

The Human Brain Project: Creating a European Research Infrastructure to Decode the Human Brain

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Decoding the human brain is perhaps the most fascinating scientific challenge in the 21st century. The Human Brain Project (HBP), a 10-year European Flagship, targets the reconstruction of the brain's multi-scale organization. It uses productive loops of experiments, medical, data, data analytics, and simulation on all levels that will eventually bridge the scales. The HBP IT architecture is unique, utilizing cloud-based collaboration and development platforms with databases, workflow systems, petabyte storage, and supercomputers. The HBP is developing toward a European research infrastructure advancing brain research, medicine, and brain-inspired information technology.

Introduction

The Human Brain Project (HBP) is a multinational European brain research initiative to advance neuroscience and medicine and to create brain-inspired information technology. The HBP is funded by the European Commission Directorate General for Communications Networks, Content, and Technology (DG CONNECT) in the framework of the EU's Horizon2020 research funding program and is one of the first two Future and Emerging Technologies (FET) Flagship projects. These were conceived to allow the EU to support larger, longer-term research efforts, with a view to generating significant innovation which would benefit citizens in Europe and further afield.

As the first initiative of its kind, the HBP has inspired and even triggered similar initiatives around the world. The HBP is one of the largest European-funded research projects ever and one of the most comprehensive in its field. With a total funding period of 10 years foreseen for the HBP, it is also one of the longest. In fact, decoding the multi-scale enigmas of the human brain is a task of such complexity that the sum of all the resources mobilized to date by all brain research initiatives pales facing this challenge.

It is a central tenet of the HBP strategy that a comprehensive understanding of the brain requires deep insight into structure and function across all levels of brain organization, from genes to the whole brain; a useful understanding cannot be achieved at any one level alone. To achieve this, interdisciplinary expertise joining neuroscience, computer science, informatics, physics, and mathematics is key. A massive scientific collaboration is required to reconstruct the required multi-level models. The social internet and open source software communities have shown that modern information and communication technologies (ICTs) permit the massive collaborative efforts needed.

Therefore it became the underlying paradigm of the HBP—which so far is unique in brain research—to utilize a broad toolbox of the most advanced ICT to the challenge of decoding the human brain. These tools include cloud-based collaboration and development platforms, with databases for metadata and provenance tracking, as well as data analytics and compute services, right up to leading-edge supercomputers, neuromorphic systems, and virtual robots. This involves the development of advanced software

supporting “Big Data”-dominated analytics and high-end simulation at all levels of brain organization, including metadata management, starting from the acquisition of data in the lab (e.g., Zehl et al., 2016). The HBP aims to integrate all of these inputs and catalyze a community effort. In this respect, the HBP is predestined to establish itself as *the* European research infrastructure for brain research and brain-inspired technology development.

This NeuroView describes why and how HBP has been set up to decode the human brain. Collaboration, sharing of data and tools, and exchanging ideas are central to the HBP's approach.

Scope and Coordination

The HBP started its 30-month, EUR 55 million ramp-up phase (RUP) in October 2013. After a first external expert peer review a year into the RUP, the project objectives were adjusted and underline the infrastructure aspect more explicitly. The HBP's primary objective has been confirmed as the building of a European infrastructure for brain science, and this goal has been endorsed by the EC in the more detailed roadmap for the current funding phase (known as the first specific grant agreement, or SGA1).

Over the project's 10-year overall lifetime, EC funding is awarded in 2-year increments, subject each time to the favorable review and acceptance of a formal proposal for a new SGA. These increments provide the opportunity to bring in additional partners when new capabilities are needed to fulfill the roadmap, or to remove partners who have not contributed as expected.

The approach taken in the HBP is highly coordinated and very broad: it brings together a dozen or more disciplines, drawn from 117 partner institutions in 19 countries in Europe, as well as some 120 nationally funded Partnering Projects. Some of these Partnering Projects are the fruit of transnational calls set up by the EU's FLAG-ERA research coordination mechanism, and funded by European national funding agencies. The HBP has also attracted scientists working outside Europe, and many partner institutions add substantial in-kind contributions to complement EU funding.

