Human Brain Project

8.12.2016, EUCognition Meeting

Neurorobotics – A Strategic Pillar of the HBP

Florian Röhrbein

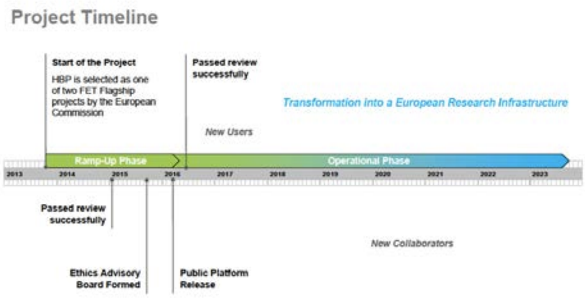
http://neurorobotics.net/

Robotics and Embedded Systems

FET-Flagships: History and Concept

- In 2009, the EU ICT Advisory Group recommended that the EC implement a new funding scheme to make Europe a major player in **big, high-risk, focused research projects in ICT.**
- As the result of a two-stage process, 23 proposals were submitted in 2010. In 2011, six candidates were selected to write a full proposal – and two were finally selected in Jan 2013.

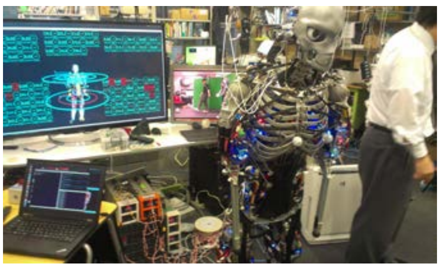
1) FuturICT – Knowledge Acce Relief System
2) **Graphene Science and tecl and beyond**
3) Guardian Angels for a Smart
4) **The Human Brain Project**
5) ITFoM: The IT Future of Mec
6) RoboCom: Robot Companio



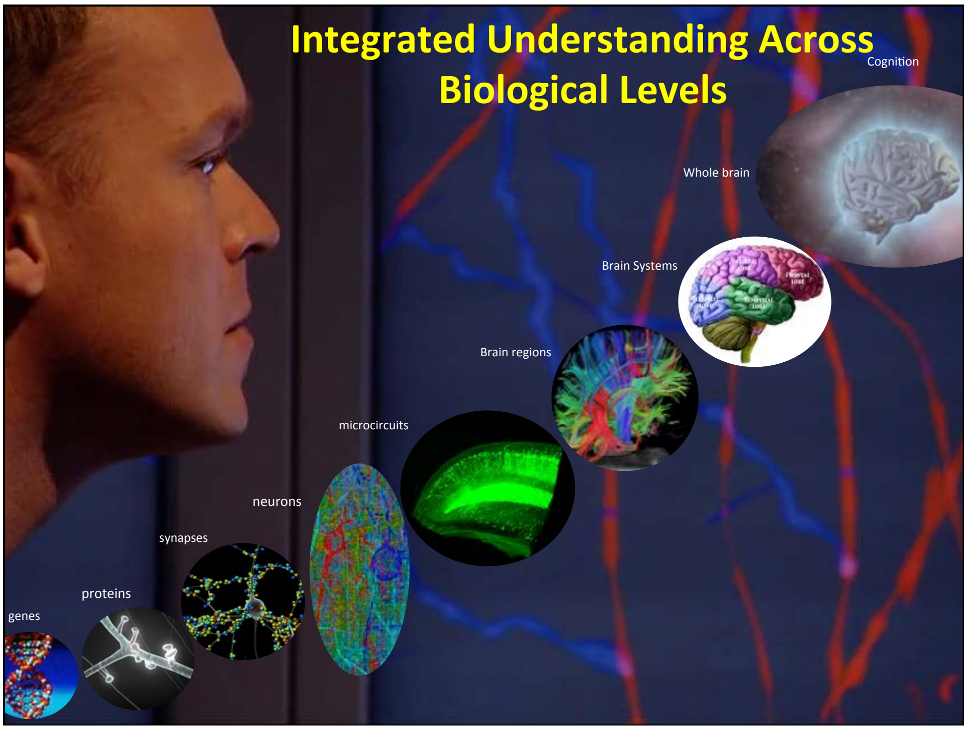
HBP at a glance

- Future Emerging Technology (FET) Flagship
- 10-year, **EUR 1 billion** Research Roadmap
  50% Core Project, 50% Partnering Projects
- Biggest EU ICT project: HBP uses ICT funding
- Ramp-up Phase (2 ½ years)
  - FP7 (54 million EUR)
  - 750+ scientists,
  - 114 institutions,
  - 24 countries, mainly Europe & Americas/Asia
- Builds on pre-existing EU & national projects:
  Blue Brain, BrainScaleS, JSC, SpiNNaker, Myorobotics
- Interfaces with EU & international efforts
  PRACE, US BRAIN initiative, …

Linking to Top Japanese Researchers and Universities




the WHITE HOUSE
PRESIDENT OBAMA IS CALLING ON THE SCIENCE COMMUNITY TO JOIN HIM IN PURSUING A GRAND CHALLENGE
BRAIN INITIATIVE
BRAIN RESEARCH THROUGH ADVANCING INNOVATIVE NEUROTECHNOLOGIES
$100 MILLION
BRAINSTEM
DARPA
DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
$50 million for understanding the dynamic functions of the brain and demonstrating breakthrough applications based on these insights
NIH
NATIONAL INSTITUTES OF HEALTH
KEY INVESTMENTS
Human Brain Project
29 – 30 NOVEMBER 2016
SAVE THE DATE
European Parliament
EUROPEAN PARLIAMENT
Science and Technology Options Assessment - STOA
UNDERSTANDING THE HUMAN BRAIN -
A new era of big neuroscience


Integrated Understanding Across Biological Levels
Cognition
Whole brain
Brain Systems
Brain regions
microcircuits
neurons
synapses
proteins
genes

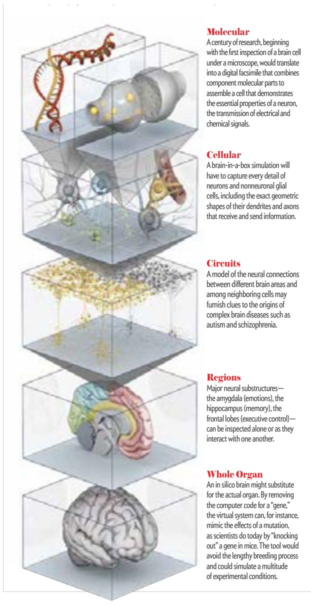
Main Research Directions of Human Brain Project

Future Neuroscience
Integrate what we know about the brain into computer models and simulations

Future Medicine
Contribute to *understanding, diagnosing and treating* diseases of the brain

