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Abstract:

This deliverable is the annual compound of HBP deliveries and results (outputs and outcomes) from Sub-Project SP10 – Neurorobotics Platform (NRP). The live complete catalogue of HBP deliveries is accessible on-line from the HBP portal.

The main deliveries from April-2017 to March-2018 for SP10 were:

- *In silico* experiments with realistic neuromusculoskeletal rodent model as co-design drivers
- The basic individual components (visual system in particular) of what will become in SGA2 the Integrated Behavioural Architecture
- The extension of the core library of off-the-shelf components for the NRP
- The continued development of compliant robotics and demonstration of what the NRP can offer in terms of knowledge transfer to such physical robots
- Release 2.0 of the NRP

Engagement and dissemination activities towards the neuroscience and robotics communities

Keywords: Neurorobotics, Virtual Robotics, *in silico* experiments

Caption of the front page illustration:

Release 2.0 of the NRP comprises multiple improvements and novelties, such as a new environment editor, a robot designer capable of handling muscle positioning and attachment a robot inspector (illustrated here). It also has been optimised in terms of general performance, especially with respect to loading times for better usability. See section 2.5 for details.

Targeted users/readers	Researchers, Policy Makers
Contributing Work-Package(s):	SGA1 WPs 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7
Initially Planned Delivery Date:	SGA1 M24 / 31 Mar 2018

Authors:	Marc-Oliver Gewaltig, EPFL (P1), Alois KNOLL, TUM (P56),
Compiling Editors:	Mahmoud Akl, TUM (P56), Daniel Reichard, FZI (P52), Fabrice Morin, TUM (P56)
Contributors:	All Task leaders and their representatives
SciTechCoord Review:	Science and Tech Coordination (SP11)
Editorial Review:	EPFL (P1): Martin O'NEILL, Annemieke MICHELS

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1. Introduction

Neurorobotics research fuses key enabling technologies emerging from brain science and robotics to lay the foundation for completely new product categories in artificial intelligence, neurotechnology, and robotics.

HBP Sub-Project 10 (SP10) strives to be a trendsetter for global neurorobotics development and the establishment of a global neurorobotics community. To this end, SP10 is building and operating the Neurorobotics Platform (NRP) where researchers from within and outside the HBP can define, run, and share neurorobotics experiments.

The primary strategy of SP10 is to provide tools and workflow for neurorobotics that capitalise on state of the art approaches and technologies for defining, simulating, and visualising models of brains, robots, and detailed environments. The underlying technologies are developed not only within, but also by groups outside HBP as open-sourced projects. Via the NRP, SP10 can offer researchers (ranging from neuroscientists to roboticists) a unique tool that serves as *common ground* on which they can evaluate, combine, and compare models ranging from simple sensory-motor models to large-scale behavioural architectures, controlling complex robot bodies with many degrees of freedom. Co-design drivers, aimed at constructing specific scaffold neurorobotics models, guide the work performed in SP10. Scaffold models are framework (neurorobotics) models that allow for continuous integration of new data and models by the community in a standardised manner.

In the period M13-M24, the key results described in sections 1.1 to 1.6 were achieved.

1.1 *In silico* experiments with a realistic neuromusculoskeletal rodent model as co-design driver

To understand how the brain interacts with its environment, we have developed a data-driven skeletal model of a rodent, along with its neuromuscular systems as a co-design driver. SP10 has also developed two pilot experiments to demonstrate how such a virtual body model can be used to study questions ranging from sensory-motor learning to recovery of motor function after stroke or spinal cord injury. The first co-design driver is the in silico reconstruction of a stroke recovery experiment, using the data-driven scaffold model of the whole-mouse brain from SP6. It is part of CDP1 and demonstrates how a large-scale data-driven brain model can be used in a realistic closed-loop experiment. The second co-design driver is a realistic model of rodent locomotion which is important for the study of spinal cord injury and recovery. SP10 has reached the first milestone which is to provide a simulation for hindlimb locomotion. Both co-design drivers use the same components which will also be available to the scientific community as part of the NRP's core component library.

1.2 Towards an integrated behavioural architecture for community adoption

SP10 has developed a library of functional modules for neurorobotics experiments. Among these modules are a model of early visual processing, based on Grossberg's LAMINART architecture and a sensory-motor map network, able to respond to stimuli in a manner similar to the somatosensory cortex of the human brain. These functional models are used in several pilot experiments, implemented on the NRP. They form the basis of the component library that will be extended in SGA2 into an integrated behavioural architecture, which will then enable users of the NRP to construct functional top-down brain models from customizable components.

1.3 Core library of robots, sensors and environments

In order to bootstrap community use and contribution to neurorobotics research, SP10 must provide a sufficiently well-equipped library of in silico robots, sensors and environments. This library should cover complex biological body models for neuroscience and neurotechnology research as well as simple mobile robot platforms for cognitive neuroscience or robotics research.

SP10 has collected a range of robot body, sensor and environment models and integrated them into the NRP for community use. Some of these models are adapted from open source projects, such as Gazebo, others have been specifically developed by SP10.

1.4 Physical neurorobotics systems as internal co-design driver

Physical neurorobotics systems are important to translate knowledge from in silico neuroscience and neurorobotics to the real world. SP10 has selected a small number of physical robot platforms to test neural control algorithms on real robots, and to co-design neural controllers for real robots, using neuromorphic hardware. These hardware platforms are: a physical rodent robot; a two degree-of-freedom tendon driven arm model (MyoMuscle); Tigrillo, a cheap compliant robot; and iCub, an open humanoid robot platform. With the exception of the rodent robot, all robot platforms were available at the respective SP10 partner institutions. To test the translation of neurocontrollers into the real world, SP10 has selected the SpiNNaker neuromorphic platform from SP9.

1.5 Neurorobotics Platform Version 2

The NRP has been continuously developed, updated and deployed over the last 12 months. The NRP is a powerful integration of models, simulation tools, visualisation environments and hardware-/software-in-the-loop facilities that allows neuroscientists and roboticists to connect brain models of different complexity to biological or technical robot bodies, real or virtual, that operate in complex virtual dynamic spaces. The NRP integrates four key components: a robot and world simulator [Gazebo from the Open Source Robotics Foundation), a neural network simulator (NEST from the NEST initiative)], a closed-loop engine (CLE from SP10) – or “director” – for the operation of the different simulators, and a web cockpit (from SP10) to interactively design, run and analyse both neurorobotics experiments and realistic physical robot scenarios. In the past 12 months, existing functionalities have been improved (e.g. loading time of the experiments was considerably shortened). Furthermore, new functionalities have been added, such as the virtual coach or robot inspector, which make the NRP more user-friendly and versatile from an experimental perspective.

1.6 Neurorobotics Platform for teaching and dissemination

The NRP offers a number of possibilities for teaching and dissemination. Using the NRP in university courses allows students to gather experience with complex (neuro-) robotics systems that would traditionally not be accessible to them. SP10 has developed advanced exercises for courses at KIT and EPFL. The first massive open online course (MOOC) on neurorobotics, using the NRP, is in preparation.

SP10 has also organised or been involved in numerous user workshops, hackathons, and education events to train existing and new users on the NRP.

2. Results

2.1 *In silico* experiments with realistic neuromusculoskeletal rodent model as co-design drivers

To understand how the brain interacts with its environment, we have developed a data-driven skeletal model of a rodent, along with its neuromuscular systems as a co-design driver. SP10 has also developed two pilot experiments to demonstrate how such a virtual body model can be used to study questions ranging from sensory-motor learning to recovery of motor function after stroke or spinal cord injury. The first co-design driver is the *in silico* reconstruction of a stroke recovery experiment, using the data-driven scaffold model of the whole-mouse brain from SP6. This co-design driver is part of CDP1 and demonstrates how a large-scale data-driven brain model can be used in a realistic closed-loop experiment. The second co-design driver is a realistic model of rodent locomotion which is important for the study of spinal cord injury and recovery. SP10 has reached the first milestone which is to provide a simulation for hindlimb locomotion. Both co-design drivers use the same components which will also be available to the scientific community as part of the NRP's core component library. In the following, we first describe the two co-design driver experiments, and then the shared components.

2.1.1 In silico motor rehabilitation experiment (CDP1)

A key result of SP10 is the in silico reconstruction of a motor rehabilitation experiment in the NRP as part of Co-Design Project 1 (CDP1). The reconstructed setup (Figure 1) consists of the following.

1) A high-fidelity reconstruction of the motor rehabilitation platform (M-platform), which comprises all important M-Platform components (i.e. linear actuator, linear slide, handle) and allows the user to define the parameters of different motor experiments. Moreover, it allows the movement and friction of the actuator to be accurately simulated and the force applied by the mouse forelimb to be measured.
2) A biologically accurate mouse body model, comprising a mouse skeleton, Hill-type muscles for the fore- and hindlimbs, as well as a spinal-cord model to generate movement primitives.
3) A biological model of proprioceptive sensory information, a necessary feature for the design of brain-inspired neurorobotic controllers that include complete action-perception loops, has been implemented on NEST and integrated into a spinal cord model to allow control of the forelimb in the rehabilitation experiment and finally tested on the NRP.
4) A scaffold model of the whole mouse brain (developed in SP6). The model has been connected to the mouse body. This connection represents an important technical milestone, as it couples for the first time the Brain Simulation Platform with the NRP.

The virtual framework will be useful for a large class of motor-rehabilitation experiments for HBP and non-HBP research communities.

Figure 1: The CDP-1 mouse experiment implemented in the NRP.

Full dynamic models of the mouse (neuro-muscular skeletal) and the M-platform.

2.1.2 In silico *hindlimb locomotion experiment*

First closed loop bipedal locomotion experiments of the mouse model have been done, using artificial networks within the NRP.

A reflex-based state machine like approach was used to develop locomotion experiment to set up the framework to study inter/intralimb coordination. Collaboration with the RYBAK team was continued to study the closed CPG models with sensory feedback to study feedback and feedforward CPG control during mouse locomotion.

At the end of SGA1, the goal is to showcase the mouse hindlimb walking experiment in NRP. As shown in Figure 2, the full articulated mouse skeleton is reduced in the number of degrees of freedom in order to speed up and reduce the complexity of the locomotion experiment. The mouse model in the current experiment has a total of six degrees of freedom in the hindlimb. Each of the hindlimb joints are actuated by a pair of antagonist muscles and bi-articular muscles. Currently, the model supports both muscle models from OpenSim and also the muscle models written in house at BioRob, EPFL. Figure 2 shows the schematic of muscle joints and muscles used for this experiment.

In order to produce locomotion, different levels of abstraction in spinal circuitry have been developed, ranging between spiking neuron model to state-machine reflex loops, namely:

1) a reflex based controller approach;

2) central pattern generator approach (In collaboration with the RYBAK team in the US);

3) spiking neuron motor reflex loop (work in progress).

Currently methods 1) and 2) are successful in producing locomotion. Figure 3 shows a snapshot of the joint angles re-plotted over time to show the gait trajectory. These models leverage the unique combination of the simulation capabilities of the NRP and the availability of the musculoskeletal rodent model in order to scientifically address and fill the knowledge gap in the connectivity between brain and spinal cord.