The FET Flagships' funding model combines an EC-funded "Core Project," complemented by a number of Partnering Projects funded by member states or other non-EC sources. Over the lifetime of the HBP, these two major components are expected to receive total funding approaching EUR 500 million each. While the Partnering Project approach has worked well on the research side (there are many bottom-up projects), attracting complementary funding to build a major research infrastructure requires a more structured and targeted approach.

As the project moves forward, components and contributions from HBP member countries will be integrated to complete specific parts of the research infrastructure, as the HBP Core Project alone was not conceived or funded to deliver a large-scale operational-grade research facility. Bringing together these different infrastructure contributions will require a very significant integration engineering effort, for which HBP member country support is crucial.

Three bodies are responsible for coordinating the HBP: the Stakeholder Board, the Science and Infrastructure Board, and the Directorate. The Stakeholder Board is the project's ultimate decision-making body and is comprised of one representative from each HBP member state. This

raises the necessary steering responsibilities and representation to a higher, aggregate level and helps create country-based support structures for the HBP. The Science and Infrastructure Board is central to the HBP, providing scientific leadership of the Core Project. It is responsible for managing the implementation of the scientific and infrastructure work plan and for proposing work plans and roadmaps for each SGA. The Directorate is responsible for the management of the Core Project.

The new governance structure is also a response to early criticism of the project, especially its original governance arrangements, which were seen as lacking adequate checks and balances for such a large project, covering a wide range of partner institutions and disciplines.

The objective of an enduring, federated, ICT-based research infrastructure for advanced brain research is supported by the creation of an HBP legal entity, modeled on an international organization. The new legal entity should be set up soon, whereupon it will take over the coordination of the HBP Core Project and oversee the integration of research infrastructure components from various member countries into an operational-grade facility.

Neuroscientific Approach and Organization of Research

What does "decoding the human brain" imply? The HBP's neuroscientific approach can be characterized as follows.

Fundamental to the HBP approach is the investigation of the brain on the many levels accessible to experiment at different spatial scales (from the molecule to large networks such as those underlying cognitive processes) and temporal scales (from milliseconds to years). This type of investigation is performed consistently throughout the project, addressing mouse brain, human brain, systems neuroscience, cognitive neuroscience, and theoretical neuroscience, using a variety of approaches, methods, instruments, and tools (cf. [Figure 1](#)).

The HBP is leveraging the productive loop approach between experiment, modeling, and simulation on all levels of brain organization. The idea behind this is that empirical results foster the development of theories, which are then

entering modeling and simulation, and simulations result in predictions. Such predictions can be verified empirically, resulting in improved experimental data and concepts *et patati et patata*. For example, the specific membrane capacitance of pyramidal neurons was recently predicted by fitting in vitro voltage transients to theoretical transients and then validated experimentally ([Eyal et al., 2016](#)).

Models and simulations generated include molecular-level principal neurons and cellular-level reconstructions of brain regions ([Markram et al., 2015](#)), brain resting state ([Hansen et al., 2015](#)), quantitative kinetic modeling ([Nair et al., 2015](#)), and spiking networks ([Kunkel et al., 2014](#); [Zenke et al., 2015](#)). Validated brain models can also be connected to detailed simulations of robot bodies and environments for in silico experiments, allowing the interaction between environment and information processing in the brain to be studied, even in combination with neuro-morphic devices ([Richter et al., 2016](#)).

Furthermore, the HBP is supporting research linking basic and cognitive neuroscience concepts with philosophical ideas, for example for elucidating technical and theoretical limits on brain-machine interface access to other minds ([Farisco et al., 2015](#)).