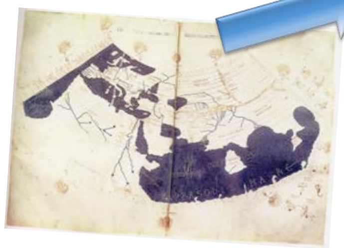
Future Computing
Learn from the brain how to build the supercomputers and robots of tomorrow

- **Virtualization of Brain and Robotics Research**



Looking back – The first *global* data integration project: Behaim's *Erdapfel (earth apple)*

1493 → 2016



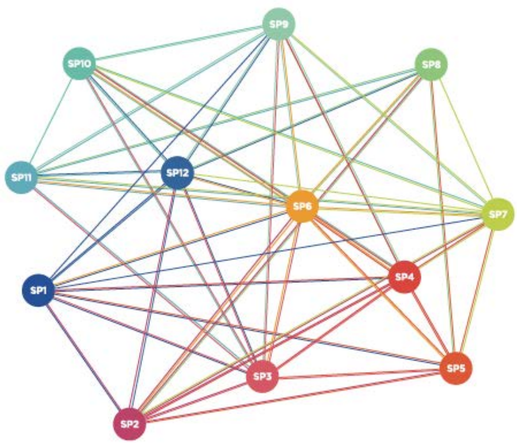
- Martin Behaim integrated all available knowledge about the earth to produce the first globe.
- Maps of different size and quality had to be scaled, corrected and aligned and then projected on a sphere to produce a consistent map of the entire earth.

What can we expect from HBP?

A *consistent* view of our knowledge about the brain …
… where each piece of information fits into the global picture …
… where the first version will be far from perfect …
… but **it will tell us how far our current knowledge goes**

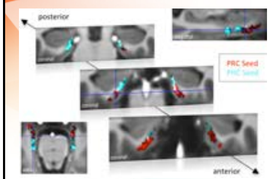
Subprojects and Collaboration in the Human Brain Project

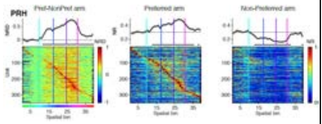
Subproject 1 SP1 Strategic Mouse Brain Data
Subproject 2 SP2 Strategic Human Brain Data
Subproject 3 SP3 Cognitive Architectures
Subproject 4 SP4 Theoretical Neuroscience
Subproject 5 SP5 Neuroinformatics
Subproject 6 SP6 Brain Simulation
Subproject 7 SP7 High Performance Computing
Subproject 8 SP8 Medical Informatics
Subproject 9 SP9 Neuromorphic Computing
Subproject 10 SP10 Neurorobotics
Subproject 11 SP11 Applications
Subproject 12 SP12 Ethics and Society



WP3.3: EPISENSE

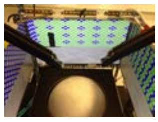
Goal: understanding the neural basis of episodic memory for spatial and multisensory integration, encoding and reconstruction





Human brain imaging of memory processing at 7T

Recordings on hippocampal pattern separation and completion



Multi-area ensemble recordings and optogenetics in cortex & hippocampus

Computational modelling of multisensory and spatial memory formation

Robotic implementation of multisensory memory

Emrah Duezel | Francesca Cacucci | Cyriel Pennartz | Tony Prescott | Martin Pearson

Subprojects and Collaboration in the Human Brain Project

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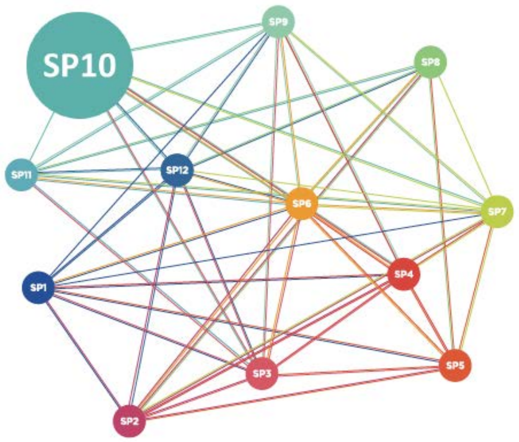
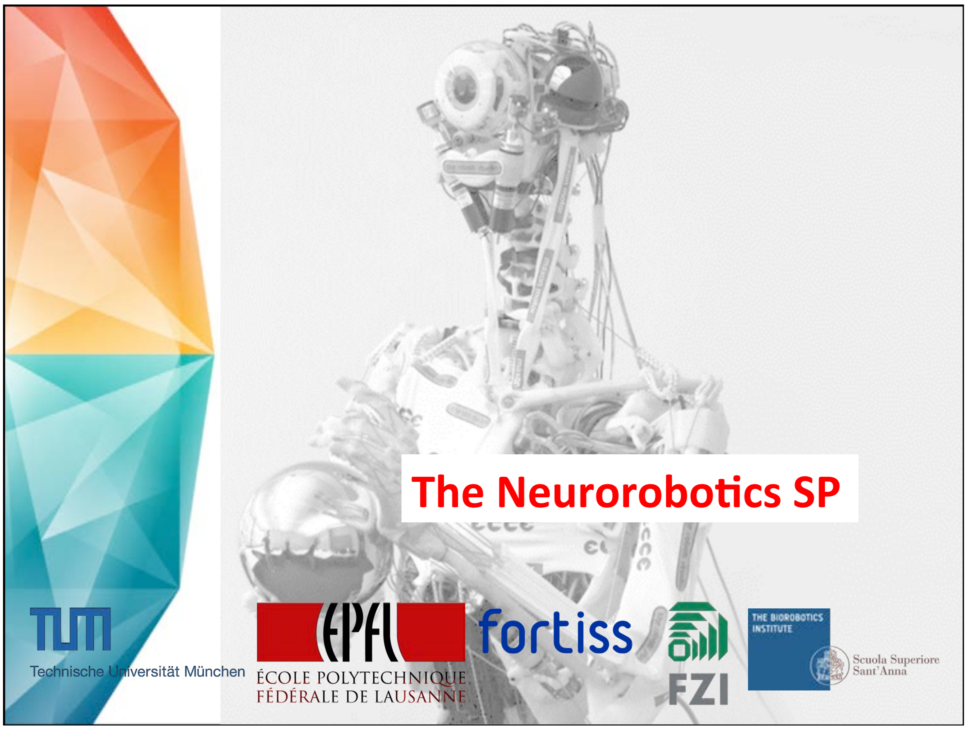




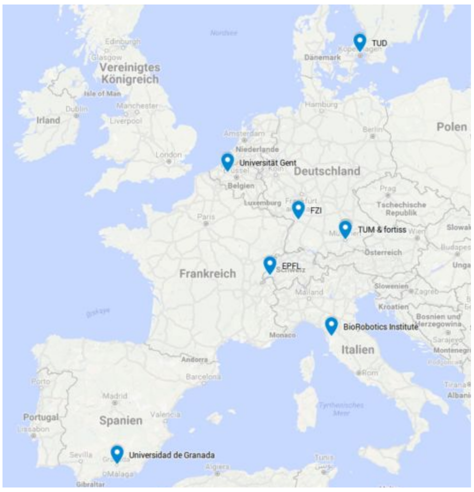
DTU

FZI

fortiss

Universidad de Granada

UNIVERSITEIT GENT



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Goals of Neurorobotic Research