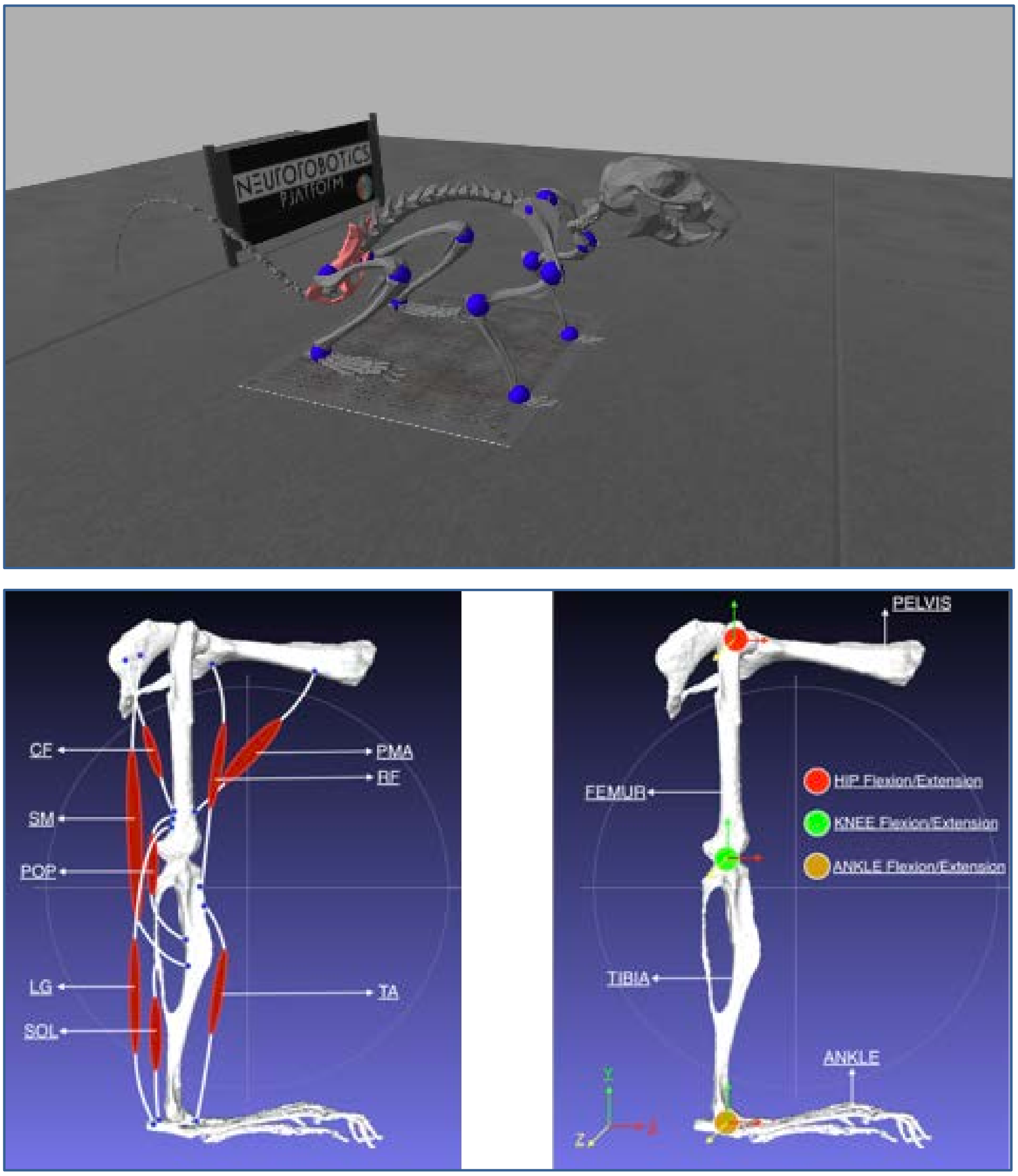

Figure 2: Locomotion Experiment in the NRP.

Top: complete mouse skeleton with joints for fore- and hindlimbs shown in blue. Bottom: Detailed view of the actuated muscles (left) and joints (right)

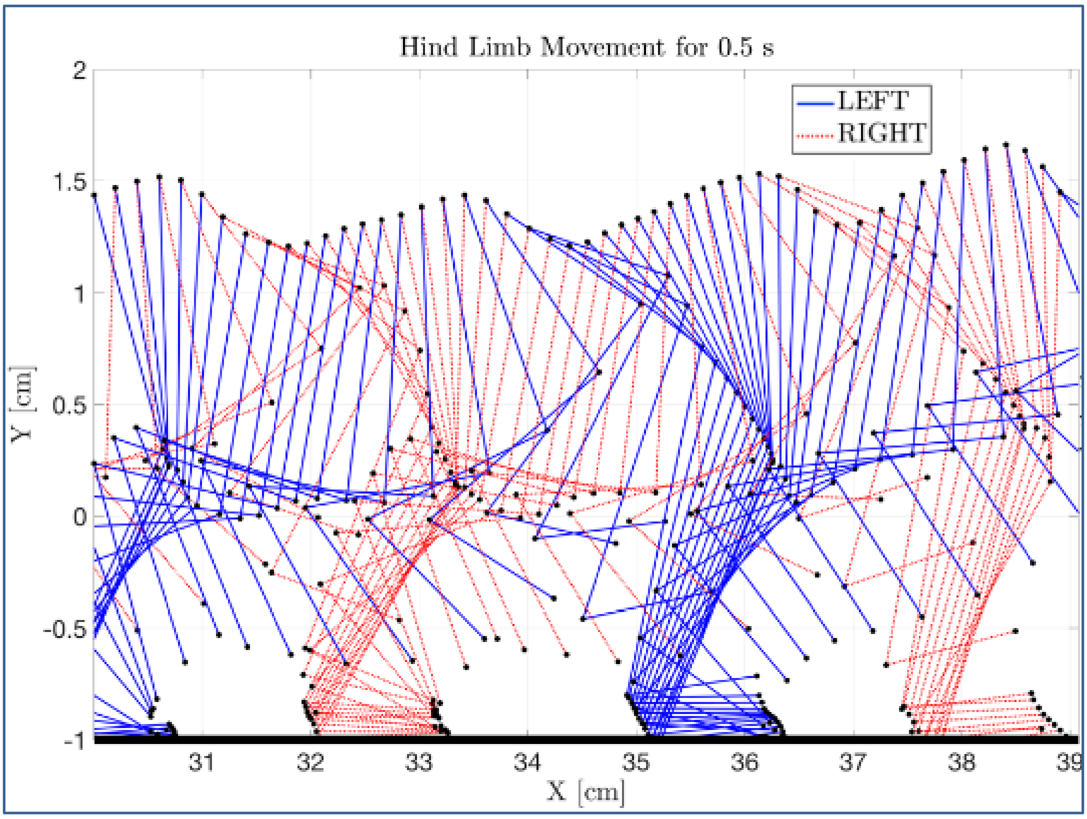

Figure 3: Illustration of the hindlimb gait pattern produced by the locomotion model.

2.1.3 Spinal-cord model for antagonistic muscle pair activation

We implemented a closed-loop simulation of the muscle spindle spinal circuitry in the NRP controlling muscles of the mouse hindlimb biomechanical model (Mouse Locomotion Experiment in the platform). The network component was fully re-designed and implemented in NEST for the mouse biomechanical model. The Hill-muscle models were adapted[1] to produce a complete biomechanical model of the mouse leg (see section 2.1.1).

The spinal cord model (Figure 4) includes primary and secondary afferent fibres from muscle spindles and a pool of alpha-motoneurons, as well as excitatory interneurons.

For a single muscle, a network with muscle spindles providing Ia and II afferent fibre activity, a pool of alpha-motoneurons and excitatory II-interneurons was considered (Figure 2). Ia afferents directly provide excitatory inputs to the alpha-motoneurons (monosynaptic stretch reflex mechanism), while the II afferents output is mediated by a set of interneurons before reaching the alpha-motoneurons, creating a disynaptic reflex. The alpha-motoneurons receive an input from a spike generator that represent the descending motor command. In order to implement the polysynaptic inhibition reflex, two populations of Ia-interneurons were added to the network. Those receive inputs from Ia afferents of the agonist muscle and provide inhibition to the alpha-motoneurons of the antagonistic muscle. In order to compute the actual muscle activation from the motoneurons activity, a special spike integration unit that sums the fibre twitches was implemented. Its output is an activation value in [0;1] that is suitable for different muscle models.

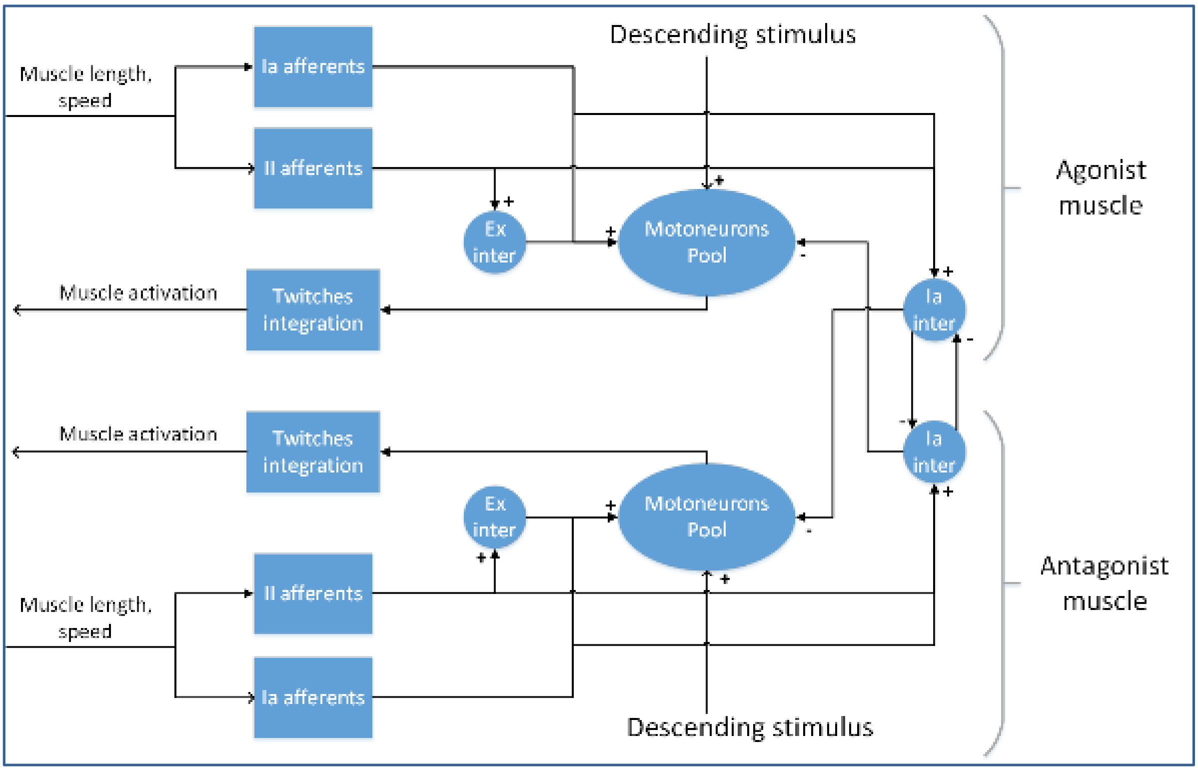

Figure 4: Spinal cord circuit for an antagonistic pair of muscles

2.1.4 Sensory-motor map for mouse model

In order to support data-driven brain models that contain sensory-motor maps, intermediate circuits like those found in the spinal cord have been developed and tested with muscle-skeletal embodiments (see Figure 4). These circuits rely on previously developed models of proprioception for the sensory feedback. Models of muscle activation have been also developed to close the sensory-motor loop.

2.1.5 Achieved Impact

1) The virtual mouse offers a common research platform for scientists ranging from neuroscience to neurotechnology and robotics.
2) The mouse model can be connected to brain models at the level of point neurons and can thus be used to study the details of central and peripheral motor control.
3) The virtual mouse comprises a set of components for the mouse neuromusculoskeletal system (mouse model) can be used individually or in combination.
4) We have demonstrated the successful integration of the mouse neuromusculoskeletal model in two pilot experiments that also serve as co-design drivers.

2.1.6 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
209	NEST - The Neural Simulation Tool (software)	*No*	The Neural Simulation Tool is the usual backend neural simulator for the NRP
830	Closed-Loop Engine	*No*	The Closed-Loop Engine is the core simulator middleware component and integrates Gazebo and OpenSim.
841	Web Cockpit	*No*	Main client for the Neurorobotics Platform, it presents the muscle simulation to the user in 3D view
884	Robot Designer	*No*	Only graphical tool to add a muscle system to a skeletal model in the Neurorobotics Platform, it plays a central role in the model design
838	Brain-Body Integrator	*No*	With the Transfer Function mechanism, users can actuate and read muscles in the Brain-Body Integrator interface to control musculoskeletal models
845	Rodent Body Model for the Neurorobotics Platform	*No*	Rodent body model
847	Musculoskeletal models of rodents for the Neurorobotics Platform	*No*	Musculoskeletal Rodent model
899	Sensory Models	*No*	Extension of current sensory models for detailed closed loop locomotion experiments
903	Sensory Motor-Maps	*No*	Will be key to link the sensory pathways to the brain centres involved in locomotion

2.2 Towards an integrated behavioural architecture for community adoption

SP10 has developed a library of functional modules for neurorobotics experiments. Among these modules are a model of early visual processing, based on Grossberg's LAMINART architecture and a sensory-motor map network, able to respond to stimuli in a manner similar to the somatosensory cortex of the human brain. These functional models are used in several pilot experiments, implemented on the NRP. They form the basis of the component library that will be extended in SGA2 into an integrated behavioural architecture, which will then enable users of the NRP to construct functional top-down brain models from customizable components.

