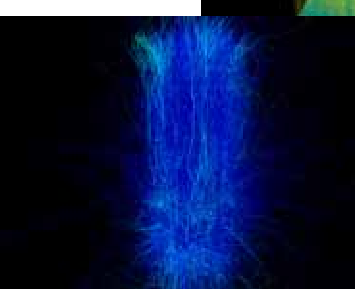
Usage of BG/L in the BBP

Dedicated 4 rack BG/L @ EPFL with 8192 processors, 2TB of distributed memory, 22.4 TFlop (peak)

→Used throughout all parts of the project

→Allows iteration of complete process within a week





- **Building: Run evolutionary algorithms for fitting of thousands of single cell models to data**
  typical job size: 2048 procs

  S. Druckmann et al., *A Novel Multiple Objective Optimization Framework for Constraining Conductance-Based Neuron Models by Experimental Data,* Frontiers in Neuroscience 2007

- **Constructing: Run dedicated algorithm to establish connectivity between cells**
  typical job size: 8000 procs

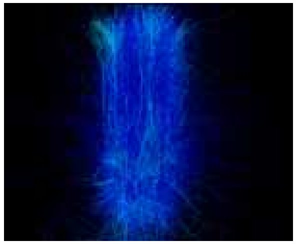
  J. Kozloski et al., *Identifying, tabulating, and analyzing contacts between branched neuron morphologies,* IBM Journal for Research and Development, Issue 52, Number 1/2, 2008

- **Simulating: Run simulation of cell networks**
  typical job size: 8192 procs

  M. Hines et al., *Fully Implicit Parallel Simulations of Single Neurons*. Journal of Computational Neuroscience, accepted

Blue Brain Project

A Grand Challenge Problem



A Rat's Neocortical Column

10,000 (10^4) neurons
30,000,000 (10^7) synapses

~1 neuron/core → 1:10-100 time penalty

~10^4 cores
~10^13 Flops (~10TeraFlops)
~10^12 Bytes RAM (TeraBytes)

20,000X

A Rat's Brain

200,000,000 (10^8) neurons
10^11 synapses

PetaScale HPC

~10^5-10^6 cores
~10^15 Flops (PetaFlops)
~10^14 Bytes RAM (~100TB)

~500 neurons/core → 1:5,000 - 50,000 time penalty

1,000X

A Human's Brain

10^11 neurons
10^14-10^15 synapses

ExaScale HPC

~10^18 Flops (ExaFlops)
~10^17 Bytes RAM (~100PB)

…but you wanted to give me 10^23 – right?

10^18 = ExaFlops **1 sec biological time = 1/2 day computation**
→ unique brain research facility

10^21 = ZettaFlops **1 sec biological time = few seconds computation**
→ brain-scale plasticity simulations
→ desk-side brain simulations

10^23 = 100 ZettaFlops **1 year biological time = 1 day computation**
→ brain-scale developmental simulations
→ personalized models

But all this scaling is based on electrical models…

- Glial cells
- Vasculature
- Ligand-gated ion channels
- Second-messengers
- Receptors
- Organelles
- Bio-chemical pathways/cascades
- Proteins, Protein-interactions
- Genes

Hodgkin-Huxley → Langevin Description → Fokker-Planck → Master Equation → Ensembles of stochastic channels → Reaction/Diffusion Models → …

What can we learn for Building Computers?

- The general recommendations from biology are clear
  - → go analog (energy)
  - → go local persistent memory (energy)
  - → go sparse activity (energy density)
  - → go 3D (integration, connectivity)
  - → go distributed encoding (robustness)

- Along the way we will be able to extract principles for specific applications
  - →generic building principles (structure, composition, connectivity)
  - →specialization rules (circuit rewiring)
  - →learning rules (local learning, homeostatic principles)

- We will have to go quite some way with computers that at least *look* like digital Von-Neumann machines to reverse-engineer biology and consolidate our knowledge in a model

The People Behind BBP

Project Director

- Prof. Henry Markram (EPFL, Lausanne)

General Project Manager

- Dr. Felix Schürmann (EPFL, Lausanne)

Sub-Project Supervisors

- Prof. Idan Segev (Hebrew University, Jerusalem)
- Prof. Phil Goodman (University of Nevada, Reno)

IBM Researchers

- Dr. Eric Kronstadt (IBM, Yorktown)
- Dr. Charles Peck (IBM, Yorktown)
- Dr. Sean Hill (IBM, Lausanne)
- Dr. James Kozloski (IBM, Yorktown)

Secretary

- Christiane Debono (EPFL, Lausanne)

Postdoctoral Fellows

- Dr. Michele Giugliano
- Dr. Philippe Rochat
- Dr. Konstantinos Sfyrakis

Engineers

- Dr. Raphael Holzer (EPFL, Lausanne)
- James G. King (EPFL, Lausanne)
- Barry Sefton (EPFL, Lausanne)

PhD students

- Thomas Berger (EPFL, Lausanne)
- Shaul Druckmann (Hebrew University, Jerusalem)
- Luca Gambazzi (EPFL, Lausanne)
- Albert Gidon (Hebrew University, Jerusalem)
- Etay Hay (Hebrew University, Jerusalem)
- Asif Jan (EPFL, Lausanne)
- Georges Khazen (EPFL, Lausanne)
- Sebastien Lasserre (EPFL, Lausanne)
- Shruti Muralidhar (EPFL, Lausanne)
- Rodrigo Perin (EPFL, Lausanne)
- Srikanth Ramaswamy (EPFL, Lausanne)
- Rajnish Ranjan (EPFL, Lausanne)
- Imad Riachi (EPFL, Lausanne)
- Sandrine Romand (EPFL, Lausanne)
- Guilherme Silva (EPFL, Lausanne)
- Juan Hernando Vieites (Universidad Politecnica de Madrid, Madrid)

Visiting Students

- Kazim Ali (EPFL, Lausanne)
- Afrasyab Bashir (EPFL, Lausanne)
- Jean-Pierre Ghobril (EPFL, Lausanne)
- Garik Suess (EPFL, Lausanne)
- Adithya Vasudevan (EPFL, Lausanne)

Student Assistants

- Guillaume Jacot (EPFL, Lausanne)
- Pierre Boufayssal (EPFL, Lausanne)
- Javier Sanchez Tamargo (EPFL, Lausanne)

Technicians

- Katia Antoniello (EPFL, Lausanne)

External Collaborators

- Dr. Michael Hines (Yale University, New Haven)
- Prof. Yun Wang (Boston)
- Dr. Maria Toledo
- Dr. Tania Rinaldi
- Dr. Gilad Silberberg
- Dr. Pablo de Heras (VisualBiotech, Lausanne)
- Haroon Anwar (OIST, Okinawa)
- Thomas Tränkler (Munich)

Affiliated or Former Collabators

- Adnan Abid, grant undergraduate student
- Prof. Georges Abou-Jaoudé (EPFL, Lausanne)
- Marco Belotti, assistant
- Alexandra Boussommier, student assistant