Robotics

- Apply findings from neuroscience
- Overcome the limitations of standard control architectures
- Use neuromorphic hardware for robot control tasks

Neuroscience

- Use robots as a tool for testing hypotheses
- Full observability of brain models during interaction with the realistic environments

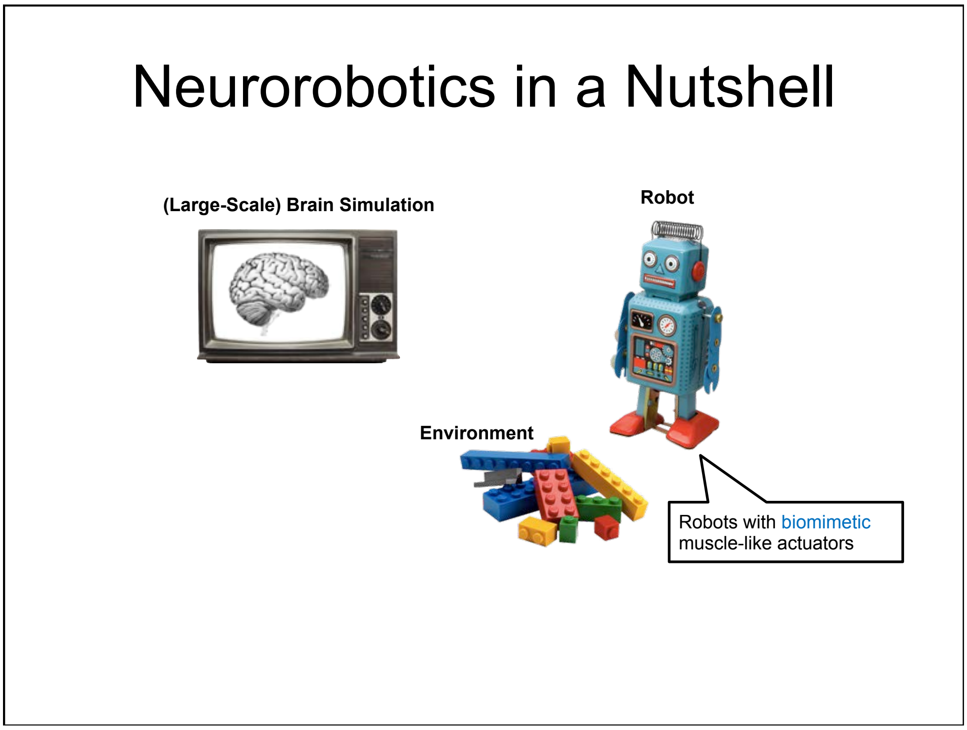
Learning

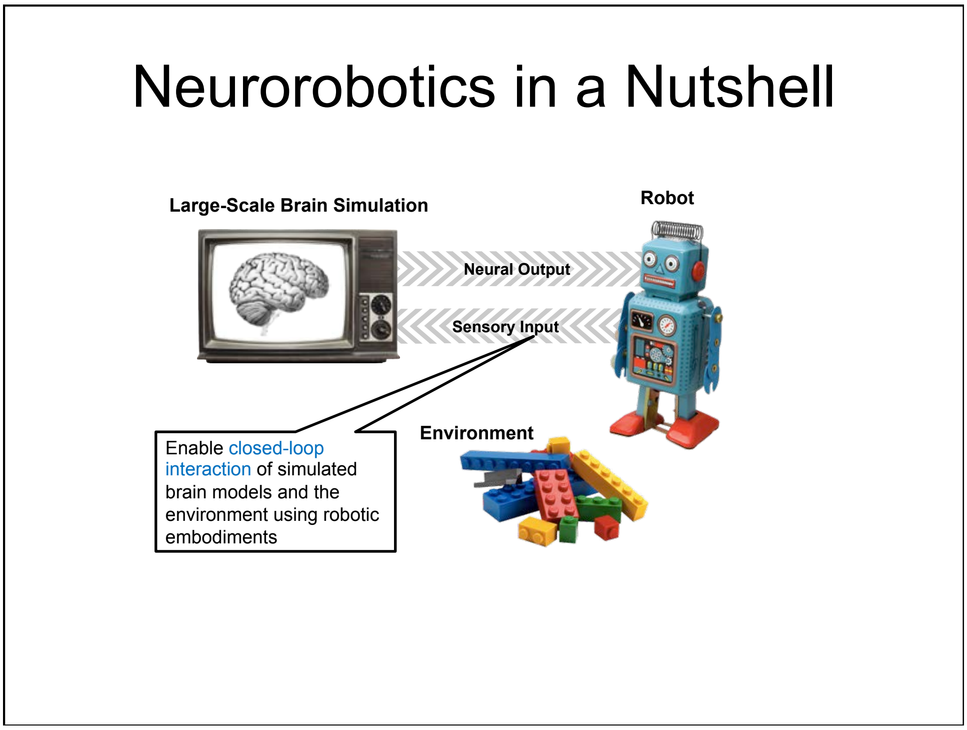
- Leverage robotic embodiment to study and develop neurobiological models of learning
- Endow virtual brains with the desired behavior

Neurorobotics in a Nutshell

(Large-Scale) Brain Simulation

Biologically realistic large-scale models with millions of neurons

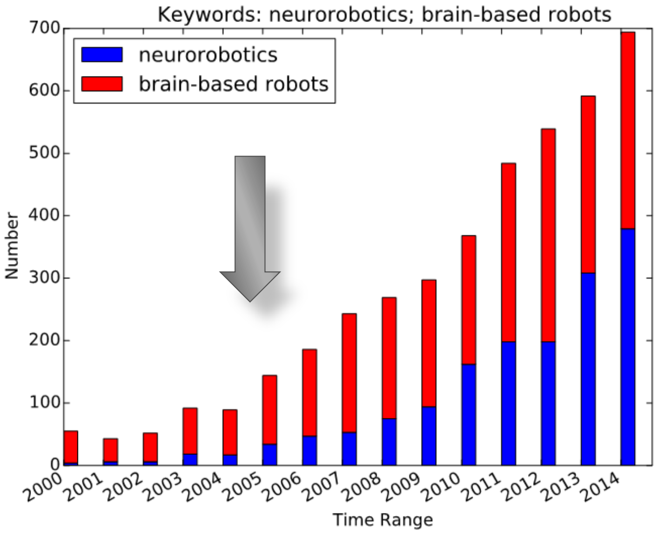

Neurorobotics in a Nutshell
(Large-Scale) Brain Simulation
Robot
Environment
Robots with biomimetic muscle-like actuators