2.2.1 A modular visual system model

Vision modelling requires large-scale, cooperative simulations to integrate all known global features of visual perception. In SGA1, SP10 therefore worked to have all components of a modular and flexible visual system available on the NRP, based on simulations of spiking neurons, with a view to making it as functionally complete as possible. Such an integration of different components into one system is non-trivial because they are usually built upon different frameworks. A major contribution of SP10 was therefore not only to develop new models, but more importantly to use the NRP as the single integrative framework for all these models.

During SGA1, multiple components were thus integrated into the NRP. These comprise a retinal model for gain control and retinal magnification (coming from work carried out in SGA1 T10.2.2), a cortical model for early-stage visual segmentation (LAMINART model, SGA1 T10.2.1), a deep neural model for visual saliency (collaboration between SGA1 T10.2.3 and CDP4), and an echo state network for saccade generation.

After integration into the NRP, SP10 proceeded to connect models to each other, thereby demonstrating both the feasibility of the approach and its relevance (see Figure 5).

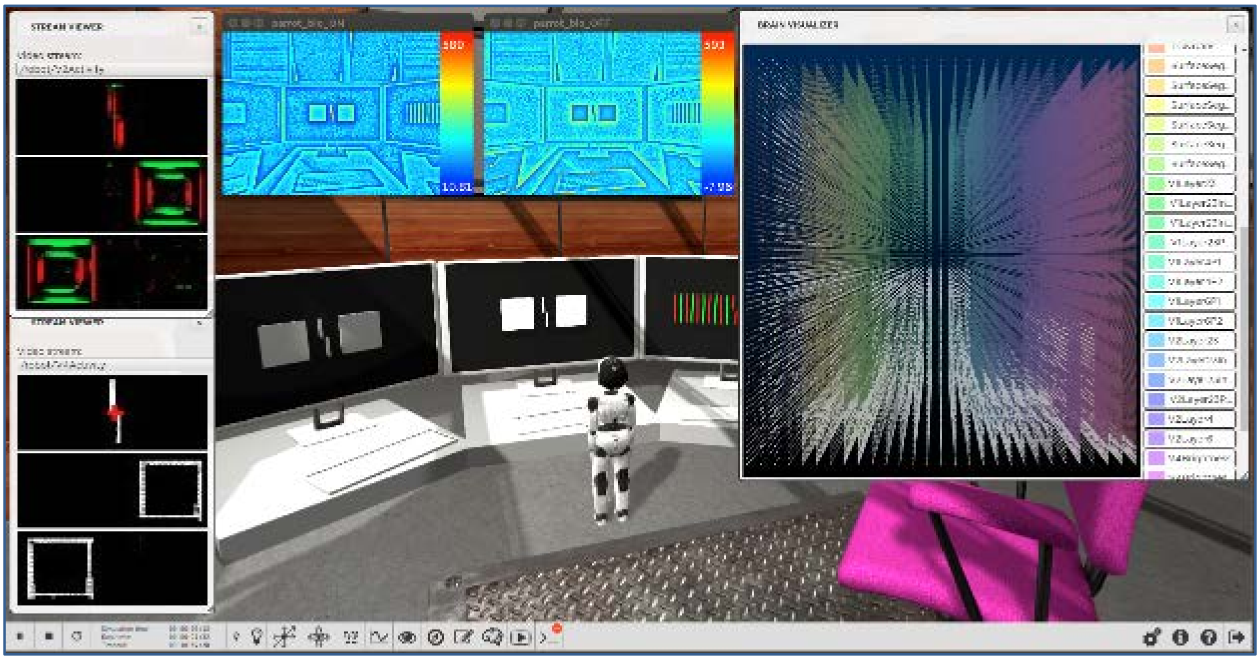

Figure 5: Example of how it is possible to connect several functions of the visual system, using the NRP

The output of the retina model (top-centre windows) is fed to the LAMINART model (left windows), for gain-controlled segmentation. The brain visualiser (right window) displays the neurons of the LAMINART model, layer by layer (approx. 500,000 neurons). This demonstrates that large-scale, cooperative simulations can be performed on the NRP.

In particular, SP10 supported two very different NRP experiments, to demonstrate that the visual system can be exploited by a broad range of users. The first experiment was done by a neuroscientist and investigated how pure bottom-up influence, simulated by the saliency model, can drive visual segmentation, simulated by the LAMINART model. The second was proposed by a roboticist and aims to create a robotic system that uses visual attention and saccade generation in a short-term visual memory task.

The results from the neuroscientific experiment described above triggered new research in the Laboratory of Psychophysics at EPFL (LPSY, Michael H. HERZOG, Gregory FRANCIS). It indeed turns out that the complex of the saliency and the LAMINART model groups elements of the visual field in the same way as observed in psychophysical experiments (see Figure 6). As a consequence, LPSY started several behavioural experiments whose goal is to disentangle bottom-up from top-down influence on visual grouping. Both NRP and behavioural experimenters will continue to tightly collaborate to gain precious insights about visual processing.

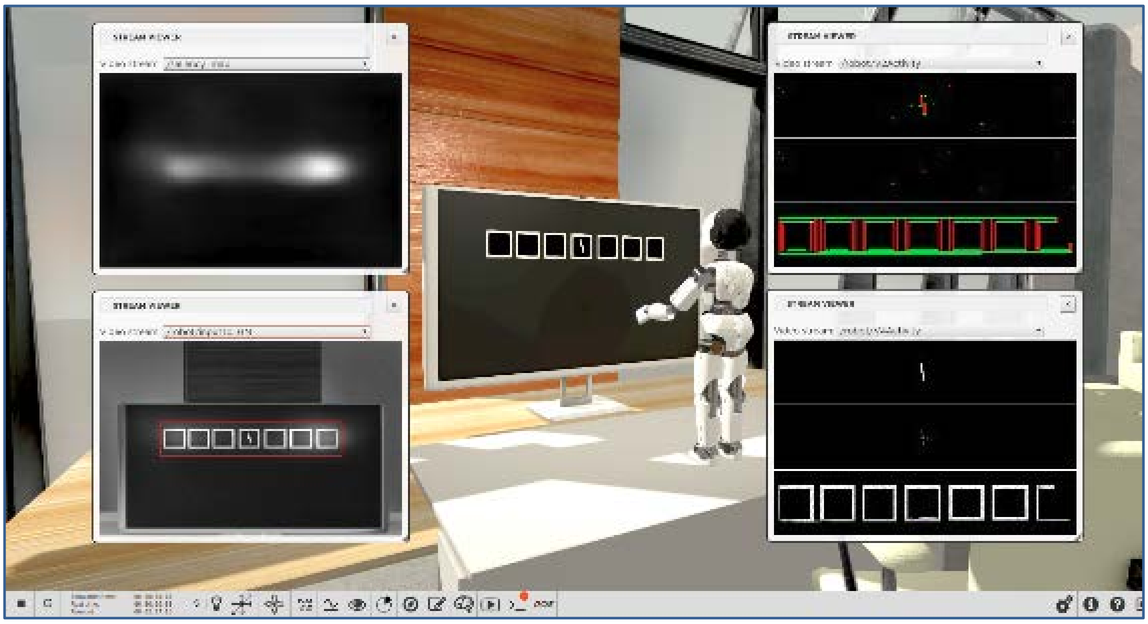

Figure 6: Coexistence of the saliency model and the segmentation model.

The saliency model is used to trigger spreading signals in the segmentation model. The windows on the left display the saliency model (top) and where segmentation signals are triggered in the segmentation model (bottom). The windows on the right display the output of the LAMINART model (top: V2 oriented contrasts signals, bottom: V4 surface signals).

Moreover, this endeavour of building up a complete visual system in the NRP has triggered many collaborations between SP10, CDP4 and other SPs, which have been formalised in the SGA2 DoA. The GOEBEL laboratory (CDP4, SP2) will cooperate with SP10, continuing the integration of the saliency model with the LAMINART model. The GERSTNER laboratory (SP4) will also work together with SP10 to integrate a model of predictive coding to the visual system on the NRP. Further, the ROELFSEMA laboratory (SP2) will join forces with SP10 to augment the visual system with attentional tracking data from monkey experiments. In addition, the ROELFSEMA laboratory is considering recording the neuronal activity in the early visual cortex of monkeys, related to the onset of visual crowding stimuli that are used in behavioural experiments of LPSY.

Finally, it is important to recognise that this result will be essential for the NRP to keep demonstrating its usefulness in SGA2 beyond the HBP community. First, it will enable, in conjunction with the development of an Integrated Behavioural Architecture, the implementation of more complex behavioural experiments. Second, because vision is such a fundamental sensing modality, having the visual system on the NRP available for off-the-shelf implementation into robotic or AI experiments will considerably facilitate NRP adoption and user engagement in these communities. This is a specific SP10 objective in SGA2 which would be hard to attain without the above-described result.

2.2.2 Functional sensory motor map

We developed a functional model of a Sensory-Motor Map, a network able to respond to a stimulus by activating some specific units in a manner similar to the somatosensory cortex of the human brain. This model was used for two tasks: visual tracking using eye and head coordination; and reaching using an arm. In the first case, the stimulus, is the proprioceptive feedback combined with the current displacement in space of the gaze fixation point with respect to the desired target. In the reaching task, the stimulus includes the end effector displacement compared to the target position. We integrated these controllers with the gaze stabilisation model previously developed. This will allow complex behaviours, such as active visually guided manipulation, to be generated.

2.2.3 Cerebellar stabilisation of gaze

A functional cerebellar model has been employed as an inverse internal model in a comprehensive gaze stabilisation architecture. The cerebellum model comprised of a machine learning algorithm, locally weighted projection regression (LWPR), that models the cerebellar granular layer (mossy fibres and granule cells) and of a linear readout modelling the integration of information performed by the Purkinje cells. The gaze stabilisation system included the vestibulo-ocular reflex, the optokinetic reflex and the vestibulocollic reflex, each with its own internal model able to cancel out the dynamics of plant through sensory-motor anticipation. The control architecture is capable of offline and online learning and was tested on the physical iCub head mounted on a platform capable of generating disturbances at various frequencies and on the SABIAN humanoid robot, for gaze stabilisation during locomotion. The stabilisation controller was also implemented inside the NRP.

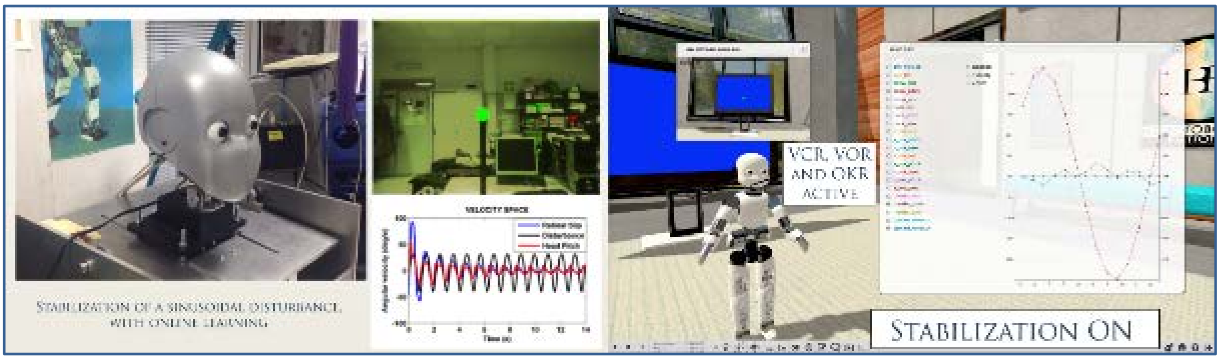

Figure 7: Gaze stabilisation

Gaze stabilisation with cerebellar internal models on the real iCub head (left) and in the NRP (right).

2.2.4 Achieved Impact

We used the NRP to evaluate the vestibulo ocular cerebellar adaptation (vestibulo-ocular reflex, VOR) mediated by two STDP mechanisms located at the cerebellar molecular layer and the vestibular nuclei respectively. In the simulation study we reproduced an experimental setup (rotatory VOR) widely used by neuroscientists to better understand the contribution of certain specific cerebellar properties (i.e. distributed STDP, neural properties, coding cerebellar topology, etc.) to r-VOR adaptation. The work carried out focused on an embodiment solution for which we endowed a simulated humanoid robot (iCub) with a spiking cerebellar model by means of the NRP, and we had the humanoid perform an r-VOR task. The results validate the adaptive capabilities of the spiking cerebellar model (with STDP) in a perception-action closed-loop (r-VOR) causing the simulated iCub robot to mimic a biologically plausible gaze stabilisation.