Neuroscience Sub-Projects

Scientific and technological research is performed in all parts of the project, including the platform sub-projects. However, four sub-projects have a particular focus on the different facets of neuroscience: Mouse Brain Organization, Human Brain Organization, Systems and Cognitive Neuroscience, and Theoretical Neuroscience. They contribute data, concepts, and tools to solve neuroscientific questions, and they support the development of the research platforms. There, in an iterative way, neuroscience contributes to the Platforms in the form of a co-design process. Researchers in the four sub-projects represent the initial users of the HBP research infrastructure, piloting the opening up of the platforms to the broader science community. Empirical research will enable the formulation of multi-scale theories and predictive neuroinformatics by modeling and simulation to identify organizational principles of spatial and temporal brain architecture.

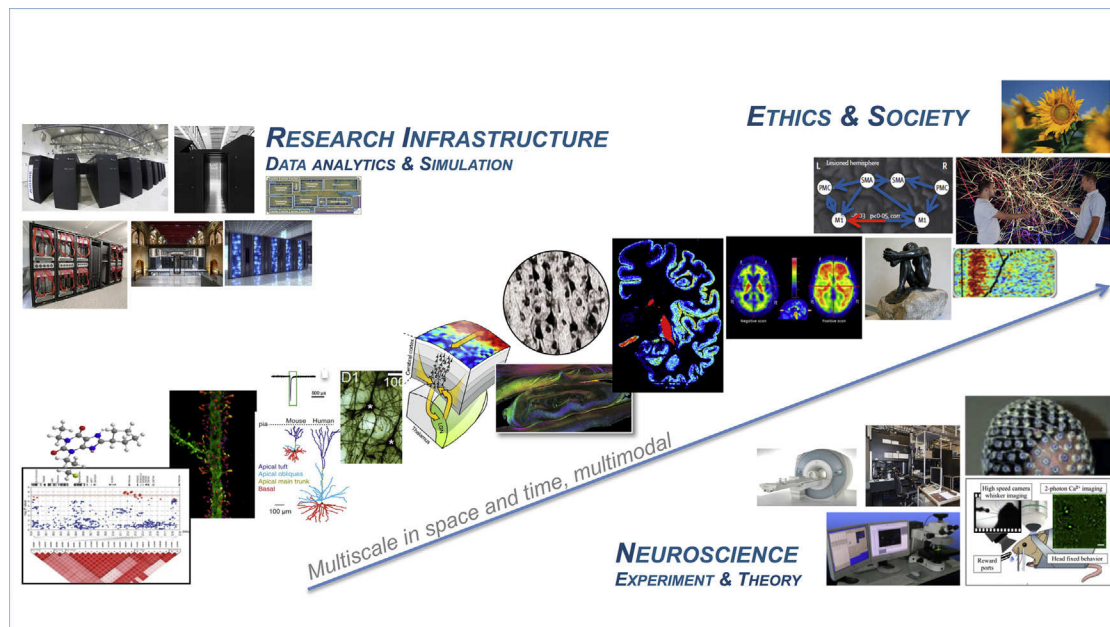


Figure 1. Approaching the Multi-Level Organization of the Human Brain

Mouse Brain Organization. The mouse remains a premier model to approach human brain function, because it is possible to directly study genetic, molecular, and cell biological processes, including neuronal and glial physiology and cognitive processes in living animals, and in genetic models of human diseases. Mouse brain research will result in the most complete multi-level map of a vertebrate brain ever produced, spanning all levels of biological organization, including maps of the vasculature, different cellular types based on gene expression, long-range axonal projections, synaptic proteins, and whole-brain activation maps related to selected behavior. These data are highly relevant for the development of simulation and neuroinformatics tools. During the next few years, researchers will go further and further beyond domain-specific datasets toward integration of different datasets, introducing disease- and pharmacology-relevant approaches, and genetics, as well as contributing to the development of new drugs, to meet the pressing medical and societal needs stemming from the growing burden of brain disease. The different aspects of both mouse and rat brain organization are accessible through the HBP Rodent Brain Atlases.