Neurorobotics in a Nutshell
Large-Scale Brain Simulation
Robot
Neural Output
Sensory Input
Environment
Enable closed-loop interaction of simulated brain models and the environment using robotic embodiments

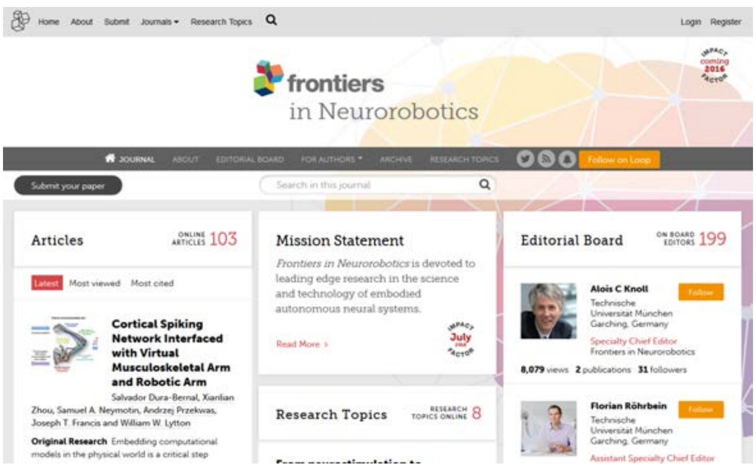
Neurorobotics: An emerging field

1950

Today



Our Journal:
frontiers in Neurorobotics



Our Journal:
frontiers in Neurorobotics

- The only journal which is dedicated exclusively to neurorobotics
- High-quality peer-reviewed articles
- Strategic alliance with Nature Publishing Group
- Open Access

http://www.frontiersin.org/neurorobotics

Motivation: Why is the brain interesting for us, anyway?

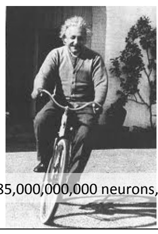

10,000 neurons


850,000 neurons


1,000,000 neurons


75,000,000 neurons

200,000,000 neurons


~85,000,000,000 neurons, 10^{15} synapses

- Algorithms are embedded in hardware
- Sensors and effectors operate in real-time
- The brain is massively parallel, but does not suffer from the problems of parallel computing: dead-locks, non-determinism, race-conditions, …
- … and decomposition into parallel tasks is self-organized/evolved
- Architecture is scalable from thousands to billions of "processors"
- Performance is robust – with graceful degradation
- Brains are extremely power and space efficient ("peta-flop computer on 20 Watt")
- Calls for a "neurorobotics approach"

Human Brain Project

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2015 Special Issue

Neuromorphic implementations of neurobiological learning algorithms for spiking neural networks

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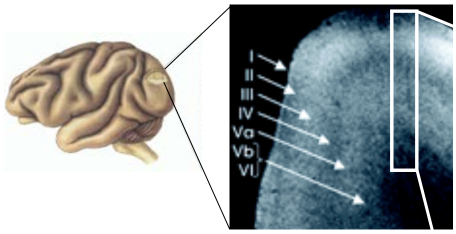
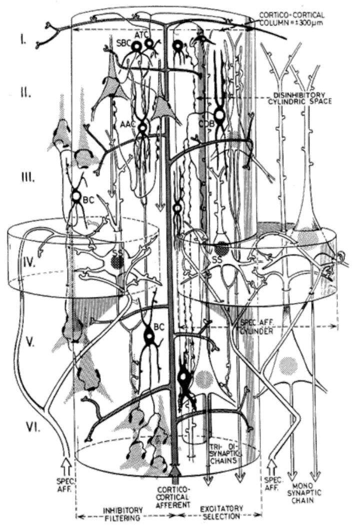
ABSTRACT

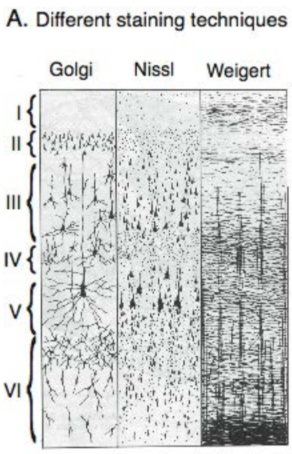
The application of biologically inspired methods in design and control has a long tradition in robotics. Unlike previous approaches in this direction, the emerging field of neurorobotics not only mimics biological mechanisms at a relatively high level of abstraction but employs highly realistic simulations of actual biological nervous systems. Even today, carrying out these simulations efficiently at appropriate timescales is challenging. Neuromorphic chip designs specially tailored to this task therefore offer an interesting perspective for neurorobotics. Unlike Von Neumann CPUs, these chips cannot be simply programmed with a standard programming language. Like real brains, their functionality is determined by the structure of neural connectivity and synaptic efficacies. Enabling higher cognitive functions for neurorobotics consequently requires the application of neurobiological learning algorithms to adjust synaptic weights in a biol[illegible]is paper, we therefore investigate how to program neuromorphic chips by m[illegible]provide an overview over selected neuromorphic chip designs and analyze [illegible]mputation, communication systems and software infrastructure. On the theo[illegible]robiological learning techniques. Based on this overview, we then examine [illegible]these learning algorithms on the considered neuromorphic chips. A final discu[illegible]this work into context and highlights how neuromorphic hardware can pote[illegible]utonomous robot systems. The paper thus gives an in-depth overview of neu[illegible] of basic mechanisms of synaptic plasticity which are required to realize adva[illegible]with spiking neural networks.