2.2.5 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
658	LAMINART with segmentation and retina into the NRP	No	The retina model has been connected to the LAMINART model. This was followed by the whole “strategic WP2 experiment” of model integration.
908	Reactive perception-action loops	No	The cerebellar gaze stabilisation architecture is a functional behavioural model of a perception-action loop.
830	Closed-Loop Engine	*No*	The Closed-Loop Engine is the core simulator middleware component and integrates Gazebo and OpenSim.
841	Web Cockpit	*No*	Main client for the Neurorobotics Platform, it presents the muscle simulation to the user in 3D view.

209	NEST - The Neural Simulation Tool (software)	*No*	The Neural Simulation Tool is the usual backend neural simulator for the NRP.

2.3 Core library of robots, sensors and environments

In order to bootstrap community use and contribution to neurorobotics research, SP10 must provide a sufficiently well-equipped library of *in silico* robots, sensors and environments. This library should cover complex biological body models for neuroscience and neurotechnology research as well as simple mobile robot platforms for cognitive neuroscience or robotics research. SP10 has collected a range of robot body, sensor and environment models and integrated them into the NRP for community use. Some of these models are adapted from open source projects, such as Gazebo, others have been specifically developed by SP10.

We established a core library of robots, sensors and environments, as well as an easy way to incorporate new custom models in these libraries.

These allow users to add their own models and combine them into an experiment with the help of a "wizard" user interface. Users can easily add new robots and environments locally or by making pull requests to the Neurorobotics open-source codebase on Bitbucket https://bitbucket.org/hbpneurorobotics/models/ [viewed 2018-03-27].

The way in which users can add new sensors is documented for the example of a strategically relevant neuromorphic sensor (Dynamic Vision Sensor) on the Neurorobotics Blog: http://neurorobotics.net/researchBlog.html [viewed 2018-03-27]. Unlike models that consist only of data, custom sensors encapsulate logic and are therefore integrated as Gazebo plugins in https://bitbucket.org/hbpneurorobotics/GazeboRosPackages/ [viewed 2018-03-27]. This enables the NRP to run any custom Gazebo plugins. So far, the official new sensors developed and supported by SP10 are the Dynamic Vision Sensor plugin and the COREM retina framework, also implemented as a Gazebo plugin.

2.3.1 Musculoskeletal models of rodents

We developed a new biomechanical model of the mouse for the NRP. The skin of the body model was created and then connected to the initially developed model. While the skeleton is important to model realistic movement patterns (see CDP1 and locomotion experiment above), a detailed (high-resolution) deformable skin model is needed to determine ground- and object reaction forces that occur during locomotion and manipulation. These forces can then be conveyed to touch sensors in the skin that in turn play an important role in low-level motion reflexes, such as the stretch reflex.

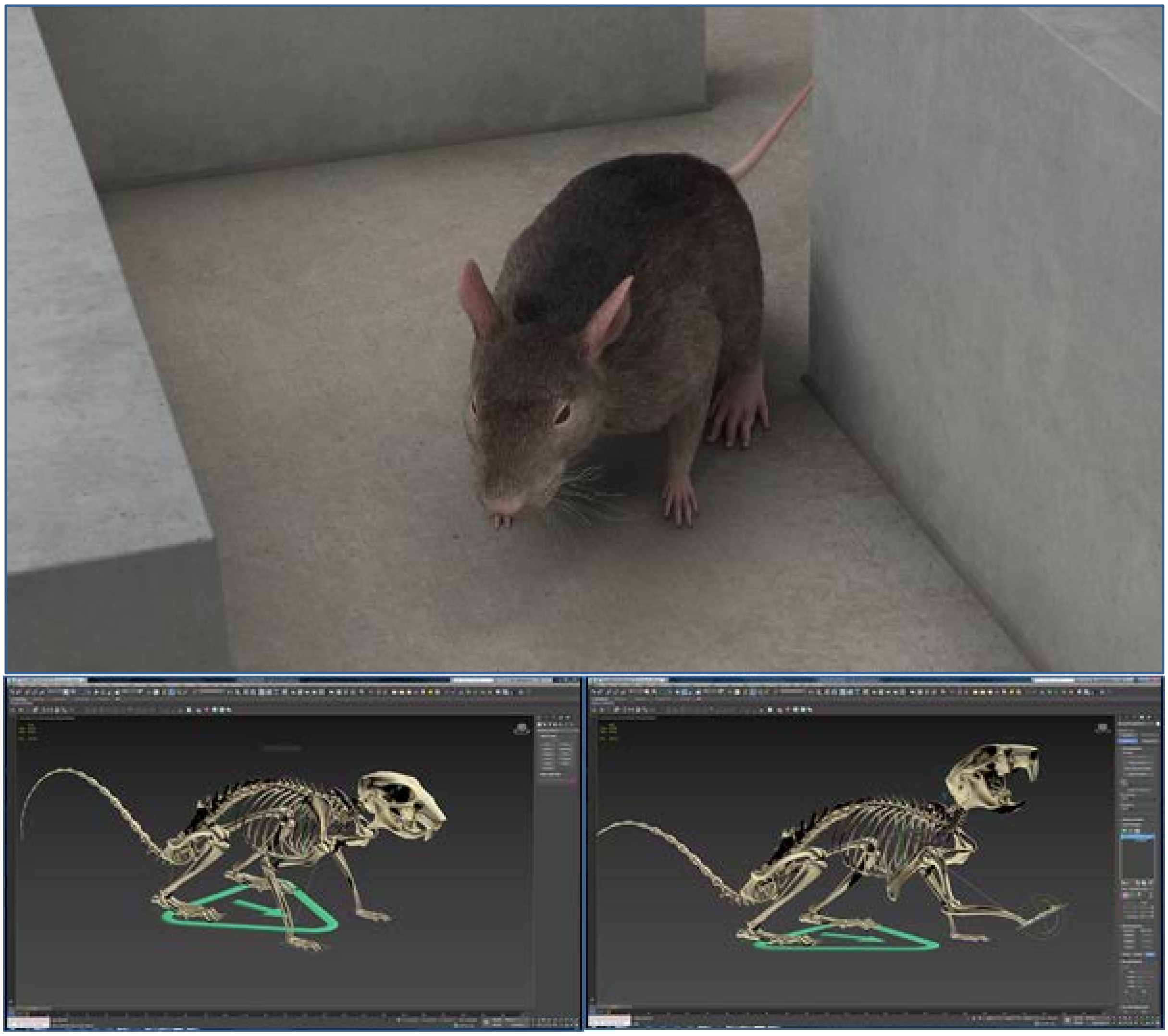

Figure 8: SP10 virtual mouse

Top: Detailed rendering of the SP10 virtual mouse. The skin of the mouse is rigged to the internal skeleton (bottom). While the skeleton is important to model realistic movement patterns, a detailed (high-resolution) deformable skin model is needed to determine ground- and object reaction forces that occur during locomotion and manipulation. These forces can then be conveyed to touch sensors in the skin that in turn play an important role in low-level motion reflexes, such as the stretch reflex.

2.3.2 Environment library:

In the 12 months prior to publication, we have greatly improved the capabilities of the user to create and use complex virtual environments that offer sufficient structure for experiments with visual orientation and visual learning. We have created a so-called Holodeck environment that offers a common space for a wide range of robotics experiments. The Holodeck is the virtual equivalent of a robot lab where different robots operate in a common room. The Holodeck consists of many well-calibrated objects that can be moved and rearranged. All parts are also available in the new environment designer, so that users can build personalised environments based on the Holodeck and store them in the environment library.

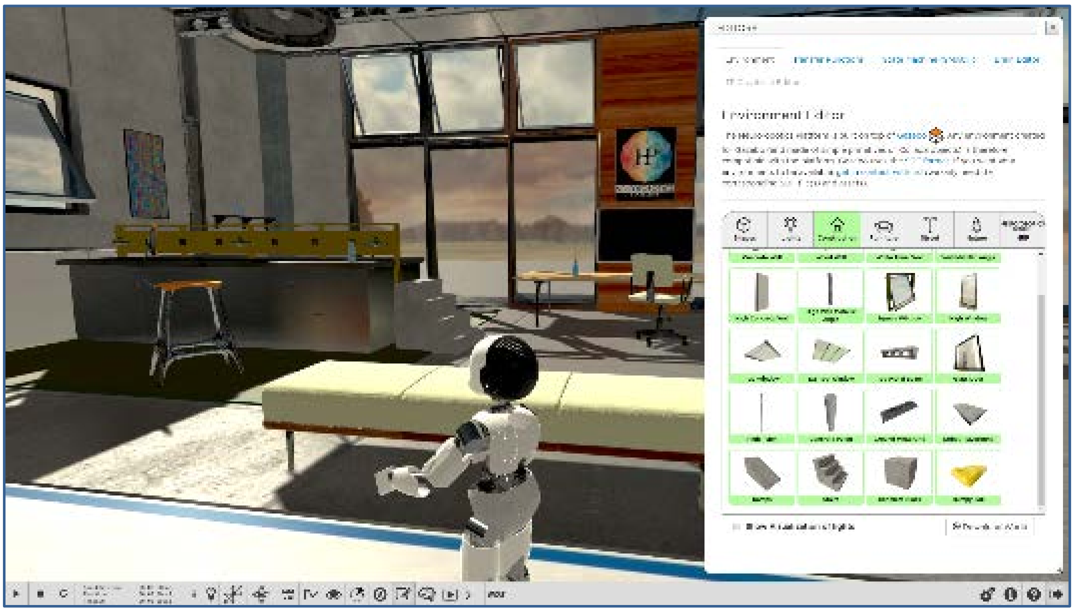

Figure 9: iCub in the holodeck environment

All parts are also available in the environment designer allowing users to customise the Holodeck or to create entirely new environments.

2.3.3 Robot/Avatar Library

Many robots have been added to the NRP, some by our developers and others by users. Currently supported robots are listed in Table 1.

Table 1: Currently supported robots

Robots	Support Level	Location (all [viewed 2018-03-28])
HBP Mouse	Fully supported	https://bitbucket.org/hbpneurorobotics/models/src/master/mouse_v2_model
Husky	Fully supported	https://bitbucket.org/hbpneurorobotics/models/src/master/husky_model
Schunk Arm	Fully supported	https://bitbucket.org/hbpneurorobotics/models/src/master/arm_robot
iCub	Fully supported	https://bitbucket.org/hbpneurorobotics/models/src/master/icub_model
Roboy	Partially supported	https://bitbucket.org/hbpneurorobotics/models/src/master/roboy
Lauron	Partially supported	https://bitbucket.org/hbpneurorobotics/models/src/master/lauron_model
MMM	Partially supported	https://bitbucket.org/hbpneurorobotics/models/src/master/mmm_robot
Tigrillo	Partially supported	https://bitbucket.org/hbpneurorobotics/models/src/master/tigrillo
Pioneer3DX	Partially supported	https://bitbucket.org/hbpneurorobotics/models/src/master/p3dx

Baxter	Partially supported	https://bitbucket.org/hbpneurorobotics/models/src/master/baxter
MiRO (Consequential Robotics)	Supported by NRP users	Private (user content)
Snake robot	Supported by NRP users	Private (user content)

2.3.4 A Myorobotics muscle-tendon model

We implemented a plugin for the NRP that simulates a Myorobotics muscle unit. The model comprises the motor dynamics, the gear dynamics and a proportional-integral-derivative (PID) controller, spring elasticity and tendon routing in synchronous update with the physics engine. The plugin can be used with any robot model. A single instance of the plugin can simulate an arbitrary number of Myorobotics muscles, which are defined by their attachment points and wrapping surfaces on the robot model.

Using this plugin, we then set up two Myorobotics robot simulations: a single rotatory joint one degree of freedom arm with two antagonistically arranged muscles and a two degree of freedom arm with four muscles. The plugin automatically loads robot operating system (ROS) topics that subscribe to actuation commands and publish sensor values in terms of position, velocity, and force of the muscle for every muscle. This combination of plugin and prototypes will be used in SGA2 to continue the work started in SGA1 dedicated to testing different strategies developed by simulation inside the NRP for controlling tendon-driven actuators of increasing complexity.