Human Brain Organization. The second sub-project provides neuroscientific concepts, knowledge, datasets, and tools for a better understanding of the multi-level and multi-scale organization of the human brain. Human brain functional and structural segregation, its inter-subject variability, and genetic factors represent central elements and contribute to the multi-modal human brain atlas of the HBP. In collaboration with the first sub-project, researchers will study differences between the human brain and those of other species, making it possible to use transformed versions of data for mouse genes, transcripts, proteins, neuron morphologies, etc., to fill gaps in our knowledge of the structural organization of the human brain. Research is also linked to theory, by contributing data on top-down modeling at the systems and cognitive levels. Considering the sheer size and complexity of the human brain, this research requires the development and application of big-data analytics.

Systems and Cognitive Neuroscience. The third sub-project is building experimental setups, methods, and simulations of behavioral-cognitive processes and brain states. This includes, for example, context-sensitive multisensory object recognition to provide an understanding of how the human brain achieves invariant

and context-sensitive representations of objects. It will also address episodic memory, validate the results of such experiments by computational models and robotic systems, and test how they fail in old age and dementia. Other research concerns wave scaling experiments and simulations, which explore how disparate multi-scale phenomena, such as those underlying sleep and wakefulness, can emerge from the same cortico-thalamic system. Finally, experimental and computational exploration of consciousness mechanisms in mice and humans will be performed, as these have wide-ranging theoretical and clinical implications.

Theoretical Neuroscience. The fourth sub-project aims to develop models of the brain from cellular to network levels, including detailed, simplified, and population models, relying on data from the first three sub-projects. The idea is to understand how scales interact in specific and general terms and to bridge the scales. The development of mean-field models will enable this sub-project to integrate directly mesoscopic and macroscopic signals, ranging from LFP and EEG, up to fMRI. For instance, it is planned to reach a whole-brain model of the mouse using population models. Building blocks for other, large-scale models will be

developed, which include the different signals of the brain, simplified models with dendrites, and generic (single-compartment) models of different brain areas, plus algorithms for synaptic plasticity and memory. These will enable investigations of the mechanisms for learning, memory, attention, and goal-orientated behavior and begin to determine the way in which function emerges from structure. Fundamental aspects of brain function, such as the genesis of spontaneous activity, low-level vision, motor control, sensorimotor coordination, and spatial navigation, will also be investigated. Models and mechanisms will be conceived so they can be implemented directly on the neuromorphic hardware developed in another HBP sub-project.

Further Sub-Projects and Co-Design Projects

In order to support not only activities of these four sub-projects but also research in more general terms, the HBP features a new European scientific research infrastructure initially containing six research platforms—Neuroinformatics, Brain Simulation, High-Performance Analytics and Supercomputing, Medical Informatics, Neuromorphic Computing, and Neurorobotics—connected through the “Collaboratory” (COLLAB) interface. The platforms are inspired by and developed in co-design with neuroscientific investigators.

Furthermore, in order to interconnect the sub-projects, each of which has its own disciplinary focus (either more neuroscience or more platform oriented), six Co-Design Projects (CDPs) have been set up, which bring together scientists and engineers developing specific parts of the infrastructure, ensuring that they both are robust and respond to real scientific needs.

Two sub-projects cross-link all the other ones: “Ethics and Society” explores the project’s social, ethical, and philosophical implications. It promotes engagement with decision-makers and the general public, fosters responsible research and innovation by raising social and ethical awareness among project participants, and ensures that the project complies with relevant legal and ethical norms (Christen et al., 2016).

All fields are supported by the Coordination and Central Services Sub-Project,

which coordinates governance, leadership, and decision-making mechanisms, provides central support for administration and reporting, designs and coordinates a program of transdisciplinary education, and handles the HBP’s open calls program.

ICT Architecture of the HBP Integrated System of Platforms

The entire HBP is deeply rooted in information and communication technology (ICT): two of HBP’s platforms, the Neuroinformatics Platform (NIP) and the High-Performance Analytics and Computing Platform (HPAC), are delivered primarily as IT service infrastructures; they are enabled by advanced cloud technologies, a federation of supercomputing centers, and are continuously developed by targeted research. The nerve system of HBP’s collaborative research environment, the COLLAB, is being developed within the NIP.