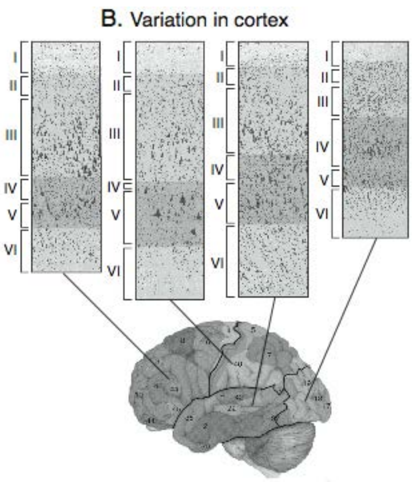
The Basic Computational Unit





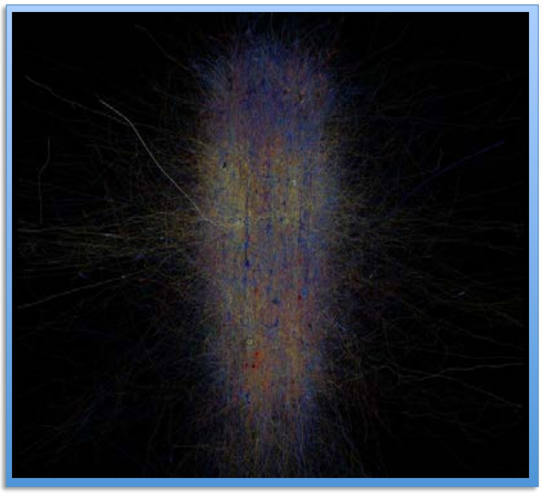
Layered cortex





State of Simulation: Column of the Blue Brain Project

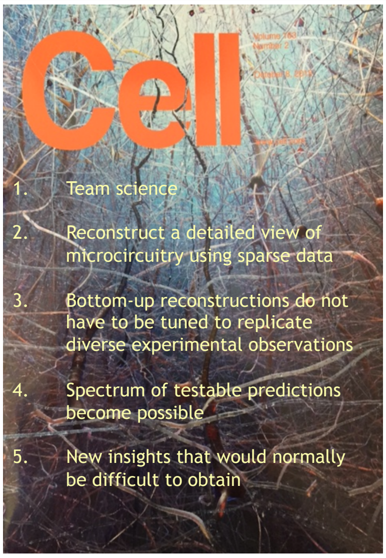
- Clearly, the simulation of even the smallest network in full detail will take today's supercomputers to their limits
- Example: the cortex-column of the blue-brain project
  - ~70,000 neurons
  - computation of voltage levels at every point in space
  - Modeling of electrical/chemical processes at synapses, dendrites, axons, and in the neuron
  - Simulation takes **several days to complete** on IBM Blue Gene HPC



Human Brain Project

SP6

Concepts for Reconstruction and Simulation

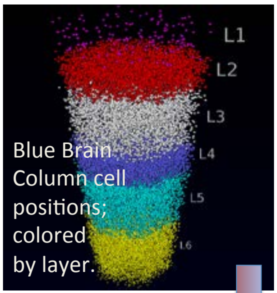


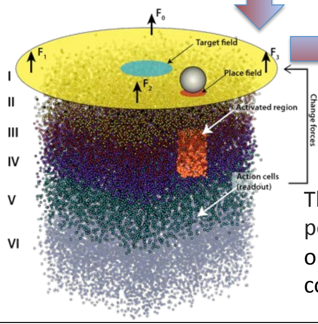
1. Team science
2. Reconstruct a detailed view of microcircuitry using sparse data
3. Bottom-up reconstructions do not have to be tuned to replicate diverse experimental observations
4. Spectrum of testable predictions become possible
5. New insights that would normally be difficult to obtain

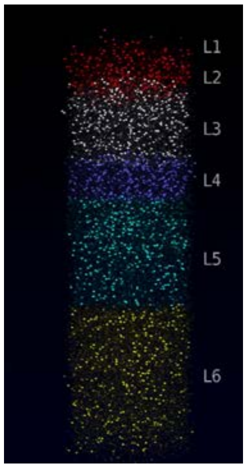
Henry Markram,[1,2,19,*] Eilif Muller,[1,19] Srikanth Ramaswamy,[1,19] Michael W. Reimann,[1,19] Marwan Abdellah,[1] Carlos Aguado Sanchez,[1] Anastasia Ailamaki,[16] Lidia Alonso-Nanclares,[6,7] Nicolas Antille,[1] Selim Arsever,[1] Guy Antoine Atenekeng Kahou,[1] Thomas K. Berger,[1] Ahmet Bilgili,[1] Nenad Buncic,[1] Athanassia Chalimourda,[1] Giuseppe Chindemi,[1] Jean-Denis Courcol,[1] Fabien Delalondre,[1] Vincent Delattre,[2] Shaul Druckmann,[5] Raphael Dumusc,[1] James Dynes,[1] Stefan Eilemann,[1] Eyal Gal,[4] Michael Emiel Gevaert,[1] Jean-Pierre Ghobril,[2] Albert Gidon,[3] Joe W. Graham,[1] Anirudh Gupta,[2] Valentin Haenel,[1] Etay Hay,[3,4] Thomas Heinis,[1,16,17] Juan B. Hernando,[8] Michael Hines,[12] Lida Kanari,[1] Daniel Keller,[1] John Kenyon,[1] Georges Khazen,[1] Yihwa Kim,[1] James G. King,[1] Zoltan Kisvarday,[13] Pramod Kumbhar,[1] Sébastien Lasserre,[1,15] Jean-Vincent Le Bé,[2] Bruno R.C. Magalhães,[1] Angel Merchán-Pérez,[6,7] Julie Meystre,[2] Benjamin Roy Morrice,[1] Jeffrey Muller,[1] Alberto Muñoz-Céspedes,[6,7] Shruti Muralidhar,[2] Keerthan Muthurasa,[1] Daniel Nachbaur,[1] Taylor H. Newton,[1] Max Nolte,[1] Aleksandr Ovcharenko,[1] Juan Palacios,[1] Luis Pastor,[9] Rodrigo Perin,[2] Rajnish Ranjan,[1,2] Imad Riachi,[1] José-Rodrigo Rodríguez,[6,7] Juan Luis Riquelme,[1] Christian Rössert,[1] Konstantinos Sfyrakis,[1] Ying Shi,[2] Julian C. Shillcock,[1] Gilad Silberberg,[18] Ricardo Silva,[1] Farhan Tauheed,[1,16] Martin Telefont,[1] Maria Toledo-Rodriguez,[14] Thomas Tränkler,[1] Werner Van Geit,[1] Jafet Villafranca Díaz,[1] Richard Walker,[1] Yun Wang,[10,11] Stefano M. Zaninetta,[1]

Simplifying the BBP Column

- L2/3: Relations with the other cortical columns
- L4: Perceptive input (from Thalamus)
- L5: Output to extra-cortical structures



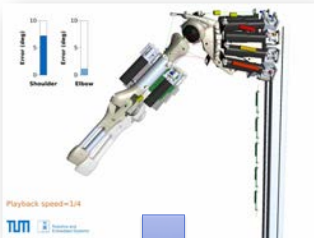




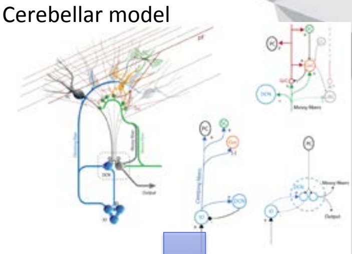
The BBP Column with point neurons; this model runs on a PC or very fast on a super-computer (NEST simulation)