In particular, in SGA1 we implemented a demonstrator that consisted of the two degree of freedom Myorobotics arm controlled by a cerebellum model running on SpiNNaker (see next section for details on the NRP / SpiNNaker interface that enabled this).

2.3.5 Sensor model library

We extended the set of sensors available in the NRP.

The spiking retina model COREM, developed during the Ramp-Up Phase, is now available as a Gazebo plugin and open sourced. Notably, the dynamic vision sensor (DVS) Gazebo plugin was used for research at ETH Zurich for a master thesis.

We implemented several somatosensors, such as mechanoreceptors for touch and muscle activations. These sensors require specific information from physics simulation necessitating modification to the Gazebo and OpenSim integration.

Additionally, contact points are now reported to a ROS topic. More information about the contact sensors is available on our forum (https://forum.humanbrainproject.eu/t/add-contact-sensor-or-example/550) [viewed 2018-03-27].

2.3.6 Achieved Impact

- The NRP provides four fully supported and six partially supported robot models each demonstrated in their own experiments.
- External users have also started to actively add and use their own robot models.
- Our biologically realistic musculoskeletal mouse model is now used in CDP1, and additional cross-SP activities are already in the works for SGA2 (e.g. collaboration with the PAVONE laboratory for mouse grasping experiments).
- The sensors and actuators relying on muscles are now supported through our OpenSim integration.

- A dynamic vision sensor simulation and a retina simulation have been developed as generic Gazebo plugins.

2.3.7 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
830	Closed-Loop Engine	No	The Closed-Loop Engine is the core simulator middleware component and integrates Gazebo and OpenSim together
841	Web Cockpit	No	Main client for the Neurorobotics Platform, it presents the muscle simulation to the user in 3D view
845	Rodent Body Model for the Neurorobotics Platform	No	Rodent body model
847	Musculoskeletal models of rodents for the Neurorobotics Platform	No	Musculoskeletal Rodent model
884	Robot Designer	No	Only graphical tool to add a muscle system to a skeletal model in the Neurorobotics Platform, it plays a central role in the model design
838	Brain-Body Integrator	No	With the Transfer Function mechanism, users can actuate and read muscles in the Brain-Body Integrator interface to control musculoskeletal models
903	Sensory-motor maps	No	This result provides a first prototype of sensory-motor map.
849	NRP - Robot/Avatar library (model)	No	Library of robot and environment models
850	NRP - Sensor model library (service)	No	Library of sensor models

2.4 Physical neurorobotics systems as co-design driver

Physical neurorobotics systems are important to translate knowledge from in silico neuroscience and neurorobotics to the real world. SP10 has selected a small number of physical robot platforms to test neural control algorithms on real robots, and to co-design neural controllers for physical robots, using neuromorphic hardware. These hardware platforms are: a physical rodent robot; a two degree-of-freedom tendon driven arm model (MyoMuscle); Tigrillo, a cheap compliant robot; and iCub, an open humanoid robot platform. With the exception of the rodent robot, all robot platforms were available at the respective SP10 partner institutions. To test the translation of neurocontrollers into the real world, SP10 has selected the SpiNNaker neuromorphic platform from SP9.

SP10 continues to address the duality between simulated and physical robots as well as neuronal control on PC-based and neuromorphic computing hardware, here specifically the SpiNNaker Neuro-Computing System (SP9). The ultimate goal of this WP, offering “plug and play” exchangeable robots and control systems, where both neuronal modellers and roboticists can individually decide to use simulations or existing hardware for experiments, is stringently approached by evaluating and improving existing robotic prototype systems and their implementations in the NRP.

2.4.1 A physical rodent robot.

We created a prototype of a mouse robot able to produce simple locomotion. The mouse robot is controlled by an open-loop software controller, running on an Intel Edison mini-computer. The small size and low power consumption of the on-board computer allow at least 60 min of autonomous operation. The mechanical design of the mouse was validated by comparing joint angles at key moments during locomotion (e.g. touchdown and lift-off of front and back paws) with x-ray videos of rodents performing the same gait (Figure 10 A).

For the next version of the robot mouse, we explored the practical possibilities for fabrication and actuation of a flexible, biologically realistic spine. This allowed us to come up with a mechanical design compatible with 3D printing technology that adequately mimics the flexibility of the rodent spinal cord (Figure 10 B). Based on this design, the development of a second version of the mouse robot was started, which will also include a knee sensor in order to create a closed-loop control for gait adaptation (Figure 10 C).

A third version of the mouse robot is already considered and will implement a more realistic shoulder actuation required for not only more realistic locomotion, but also manipulation tasks (Figure 10 D). This feature has not been implemented so far on biologically-inspired robots and will allow the robot to perform complex manipulation tasks, which will be a focus of SP10 work in SGA2.

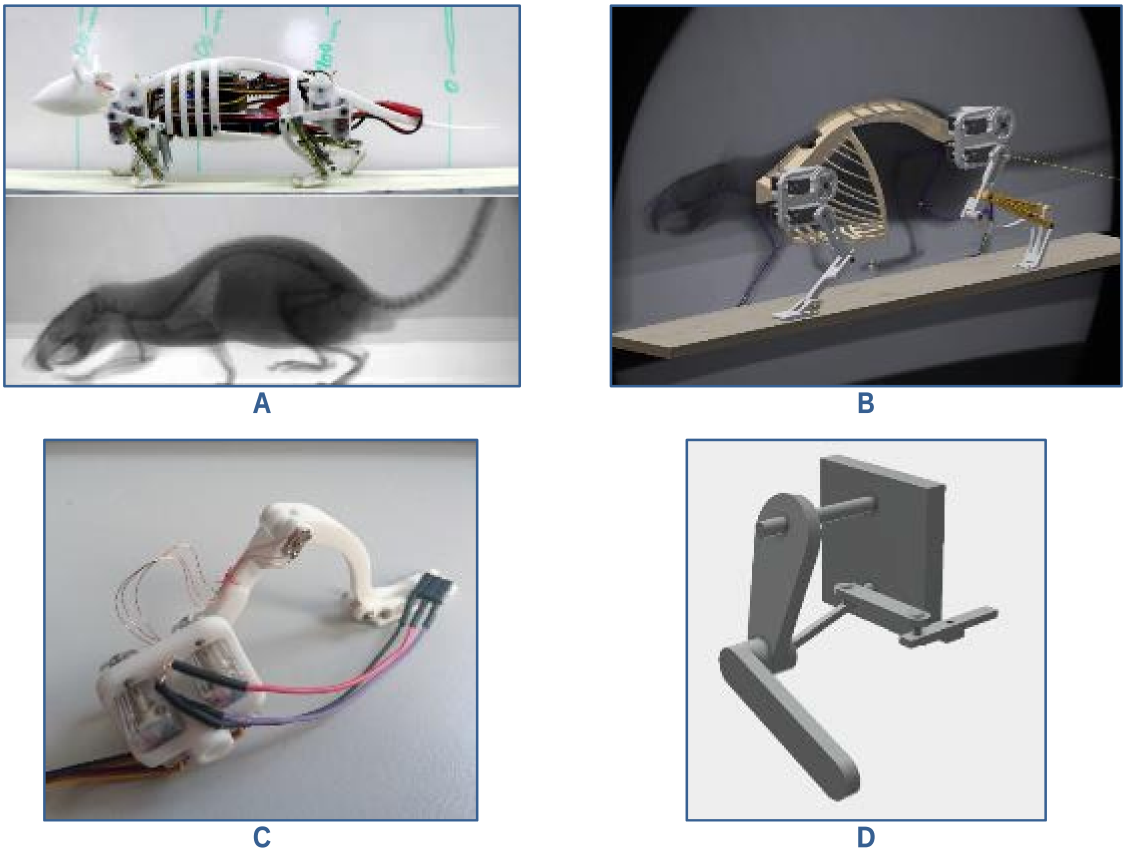

Figure 10: Development of robotic mouse prototype

A) Comparison of walking motion between first prototype and rodent; B) CAD model of the second prototype with flexible spinal cord, together with rodent model as background; C) New leg design with integrated rotational sensor in the knee; D) First shoulder design

2.4.2 Compliant 2DoF Myorobotics Arm

The new ROS-based electronics backend and a Myorobotics 2-DoF arm allowed a controller to be created, such that the MyoMuscle system behaves like Hill-muscles. The test setup used recorded electromyographs (EMGs) with model parameters from the literature to compare the results with human muscles; the results showed an excellent model fit. Additionally, the cable-robot analysis and simulation platform for research (CASPR) from the LAU laboratory (CUHK) has been integrated with the Myorobotics framework to work towards inverse kinematics and task-space-control for complex musculoskeletal robots.

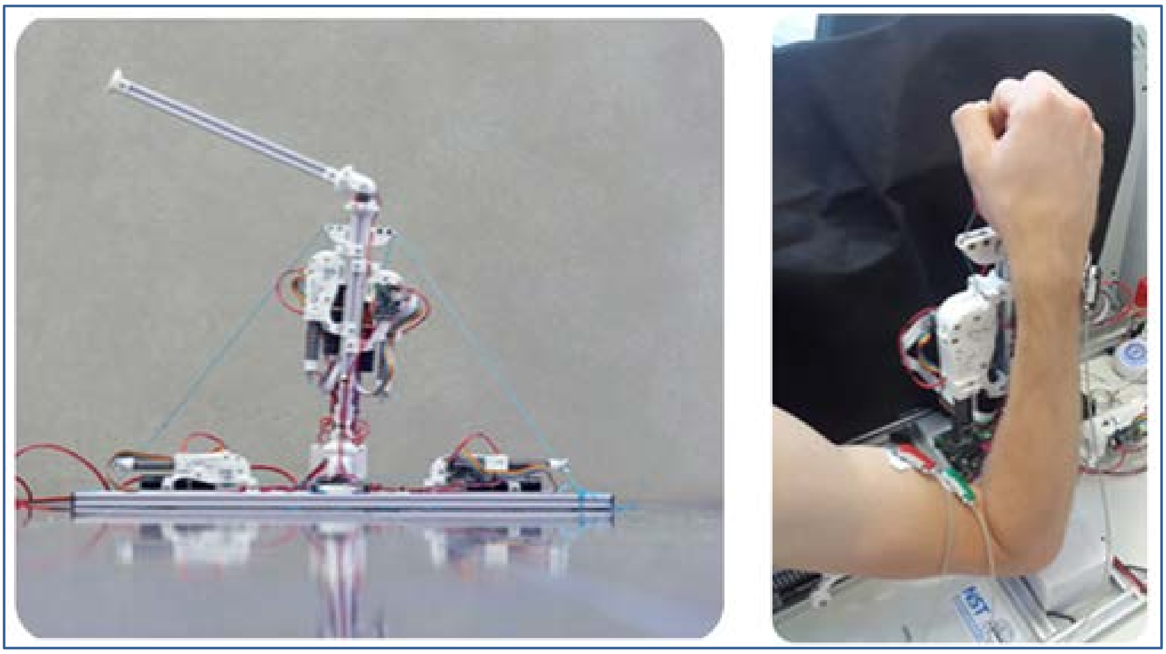

Figure 11: A 2-DoF arm (left) with human electromyograph recordings for comparison (right).

2.4.3 Enhanced IO Interface Board for SpiNNaker for neuromorphic robot control

The previously developed SpiNNaker IO interface board was extended in terms of IO capabilities (additional ports and protocols, e.g. to connect to a PC for debug, and to multiple robots for direct communication), and improved in terms of higher data transfer rates. Significant work effort went into the software integration into the SpiNNaker (SP9) development toolchain to increase usability. A newly created software interface between SpiNNaker and the closed-loop-engine of the NRP now allows running brain simulations on SpiNNaker that control robots or robot models in the NRP, from significantly slowed-down time up to real-time.

2.4.4 Reservoir computing for robot control

The complete design flow for **reservoir computing for motor control** was implemented in the NRP. It was applied to create stable spiking closed-loop control for two different gait patterns (walking and bounding). In addition, higher level control signals can be used to trigger gait transitions between both gaits or to tune the gait frequencies. The SpiNNaker Tigrillo robot was finished and spiking open-loop control models in the NRP were successfully transferred to the physical robot. Finally, the methodology for obtaining robust gait patterns in simulation that are transferrable to robots with slightly different morphological parameters was extended and evaluated.