The remaining four platforms rely heavily on the data, software, and service infrastructure provided by the NIP and HPAC Platform. The Brain Simulation Platform and the Neurorobotics Platform pursue the creation of advanced application software systems: the first focuses on data-driven modeling and brain simulations on all scales, while the second concentrates on connecting virtual brain models to virtual robots in simulated environments and to real robots. The Medical Informatics Platform (MIP) pursues the mining of medical data from hospitals; this is intended to support personalized medical applications as well as hypothesis generation for disease models. The sixth platform, the Neuromorphic Computing Platform, develops and provides brain-inspired neuromorphic hardware-software prototypes promising to outperform brain simulations on classical supercomputers and enable a range of novel scientific experiments and industrial applications.

These six infrastructure platforms are starting to be intensively utilized by neuroscientists throughout the HBP, creating massive upstream and downstream data flows. To support reproducible neuroscientific analysis, modeling, and simulation workflows, researchers are combining an immense volume and complexity of internal and external neuroscience data,

high-end simulation, and massive data analysis capabilities to groups of global distributed collaborators. This is strictly necessary to support the HBP objectives and demands both continuous feature development and most-reliable operation of the underlying IT-based technologies and services.

In the following sections, we sketch out how this need is being addressed with an HBP integrated system of platforms, supported by key services from the COLLAB, the NIP, and the HPAC.

The Collaboratory

In order to most effectively enable access by HBP scientists and the entire scientific community to the HBP’s ICT Platforms and to offer cloud technology-based software services, as well as virtual development (platform) services, the HBP’s NIP is developing the COLLAB.

This web-based collaborative cloud system, on the one hand, provides access to the HBP’s research, community, and administrative activities, as well as its six ICT Platforms. On the other hand, it offers SaaS (Software as a Service) for the NIP tools. In particular, the COLLAB is the door to NIP’s KnowledgeGraph, a metadata catalog of all data flowing in and out of the HBP, allowing for comprehensive provenance tracking and supporting a deeply integrated search functionality.

The COLLAB is a social networking system to enable collaborative science around the fluid sharing of data, theories, applications, and models prior to publication, while still maintaining proper attribution. This social networking framework will be expanded throughout the operation of the HBP and has already enabled the inclusion of researchers outside the HBP into collaborations around HBP activities. This sharing of research, results, and expertise should help to accelerate neuroscience and the achievement of the HBP’s ambitious goals.

What is more, the COLLAB is enhanced by Platform as a Service (PaaS) capabilities. It is the declared goal of the HBP to have all development activities on existing and future software enabled and executed via the COLLAB. The HPAC will provide the necessary collaborative archive and Virtual Machine (VM) compute environment. Even hard-core Linux desktop developers will profit from

the COLLAB's development platform services, in particular the REST API-enabled collaborative environment and provenance tracking. The general consensus among HBP Platform teams is that provision of SaaS and PaaS is a mandatory prerequisite for the HBP to achieve comprehensive provenance tracking and to guarantee an open collaborative environment.

The Neuroinformatics Platform

The NIP has the role of the Chef d'orchestre of the IT architecture. Its teams guarantee accessibility to the platforms via the COLLAB, manage seamless access to wide varieties of curated data, guarantee coherency of ontologies (as well as present and future data types), and continuously develop advanced metadata storage and search systems like the KnowledgeGraph to provide tools to populate the rodent and human brain atlases with data and metadata of all modalities, whether it be anatomical or activity-based in nature, and to link them with maps, databases, and atlases outside the HBP (Amunts et al., 2014).

In the current phase of the HBP, the NIP will become ever more deeply integrated with the COLLAB in order to ensure an effective ecosystem for data sharing and software, enabling application of that data to scientific problems. In particular, the COLLAB provides platform services for the development of the NIP tools and beyond. To enable these services and tools, the NIP will make use of the HPAC Platform (see the next sub-section) in a variety of ways: as primary archival platform, but in particular as provider of high-end supercomputing capabilities for simulation and scientific big-data analytics, including European cloud providers like EGI.