Towards physical robotics

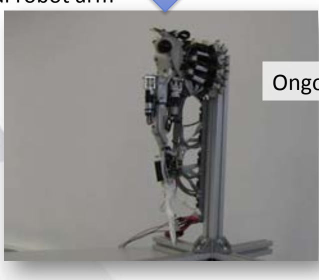
Simulated robot arm



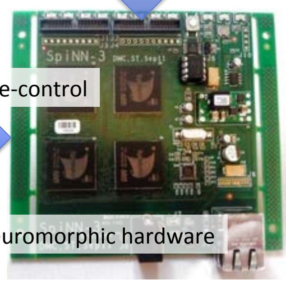
Cerebellar model



Physical robot arm

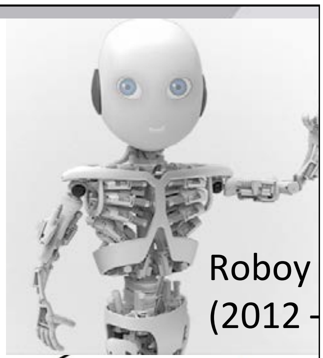


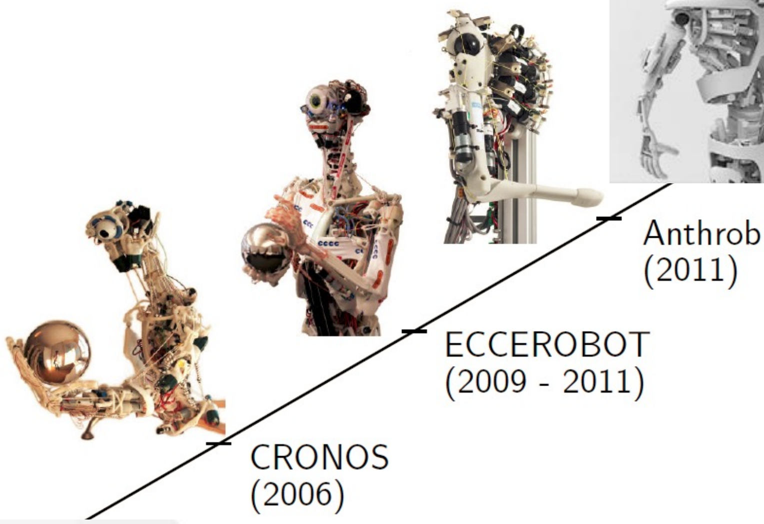
Ongoing: Realtime-control



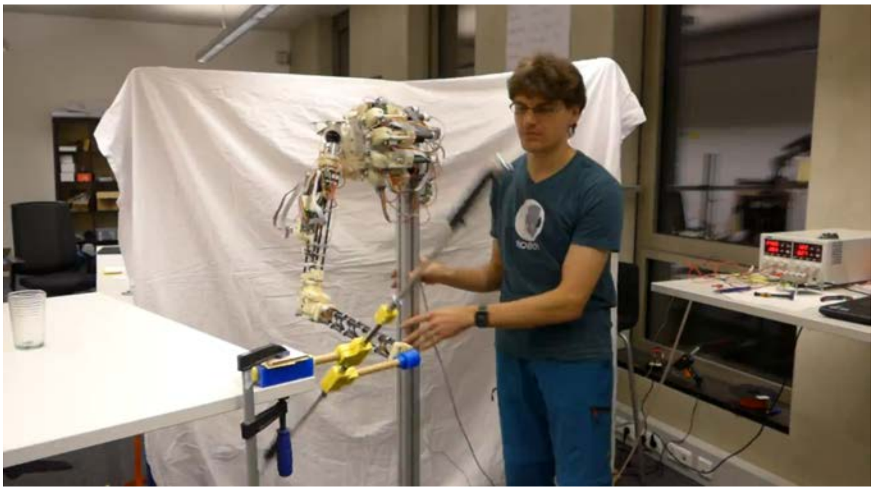
Neuromorphic hardware

Implementation in the first HBP phase: hardware base





An Anthropomimetic Myorobotics Arm



Source: Der, Martius (2015)

Deep Learning vs. Brain

Deep neural networks are assumed to process information similarly to the brain. However, there are still some important aspects missing:

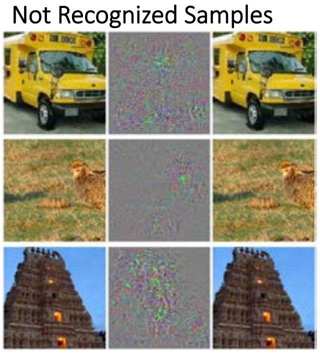
- Most deep neural networks are simple feedforward networks with unidirectional bottom-up processing logic. The brain contains lots of top-down and lateral connections.
- Deep neural networks are mostly trained offline on large datasets with supervised learning. The brain continuously learns online using unsupervised learning, supervised learning and reinforcement learning at the same time.
- Deep neural networks learn from artificial datasets. The brain learns through multimodal real-time interaction with the environment through a physical body.

Deep Learning

2014, 2015

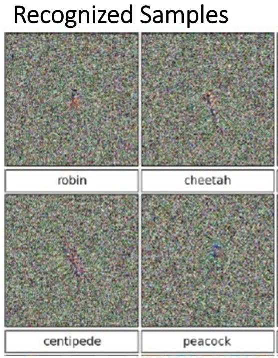
Human-like visual processing in deep neural networks?

Not Recognized Samples



(Szegedy, Zaremba et al., 2014)

Recognized Samples



(Nguyen, Yosinski et al., 2015)

The Contribution of Neurorobotics to Future Machine Learning

Neurorobotics connects physical bodies to highly realistic simulations of biological brains. It extends current deep learning approaches in several ways:

- The use of biologically more realistic neural network models (e.g. spiking neural networks) with complex connectivity yields rich neural dynamics which can perform meaningful computation.
- Closed-loop interaction through physical bodies in real-time naturally structures sensory data.
- The embodiment enabled by appropriate physical bodies can ease the learning task by outsourcing computation to the physical structure of the robot.

Neurorobotics has a huge potential to play a key rule in future machine learning!

HBP Platforms

- **Collaborative research tools** for brain research and brain-inspired computing technologies.
- Prototype hardware, software, databases, brain atlases, and programming interfaces
- Embody the key objectives of the HBP
- **Continuous refinement** in close collaboration with end users
- Access as of today via the HBP Collaboratory

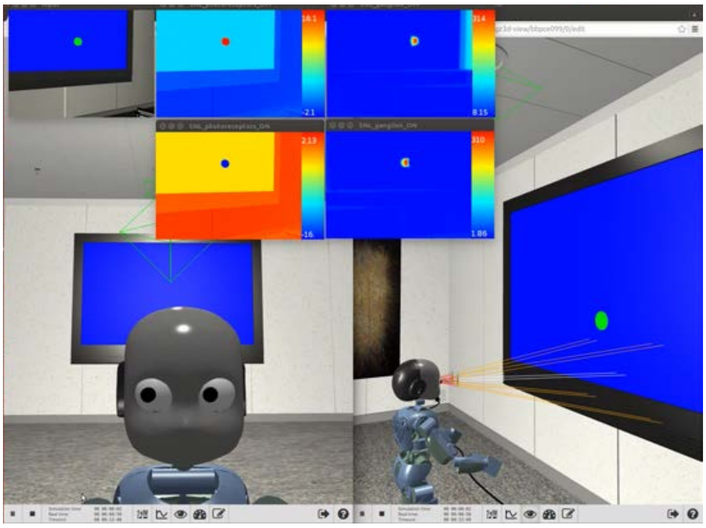
Photo: © John L Downes

SP10 Objectives of the Neurorobotics Platform

With the Neurorobotics Platform, researchers can collaboratively design and run virtual experiments in cognitive neuroscience using brain models developed within and outside the Human Brain Project.