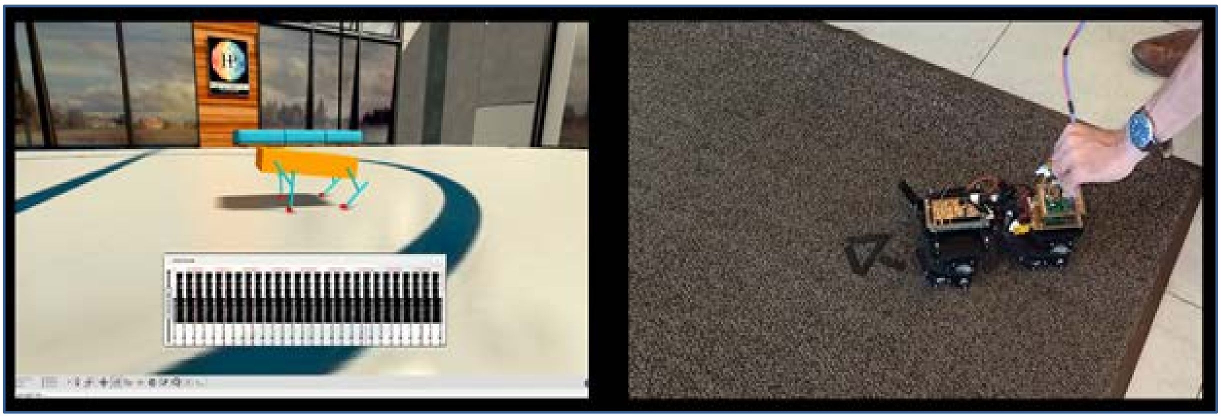

Figure 12: From the NRP to a physical robot with Tigrillo

Tigrillo with spiking open loop control in the NRP (left); experimental validation with spiking open loop control running on embedded SpiNNaker board (right).

2.4.5 Knowledge transfer from NRP to real world robots

We adapted the electronics of the Tigrillo quadruped robot available at UGent to enable experiments on knowledge transfer from the NRP to a physical instance of the robot. With SpiNNaker as the computing backend for brain models in the NRP (see IO Interface board above), training, learning, and tuning of robotic-skills in simulation on the NRP can be performed, and the acquired knowledge can be transferred in a straightforward manner to a physical version of the robot. With only the precision of the physics simulation and the robot's model in the NRP as limiting factors, operating the pre-trained controller on such robots only requires minimal real-world parameter adjustments to compensate for production variations of the physical system.

A demonstration of such capacity was provided with the quadruped walking robot Tigrillo. A spiking open-loop controller based on reservoir computing was virtually trained in the NRP to produce different type of gaits. This controller was subsequently transferred on to the physical robot, which then successfully demonstrated locomotion abilities through the expected gaits. This demonstration highlights the benefits of virtual training in simulation, as the required training iterations would have been difficult to generate with the physical robot (training time and material wear).

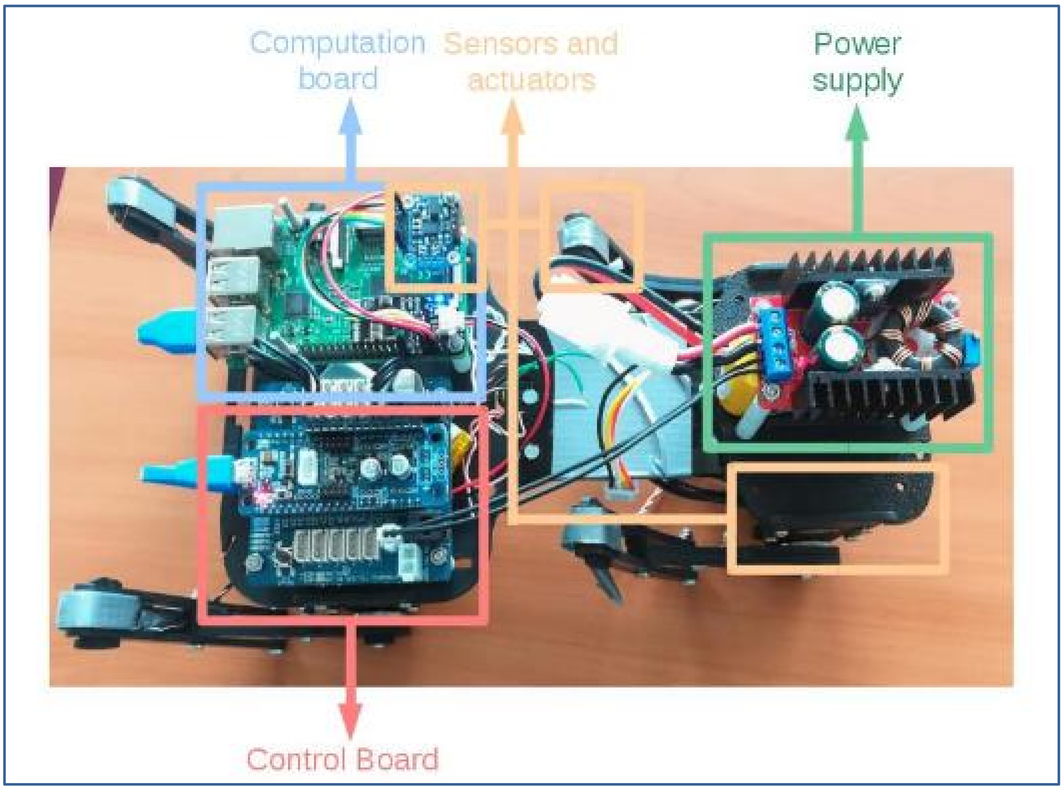

Figure 13: The developed Tigrillo robot hardware for knowledge transfer experiments.

2.4.6 Achieved Impact

The parallel development of robotic prototypes and their platform implementation provides the ability to validate in the real world experimental results that were obtained by simulation. This is a key objective of SP10, and as such the proof of concept that was achieved in SGA1 regarding transfer of knowledge acquired by simulation to real-world robotic setups is a crucial demonstration of the usefulness of the NRP as a prototyping platform for Roboticists. These efforts will be continued in SGA2 with systems of increasing complexity and, going forward, will be part of every dissemination message regarding the NRP. In this regard, it is worth noting that transfering spiking closed loop control for Tigrillo from the NRP on to the physical robot, based on reservoir computing, was presented by J. DAMBRE (UGent) at the EITN workshop “From Neuroscience to Machine Learning” (Paris, 12-13 March, 2018). A paper about this work titled “Closed Loop Control of a Quadruped with Spiking Neural Networks” was also submitted for the special session at IROS2018.

Developing the first mouse robot prototype has taught us a lot in terms of the mechanical challenges to develop tendon-actuated systems at this scale. The lessons learned are currently being leveraged in the development of the second prototype. This is important, as the mouse robot has greatly participated in giving visibility to SP10 and HBP (e.g. at the EU Digital Summit in Tallinn, Estonia, September 2017) and has also attracted the attention of neuroscientists inside and outside the HBP who are looking to validate their models on real robots. In particular, the OOTA laboratory at RIKEN (Japan) has already started the process to have their project become a Partnering Project of the HBP; their objective is to validate with this specific robotic hardware the mathematics of the “re-targeting” of biomechanical and neural functions.

2.4.7 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
739	Model of Spinal Cord using reservoir	No	NRP-based methodology for learning spiking closed loop control for Tigrillo

	computing for real time computing		
816	NRP-Robot/Sensor validation (service)	No	Rough calibration of NRP robot model and sensors for Tigrillo to allow for transferability of control learned in simulation
884	Robot Designer	*No*	Only graphical tool to add a muscle system to a skeletal model in the Neurorobotics Platform, it plays a central role in the model implementation of compliant robots
838	Brain-Body Integrator	*No*	With the Transfer Function mechanism, users can actuate and read muscles in the Brain-Body Integrator interface to control musculoskeletal models
830	Closed-Loop Engine	*No*	The Closed-Loop Engine is the core simulator middleware component and integrates Gazebo and OpenSim together
841	Web Cockpit	*No*	Main client for the Neurorobotics Platform
209	NEST - The Neural Simulation Tool (software)	*No*	The Neural Simulation Tool is the usual backend neural simulator for the NRP
1338	SpiNNaker IO Board	*Yes*	This component is a set of electronics interfaces between the NRP and neuromorphic computing hardware (such as SP9's SpiNNaker), and also between existing neuromorphic sensors/actuators and neuromorphic computing hardware.
858	Robot demonstrator – Robot arm	*Yes*	Neurocontrolled robot arm for demonstrating and evaluating translational neurorobotics on a real system

2.5 Neurorobotics Platform version 2.0 - web accessible suite of highly integrated model building and simulation tools for neurorobotics

The NRP has been continuously developed, updated and deployed over the last 12 months. The NRP is a powerful integration of models, simulation tools, visualisation environments and hardware-/software-in-the-loop facilities that allows neuroscientists and roboticists to connect brain models of different complexity to biological or technical robot bodies, real or virtual, that operate in complex virtual dynamic spaces. The NRP integrates four key components: a robot and world simulator (Gazebo from the Open Source Robotics Foundation), a neural network simulator (NEST from the NEST initiative), a closed-loop engine (CLE from SP10) – or "director" – for the operation of the different simulators, and a web cockpit (from SP10) to interactively design, run and analyse both neurorobotics experiments and realistic physical robot scenarios. In the past 12 months, existing functionalities have been improved (e.g. loading time of the experiments has been considerably shortened). Furthermore, new functionalities have been added, such as the virtual coach or robot inspector, which make the NRP more user-friendly and versatile from an experimental perspective.

2.5.1 Robot designer

The following features have been added to the robot designer with a view to simplifying the creation of complex models.

- Bones can be imported simultaneously via multi-selection.
- Automated creation of collision geometries based on vertex-weighted skinning.
- Automated computation of inertia matrices and centres of mass based on collision geometries.
- Users can "paint" muscles on a skeleton by simply dragging the mouse.
- Performance improvement and fixed issue with the creation convex hulls used as collision geometries.

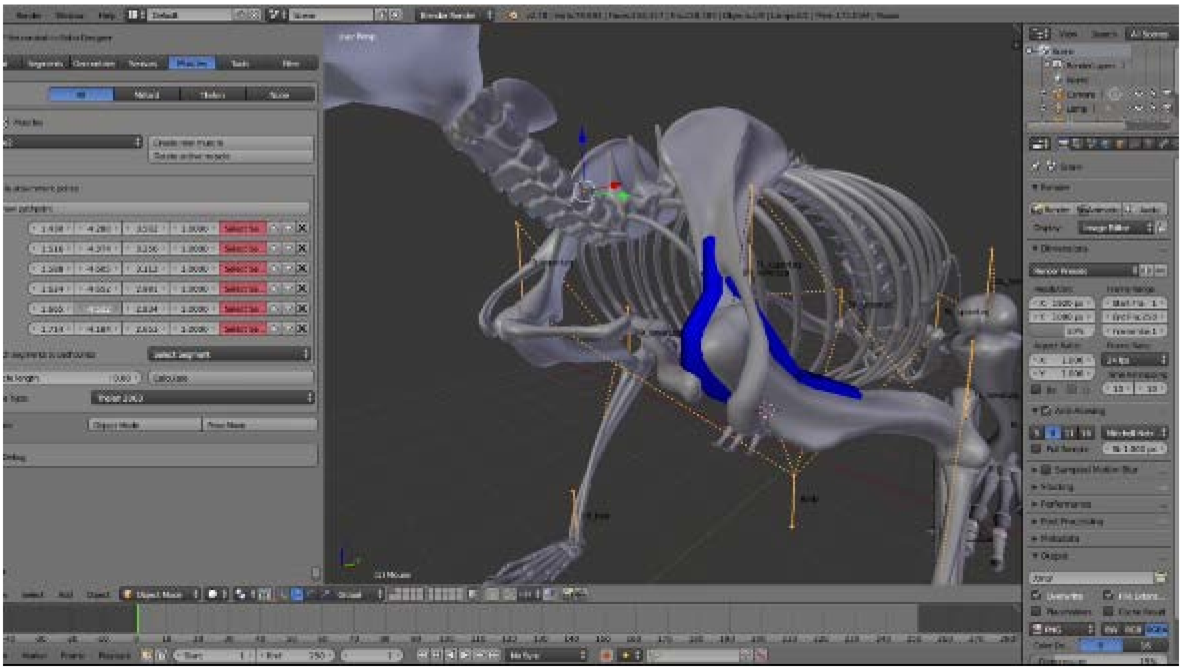

Figure 14: Screenshot of our Blender-based Robot Designer.