The character of the NIP as research infrastructure is most prominently visible in its high-level support team, named the "Data Support and Curation Lab." This team has the task of considerably reinforcing the role of the NIP as research infrastructure by actively approaching the users, performing hands-on training, and ensuring that all legacy data are discoverable in services that are developed and provided by appropriate research tasks. It is vital for the HBP that the users, both inside and outside the

HBP, are supported in providing meta-data necessary for making their data discoverable and reusable by their peers for a variety of use cases (e.g., Papp et al., 2016).

Work of the Data Support and Curation Lab will be driven by ensuring that data flows in the project are set up and realized in accordance with time frames and needs identified in the Project Lifecycle App (PLA). In this database, the HBP researchers capture scientific use cases and information on components/products needed for their realization and release schedules at the time of implementation. While some use cases can be addressed within a sub-project, others require large, orchestrated cross-domain collaborations, undertaken in CDPs. To a large extent, it is through the PLA-enabled cross-linking of all activities that such a large endeavor as the HBP can be handled and scientifically governed by the responsible project leaders, up to the Scientific and Infrastructure Board.

The High-Performance Analytics and Computing Platform

Taming the very complexity of the brain from a data and compute perspective requires the availability of high-end HPC capabilities. In this respect, the mission of the HPAC is to help the neuroscience community to become a competitive player on high-end supercomputers and systems for big-data analytics.

With a 10-year perspective, the HPAC aims to provide the HBP Consortium and the broader European neuroscience community with supercomputers at the exascale, big-data HPC systems for multi-petabyte data analytics, and distributed cloud capabilities for enabling cloud-based high-end HPC applications. This requires research on system software, middleware, interactive computational steering, and visualization. The software and tools developed here are mandatory to create and simulate multi-scale brain models on all levels of brain organization, and in particular to address the hard-scaling challenges of whole-brain modeling. On top of this, the HPAC coordinates the interaction of the HBP with high-level support groups like the Neuroscience Simulation and Data Lab at Jülich and those at other supercomputing centers.

As mentioned above, the HPAC also needs to be deeply integrated with the NIP and the COLLAB, in order to provide the computational resources, storage, and networking necessary for both the primary archive platform for the HBP and the management, analysis, transport, and storage capabilities, along with the federation of very large datasets required for key data and modeling use cases. The latter activity has been very intensively addressed by HPAC through the initiation of a federation of the infrastructure of its supercomputing centers. FENIX (short for Federated ENgine for Information eXchange) is a so-called Infrastructure as a Service (IaaS) concept. Through the COLLAB, it provides REST APIs for higher-level services of the NIP, as well as domain-specific software involving big data and HPC workflows.

Currently, four European Tier 0 supercomputer centers are members of the HBP and contribute with their efforts: the Barcelona Supercomputing Centre (BSC), the Consorzio Interuniversitario per le Applicazioni di Supercalcolo per Università e Ricerca (CINECA), the Centro Svizzero di Calcolo Scientifico (CSCS), and the Jülich Supercomputing Centre (JSC). It is planned that a French Tier 0 center soon will join the group. All four centers belong to the Partnership for Advanced Computing in Europe (PRACE), providing Tier 0 supercomputing capability to European researchers for peer-reviewed proposals. It is planned that future provision of HBP-owned supercomputing resources can utilize PRACE's well-reputed peer-review processes.

Just recently, two new pilot systems for an interactive supercomputer have begun operation at the Research Centre in Jülich. The systems—JULIA, developed by Cray, and JURON from IBM and NVIDIA—are specifically designed for data-intensive analytics and simulation applications in the neurosciences. Their installation and test phase is part of a special procurement process for the HBP, called "Pre-Commercial Procurement."

The Other Platforms

The Medical Informatics Platform. The goal of the MIP is to gain fundamental insights into brain function through the convergence between ICT and biology/medicine, leading to new diagnostics

categories, supported by strong hypotheses of disease causation. In the end, this will support the development of new treatments for brain diseases. The MIP will include federation nodes in different hospitals for in situ querying of anonymized clinical data and data integration (Venetis and Vassalos, 2015). A clinical advisory board will be set up to ensure that the MIP services are designed to support clinicians as well as medical research.