The Neurorobotics platform provides software and hardware tools for researchers to demonstrate how brain models can control robots in complex environments.

Sensors: Retina Model

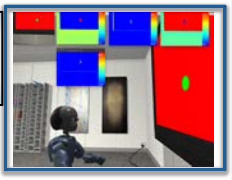


SP10

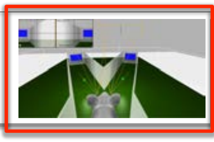
NRP Experiments

1- Braitenberg Experiment v1 - *Closed-loop simulation*
2- Braitenberg Experiment v2 - *Events Control*

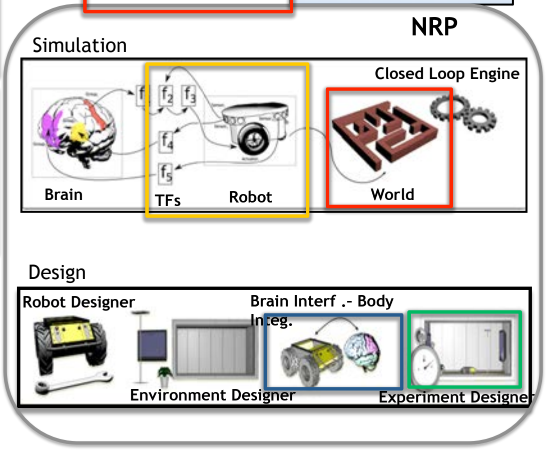
4- Visual Tracking Experiment *Integrating a retina model*



5- Sensory-Motor Learning Experiment *Based on Robot to Robot Transfer Functions*

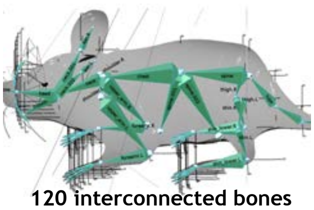


3- Mouse Experiment - ***Soft body simulation*** *Mouse has deformable skin*



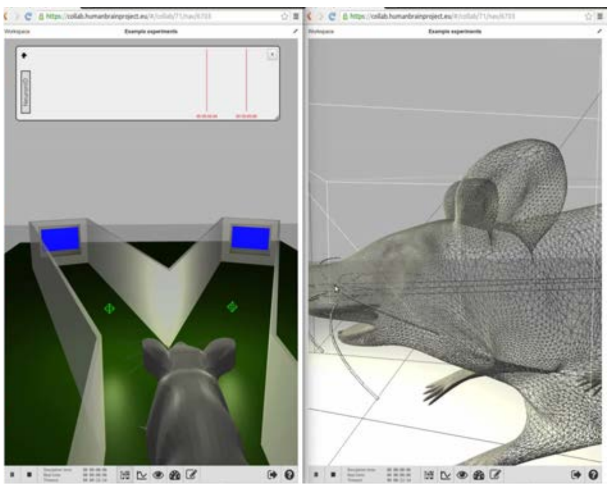
SP10

Mouse Experiment



120 interconnected bones

- A mouse model featuring skinning, i.e. deformation of the surface triangles, based on bone movements
- The skin deforms when the mouse turns the head.



Detailed surface model with 135588 triangles

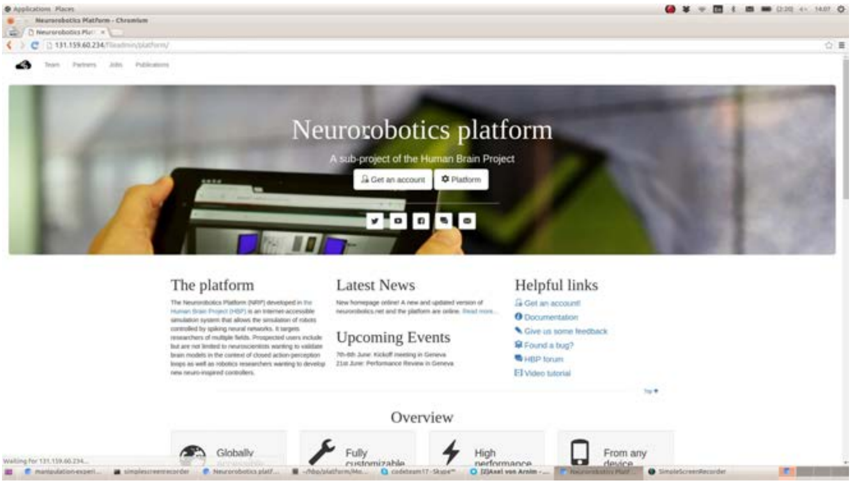
SGA1 experiment proposals

SP10

- Science drives the development of the neurorobotics platform
- SP10 participates in three cross-SP co-design projects
- 40 experiment proposals from all SP10 partners
- Managed process to integrate research and software development

- MOUSE 2 [TUM] Simulation of Basic Musculoskeletal Reflexes
- MOUSE 3: [BioRob] Forelimb Neuroprosthetic Setup
- MOUSE 4 [Mouse] Mouse walking in hamster wheel/treadmill
- MOUSE 5: [Mouse] Freewalking
- MOUSE 6: [UGent] Evolving mouse and brain model
- ROBOTIC-MOUSE (SSSA) Gaze-guided locomotion for a biped robot
- ROBOTIC 1. (FZI manipulation) Grasping: hand movements for different grasping types
- ROBOTIC 2. (FZI vision) Visual object recognition
- ROBOTIC 3. (FZI) Serial working memory and recall
- ROBOTIC 4. (FZI vision) DVS: Object motion prediction
- ROBOTIC 5.(Japan) Parkinson disease simulation
- (Cross-SP) integrating MiRo from Consequential Robotics (Sheffield)
- (FZI) DVS: Prediction of affordances
- (FZI) Manipulation
- (FZI manipulation) Grasping: benchmark scenario
- (FZI manipulation) Model learning of robotics arm
- (FZI manipulation) Reinforcement learning: Target reaching task for robotic manipulator
- (FZI) Reinforcement learning: Mouse learning to survive
- (FZI vision) DVS: Drone with automatic neuronal stabilization
- (FZI) Vision
- (Japan) Motion recognition and generation with text
- (Japan) Neural maze solving
- (Japan) Parkinson simulation
- (Mouse) Mouse Whiskers Detect Collision
- (Mouse) Real mouse vs. virtual mouse
- (Mouse) Suspended mouse walking on moving walkway
- (Mouse) Turning Mouse Head Using Muscles with Visual Representation
- (Mouse) Turning Mouse Head Using Tendon-driven Concepts with Visual Representation
- (Mouse) Walking mouse in glass box
- (SSSA) Emotion-based emergent decision-making on a humanoid robot
- (SSSA) Implementing visual attention models on virtual humanoid robots
- (SSSA) Invariant object recognition for motor sequence generation on a humanoid robot.
- (SSSA) Learning motor coordination for visually guided bimanual manipulation
- (Step by step design of a walking mouse) (feature)

Getting Involved: Request an Account and Participate!