Muscles can be attached to a skeleton by a few clicks.

2.5.2 Enhanced BIBI editor

We have implemented a new graphical robot inspector in our 2.0 release that allows users to browse the different parts of the robot and discover its sensors and actuators in an intuitive way. From there, the creation of a transfer function is as simple as a right click on a sensor or actuator topic. This feature addresses recurrent user requests that the programming interface of sensors and actuators should be easy to access.

Figure 15: Sensor and actuator labels displayed by the Robot Inspector

The "classical" Brain Interface and Body Interaction (BIBI) designer proposes a Python interface to the user. The user programs transfer functions using so-called function decorators and has to know which inputs and outputs they will connect together. This is satisfying for advanced users, but confusing for users without development knowledge.

Therefore, we added a structured, more guided version of the BIBI designer that enables the user to discover inputs and outputs (ROS sensor and actuator topics or neurons) dynamically and to connect them by graphical selection. Then, they can concentrate only on the actual code of their transfer function without the need to bother with the wiring.

In the near future (beginning of SGA2), it will be possible to create a transfer function using the graphical BIBI editor from the robot inspector (see below).

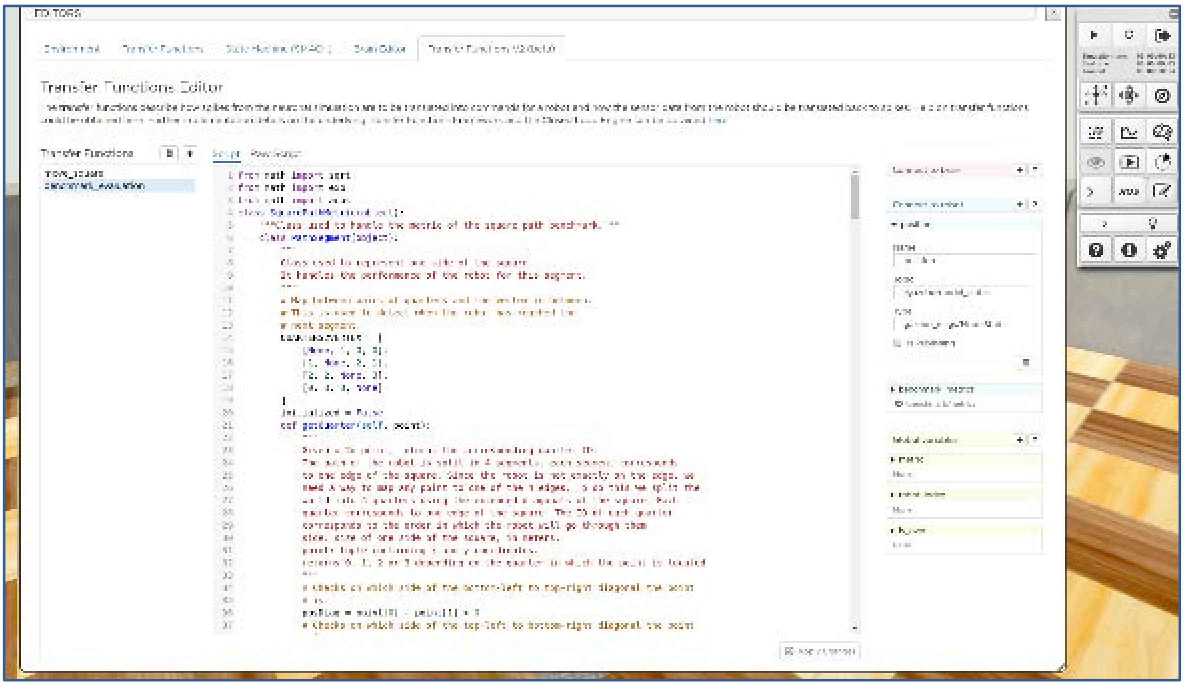

Figure 16: The new transfer function editor

Screenshot of the new transfer function editor that guides the user through the selection of available sensor- and motor- streams.

2.5.3 User interface for model libraries

The promised robot, environment and brain graphical libraries have made their way through SGA1. It is now possible for the user to create an empty experiment and select their models from these three graphical libraries. Models can be templates (available on all servers publicly), private (available from the user's private online storage space) or newly uploaded (from the user's local computer).

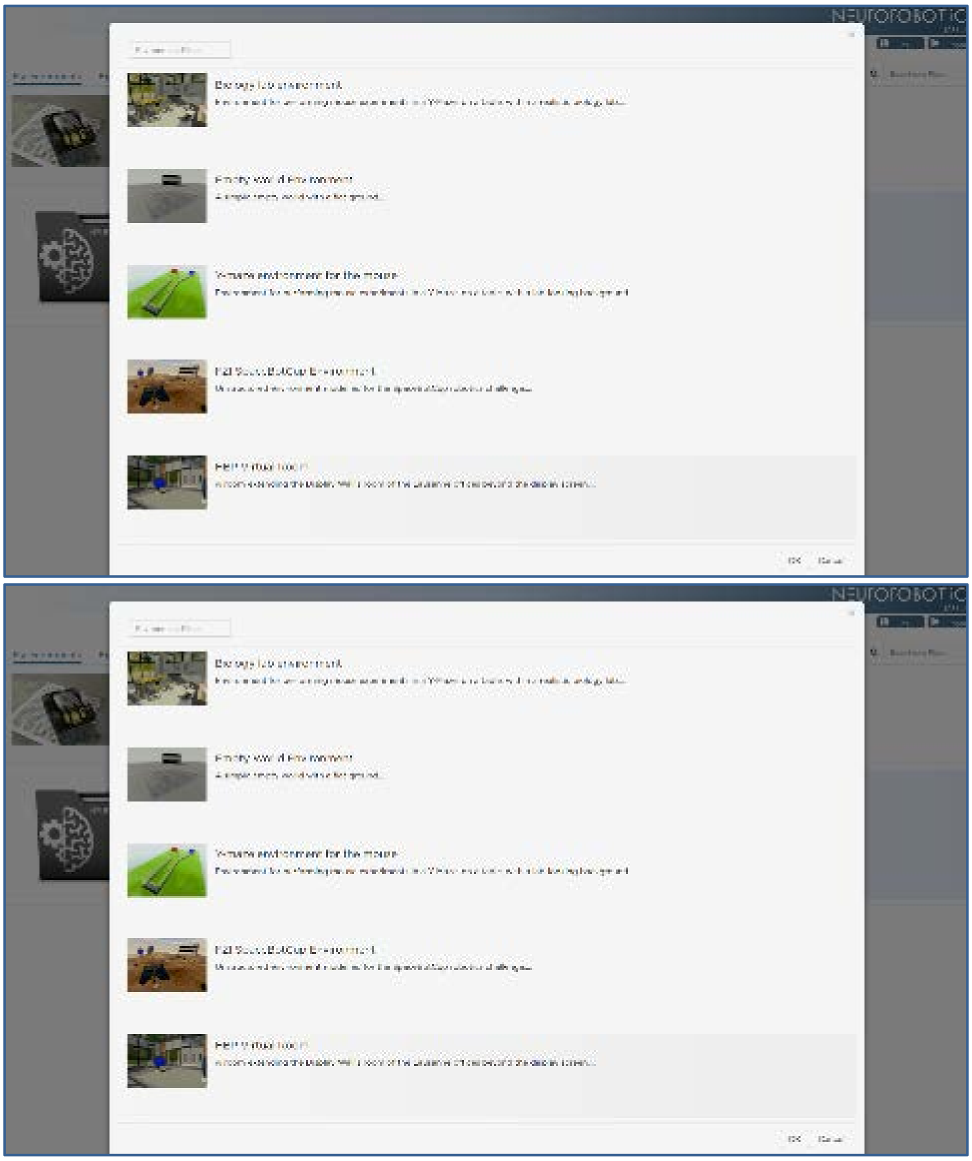

Figure 17: Screenshot of the new environment library.

Users can select pre-designed environments.

2.5.4 Environment designer

The design of a new virtual environment has been significantly facilitated by the ability to duplicate objects in the 3D scene. In addition, two powerful aids have been introduced, namely the snap-to-grid and snap-to-object features. These features help users put objects quickly into place. Furthermore, our ready-made object library has been populated with more than 50 items, classified into natural categories such as "construction", "furniture" or "outdoor".

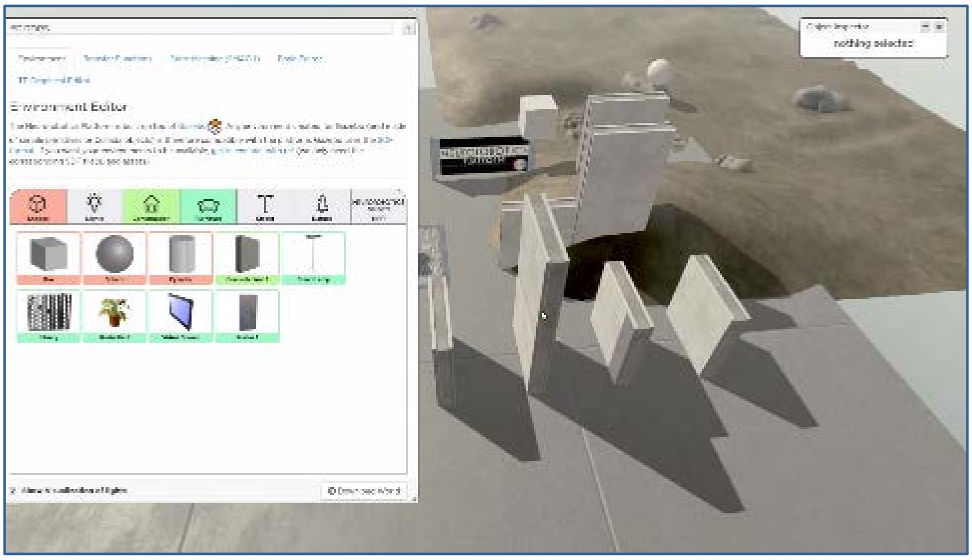

Figure 18: Different types of background can be inserted into the 3D scene.

Ready-made objects can be dragged into the scene, placed and stacked easily using the snap-to-grid or snap-to-object function.

A recurrent demand collected during user workshops and coordination meetings is the ability to build simple environments with a few clicks. It seems to be a must for any researcher willing to reproduce a physical set-up. The aforementioned enhancements have addressed this need while other requests are under review. In particular, the ability to change textures of 3D objects by means of the graphical user interface is an item in our backlog.

2.5.5 Virtual coach

One the major outputs of 2017 was the virtual coach enhancements. The application program interface (API) has been extended from basic functions like starting and stopping experiments, to more advanced functions that allow experiment editing. New functions include adding new transfer functions to the simulation, editing or deleting existing transfer functions, adding new state machines, editing or deleting existing state machines, and modifying the brain while the experiment is running.

Another feature that was added, which is important in the context of running learning experiments, is the ability to reset a simulation from the virtual coach. The typical workflow when conducting a learning experiment is to run a simulation for a certain amount of time, edit parameters, and restart the simulation. In the latest virtual coach release, users can either reset the entire simulation, the robot position, the brain or the environment.

The previous API to launch experiments and save data has also been adapted to use the new storage server. Users can now clone experiments to their own storage, launch cloned experiments, and save experiment data to their own storage from the virtual coach.

The complete API has been documented and is available in the *HBP neurorobotics guide book*, along with a tutorial that guides users through all the functions of the virtual coach and the implementation of an example evolutionary experiment that relies on the virtual coach.

2.5.6 Usability, speed and stability

In 2017, we gave maximum priority to usability improvements, based on user feedback we got from the seven pilot experiments mentioned in the previous deliverable and the new four strategic experiments. This strategy centres the research of the scientific Work Packages (WPs) on four selected and well-defined experiments.

This feedback has led to the following major improvements:

Robot interaction (as part of the Web Cockpit component): It is now possible to interact with the robot while the simulation is running, by applying a force to it, or, simply said, by pushing it.

There are both an intuitive drag-and-drop user interface and a more detailed dialogue box that allows a force value to be entered manually.