The Brain Simulation Platform. This platform aims at delivering an Internet-accessible collaborative platform for data-driven predictive reconstruction and simulation of brain models. The platform makes it possible to reconstruct and simulate models at different levels of description, e.g., abstract computational models, point neuron models, detailed cellular and subcellular level models of neuronal circuitry, molecular dynamics-based tools and models, and multi-scale models that switch dynamically between different levels of description. Tools, services, apps, and workflows provide access to the different models and allow the community to create their own models. Rodent and human brain including imaging data will be used to build these models. Simulators include STEPS, Neuron, and NEST (e.g., Kunkel et al., 2014; Markram et al., 2015; Reimann et al., 2015).

The Neuromorphic Computing Platform. This platform allows non-expert neuroscientists and engineers to perform experiments with configurable neuromorphic computing systems (NCSs), implementing simplified versions of brain models developed on the Brain Simulation Platform and on generic circuit models. The neuromorphic systems provide a powerful basis to analyze aspects such as learning and plasticity (Friedmann et al., 2016). The platform is based on two complementary systems, SpiNNaker and BrainScales, for modeling neural microcircuits and applying brain-like principles in machine learning and cognitive computing. While the latter uses analog circuits to implement physical models of neuronal processes, which have been applied, for example, to test for a model interference task (Probst et al., 2015), the former represents a massively parallel digital computer (Furber, 2016).

The Neurorobotics Platform. The Neurorobotics Platform (NRP) is an Internet-accessible simulation system that allows the simulation of robots controlled by spiking neural networks. It targets researchers of multiple fields. Prospected users include, but are not limited to, neuroscientists wanting to validate brain models in the context of closed action-perception loops as well as robotics researchers wanting to develop new neuro-inspired controllers. Neuromorphic chips can be used in combination with learning algorithms, for example to realize cognitive capabilities with spiking networks (Walter et al., 2015).

The NRP consists of a number of design programs for models (of complex environments, robot bodies, and brains) and a number of simulation engines that are integrated into the web-based front end. Using this front end, users at different locations can rapidly construct a robot model, its brain-based controller, an environment, and an execution plan. We call this a “neurorobotics experiment.” The NRP also allows re-use and sharing of previously defined experiments, which opens a new area of collaborative neurorobotics research. Moreover, these experiments can be shared among a set of users, and they can be copied partially or completely from one user to another. The platform is based on the combined computational power of several HPC centers across Europe, and it has access to the latest hardware, such as massive clusters of GPUs.

Education and Training

The HBP recognizes that co-design development of research infrastructure by neuroscientists and technology experts in a large, interdisciplinary project requires help in the form of a special education program designed to equip young researchers and developers with the multi-disciplinary outlook necessary to thrive in today’s increasingly ICT-dominated research environment, to train young scientists to exploit the convergence between ICT and neuroscience, and to create new capabilities for European academia and industry.

The program offers different teaching formats, such as student conferences, workshops, and schools, coupled with a curriculum of formal courses. The curricu-

lum consists of five online courses covering three core subjects: brain medicine, ICT, and neuroscience, taught by leading investigators and practitioners from within the HBP; the complementary subjects of research ethics and the societal impact of research; and intellectual property rights and the translation/exploitation of research. Each is designed to give a working insight into the subject discipline for students whose main specialization is in another field. In this way, a young neuroscientist might come to better understand how suitably adapted software might help to achieve his or her research goals. Equally, a young software engineer might gain an insight into the anatomy and functioning of the brain, which would better equip her or him to efficiently advance their research. In addition, the program also offers specific support to young female scientists. Courses will be taught primarily online but will conclude with an “in person” workshop and exam. The courses are not restricted to young researchers working in the HBP, but places are limited, and applications are subject to review.

Facilitating International Collaboration

While the HBP undertakes a considerable amount of research, its *raison d’être* is to build an enduring ITC-based scientific research infrastructure that serves the needs of the brain research community worldwide.