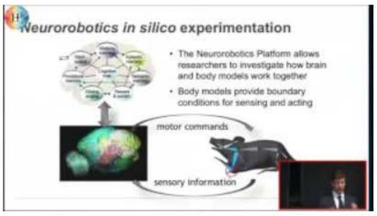
www.neurorobotics.net, www.humanbrainproject.eu, www.humanbrainproject.eu/platform-access

HBP Neurorobotics video tutorial

Feel free to select any of the videos below to get yourself familiarized with specific features of the platform. Choose from easier, basic ones if you are new to the platform or more advanced ones if you are experienced user and want to learn about specific use case scenario.

Basics

NRP Introduction



Discover platform

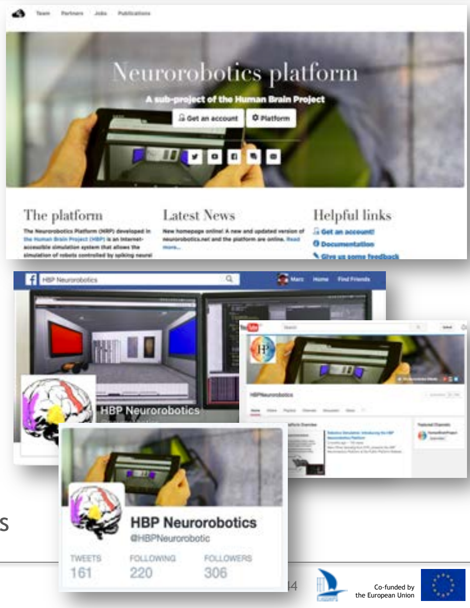
Create and share experiments

Run experiments

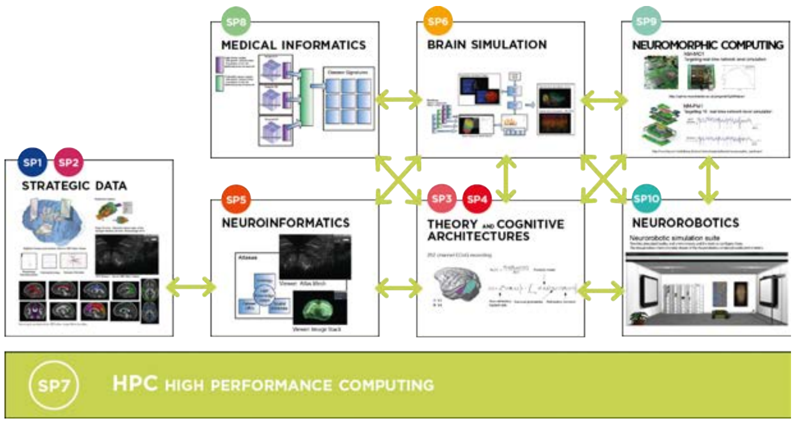
SP10

User community building

- Performance shows with open days
- Workshops and symposia
- Talks and demonstrations
- Platform homepage
  - www.neurorobotics.net
- Tutorial and demo videos
- Social Media
  - facebook.com/neurorobotics
  - twitter.com/HBPNeurorobotics
  - youtube.com/c/HBPNeurorobotics

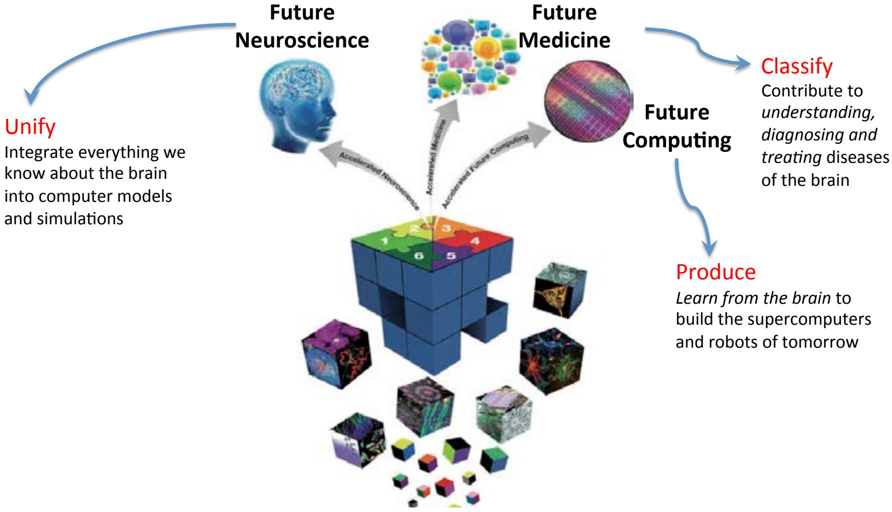


The Neurorobotics Platform within the Human Brain Project:



The HBP research areas and long-term goals

Goal: to *develop technology to unify our understanding of the human brain and to transfer this knowledge into products*



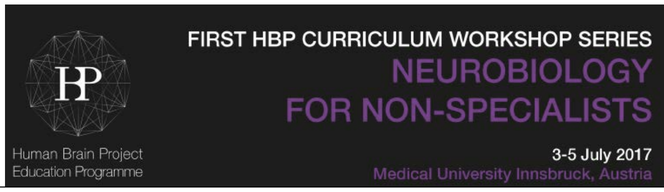
Sub-Project Leaders

Work Package Leaders

SP10 Team building: SP10 “Performance Shows”

- Quarterly meeting of the HBP Neurorobotics team
- Rotating locations (Munich, Geneva, Pisa, Karlsruhe…)
- Presentation and discussion of the latest achievements
- Setting goals for future research and development
- Talks by invited experts and collaborators
- 5 performance shows between M13 and M30

Next meeting: 9-11.1.2017 at TUM in Munich



Robotics and Embedded Systems

Thank your for your attention!

For more information visit us on

www.neurorobotics.net

and follow us on Twitter!

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Human Brain Project