In building an infrastructure to suit the needs of a large community of worldwide researchers, HBP strives to attract international researchers at an early stage; interaction with and feedback from that community is essential for the long-term success of the project.

Moreover, many of the other large international initiatives, notably US BRAIN, have objectives and approaches complementary to those of the HBP. Only by leveraging these complementarities will the global scientific community be able to address the brain challenge.

Overall, four different types or levels of interaction with the HBP are envisaged. First, there is direct collaboration via joint projects involving HBP investigators and their counterparts around the world. In addition, the HBP invites researchers and their supporting software developers

to exploit and add to the six research platforms through the COLLAB, which supports several access categories, including site visitors. The platforms are open to any researcher or developer worldwide who has the necessary credentials and a plausible motivation. Since their opening to the wider scientific community in March 2016, the HBP Platforms have attracted over 700 users from outside the project.

Second, collaboration can be done in a more formalized way through Partnering Projects. This type of collaboration has been enshrined in the HBP's funding agreement with the European Union and bestows specified benefits, such as access to platforms and data, participation in internal events such as the HBP Summit, and representation in the HBP's governance structure. A Partnering Project can be any project with funding from outside HBP that has a specific goal, complementary to the HBP, that exploits and/or further refines the HBP research infrastructure. Six Partnering Projects, funded by EU member states under the auspices of the EU FLAG-ERA initiative, started work earlier this year. It is intended that the Partnering Projects closely collaborate with the Core Project's different sub-projects and CDPs. Importantly, the Partnering Project status is not restricted to partners coming from EU member states or associated countries.

Third, there is collaboration involving joint, coordinated activities with large-scale private, national, or international research initiatives, such as the Allen Brain Institute, the US BRAIN initiative, the Brain Canada Foundation, Japan's Brain/MIND project, the Australian brain initiative, and the newly started China Brain Project (e.g., Vogelstein et al., 2016, and others in this issue of *Neuron*). Such cooperation need not be restricted to bodies focused specifically on brain research; for example, the HBP is exploring possible areas of joint interest with the EU's Innovative Medicines Initiative (IMI) and PRACE.

Fourthly, an additional node for collaboration is the education program (see above), which is open to researchers outside the HBP. The HBP is planning to implement a student and postdoctoral exchange program with its international partners.

Conclusions

The HBP proposes a unique IT-based strategy to integrate neuroscience data from around the world to develop a multi-level understanding of the human brain and its diseases. Therefore, the prototype platforms available today will be turned into a more robust, user-friendly, and closely integrated research infrastructure. The creation of an HBP legal entity will provide the organizational basis for an enduring infrastructure, beyond that of a time-limited project.

There is a growing number of well-publicized brain research initiatives around the world which are mobilizing unprecedented levels of funding for neuroscience. In that context, there is a strong interest to maximize cooperation and coordination between the various initiatives, and the HBP is keen to help lay the foundations for such interaction. If each initiative can focus on contributing in its own unique way, the most efficient use of limited resources can be made.

ABOUT THE AUTHORS

Katrin Amunts is the scientific leader of the HBP; she was elected as the Chair of the Science and Infrastructure Board in June 2016. In order to better understand the organizational principles of the human brain, she and her team aim to develop a multi-level and multi-scale brain atlas, and they use methods of high-performance computing to generate ultra-high-resolution human brain models. Chris Ebell is Executive Director of the HBP. Before he joined the HBP, he was Science and Technology Counselor at the Embassy of Switzerland in the United States and served at other institutions as well. Jeff Muller is Technical Coordinator at the HBP. He has a strong background in software development, image processing, and project management. Martin Telefont is Science Coordinator at the HBP. He has extensive knowledge of neuroinformatics and experimental neuroscience. Alois Knoll is Director for Software Development in the HBP and an expert in robotics. Thomas Lippert is a theoretical physicist who is directing the HPAC platform of the HBP; he has led a working group for developing the new IT architecture of the project.

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