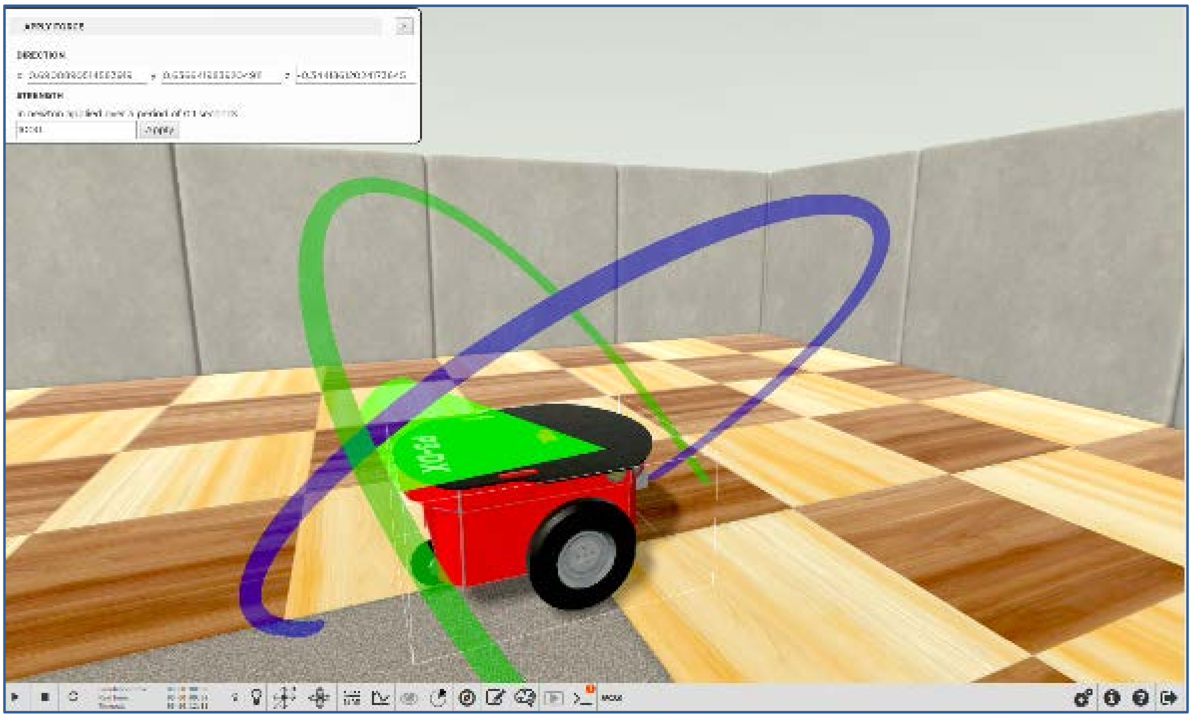

Figure 19: Dialogue box and manipulators used to apply a force to a robot

Access to lower-level ROS commands (as part of the Web Cockpit component): We have, after repeated user requests, added a ROS terminal to the Web Cockpit. It has the functionality and look-and-feel of just another console terminal, except that it is embedded in the online application and is restricted to ROS commands. Its advantage is that users can run their favourite ROS commands to query topics.

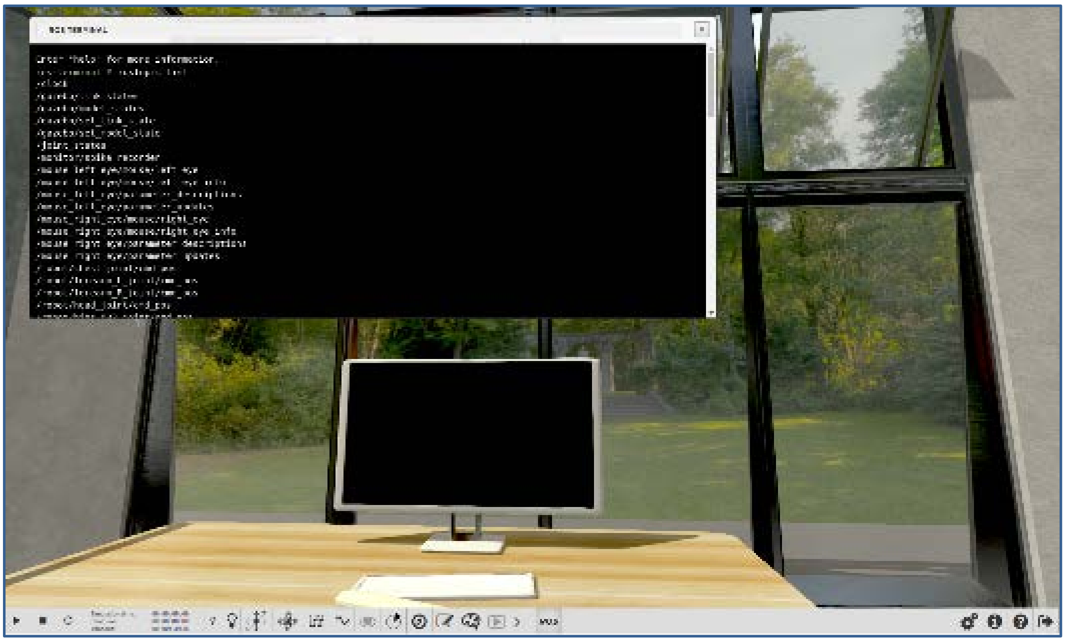

Figure 20: The ROS Console displayed in the Neurorobotics Web Cockpit

Performance enhancements (as part of the Web Cockpit and Closed-Loop Engine components): Following user complaints that the loading and saving of a simulation was too long, we dedicated a great deal of effort to improving performance in general and loading and saving in particular. We optimised the way models are loaded in the Closed-Loop Engine to make the loading of a simulation dramatically shorter. We implemented a full storage server as part of our proxy (a part of the Closed-Loop Engine) to offer fast input/output (I/O) to all our users to load and save their experiments without lagging.

Table 2: Speedup after improvements on the example of the Holodeck environment

	Speedup
Simulation launch	3×
Saving the environment	10×

2.5.7 Infrastructure scaling

Year 2 of SGA1 has seen our efforts in porting the Platform to HPC SP7 resources come to fruition. We have been able to simplify the deployment significantly (see the Docker Deployment key result) and meanwhile, we are serving the Platform over more than 130 virtual machines on CSCS (HPC SP7) resources, for different purposes.

1) We have 15 permanent servers serving regular users (see the Increased User Engagement key result for user figures).
2) 25 Servers have been created and are dedicated to the Educational programme at FZI (see NRP Used as an Education Platform).
3) 105 Servers have recently been added for another educational programme at EPFL that will start at the beginning of SGA2 with 90 students.

This would, of course, never have been possible without the unified Docker deployment process and the availability of SP7 resources.

In SGA2, we hope to achieve the dynamic on-demand creation of servers.

2.5.8 Docker-based deployment

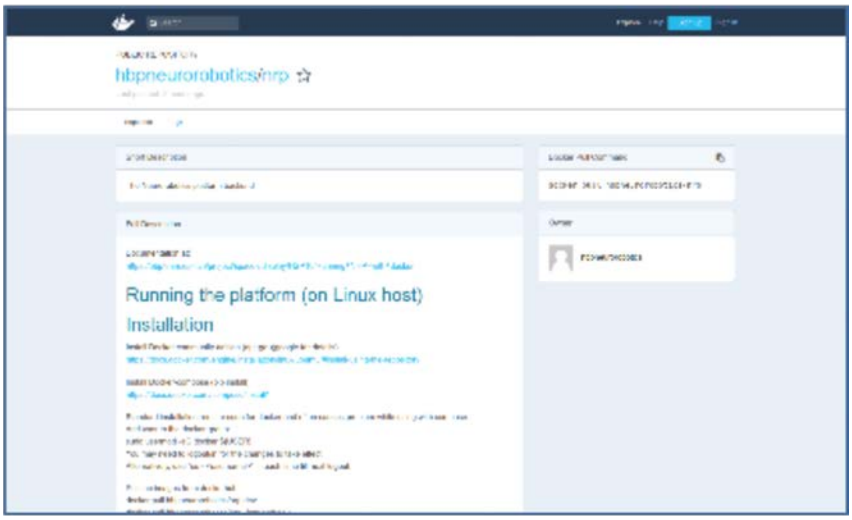

Figure 21: The HBP Neurorobotics Dockerhub

The HBP Neurorobotics Dockerhub hosting the NRP images and the installation documentation

Docker, the popular software containerisation platform, is now used to deploy any of the NRP software component. Docker images are created every 3 weeks and are used to update our development or production servers. This workflow has been set up and documented this year so that any developer can create images and update containers.

Our deployment is now completely unified and the deployed NRP closely resembles the local set up of developers.

Docker deployment makes the task of updating and debugging servers much simpler. A single server can run multiple Docker containers, which is a powerful lever to scale our services up. Thanks to Docker, the NRP can be installed on any system by pulling Docker images only. Still, the

Docker images we provide are large (all in all >15 GB). Users will adopt this means of installation only if these images can be made lighter. This is an active task in our backlog.

2.5.9 NRP and motor-actuated robots

In order to extend the usage of the NRP to physical robotics platforms, we have enriched the core NRP components like CLE and BIBI with mechanisms to control real robotics platforms in real-time closed loops with the neural simulations. In particular, we provided interfaces towards robots using ROS and YARP as communication layers. These interfaces were tested on Myorobotics hardware and on the iCub robot, respectively.

2.5.10 Achieved Impact

- Usability improvements have a dramatic impact on the user experience. For example, the I/O services in use before implementing the storage server barely made it possible to save or load custom simulations. The robot inspector fills a huge void in topics discovery. Robot interaction is a must in any robotics simulator and was missing. Finally, the ROS terminal gives advanced users the low-level access to ROS commands they have requested.
- Impactful use of the NRP by educational programmes is being made possible with the increased availability of dedicated servers. Of course, we plan also to increase resources for regular users.
- Docker deployment makes our operations easier and faster. Some of our servers use multiple containers, which scales up our resources. In addition, Docker allows users to install the NRP on any system in a straightforward way. Nevertheless, some efforts are needed to provide them with lighter images.
- The capability of using physical robotics platforms through the NRP framework can ease the transition between simulation and real-world applications. This was an essential feature requested by robotics users, therefore its implementation fosters an increased user base of the NRP.
- The NRP Environment Designer is the main entry point to the NRP for users who want to build a custom experiment set-up. The feedback from SP10 researchers indicates that the newly added features have addressed their needs specifically.
- 50 Issues and feature requests created on our online feature tracker.
- 70 Topics created on our community forum by 28 users and 368 replies.
- 154 User access requests. A 129% increase compared to the previous year.
- Community website: overview of all NRP-related links, our events and news as well as our research blog.
- User Workshops and Training (documented on the community website).

2.5.11 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
830	Closed-Loop Engine	No	It now optimises the loading of models for faster simulation launch and implements the Storage Server that speeds up saving and loading custom experiments.
838	Brain-Body Integrator	No	The Robot Inspector enables the graphical discovery of sensors and actuators, and the easy graphical creation of transfer functions

841	Web Cockpit	No	Main client for the Neurorobotics Platform, it encompasses the online NRP Environment Designer (878)
878	NRP Environment Designer	No	Tools in the Neurorobotics Cockpit to construct and to represent different environments. This is where additions to the graphical user interface have been made so as to prototype environment faster.
901	Integration, deployment and operation	No	The creation of all these servers requires also their operation and automated deployment
927	NRP interface for motor actuated robots	No	This component enriches the NRP with the necessary interfaces to connect with real robotics platform.
928	Real-time closed-loop neurorobotic systems for real motor-actuated robots	No	This component adds to the NRP CLE the capability of running in real-time, so that a physical robot can be controlled with it.
877	NRP Twitter Account	No	Introduced new users to the platform and publicised user events
905	NRP – User support and training	No	Trained users through user workshops and events as well as providing support through email, forums and bug/feature trackers

2.6 NRP for teaching and dissemination/education

Figure 22: The perception challenge developed by FZI students of the Neurorobotics Platform laboratory course

The challenge is thimblerigging: the robot observes pots (here in red), one of them containing a green ball. After being shown which one contains the ball, the pots are shuffled. The challenge is to find which pot after shuffling contains the ball, simply based on visual input.

2.6.1 Increased user engagement with the Neurorobotics Platform

Effort has been made to encourage new users and increase feedback from existing users. We have encouraged users by increasing activity on our user forum, syncing our open-source code repositories more regularly and opening up our bug and feature tracker to allow users to address their own issues.

We have also been involved in central HBP outreach activities, as well as organising our own install parties and user workshops where people could learn how to use the Platform with support from NRP developers.

2.6.2 Neurorobotics Platform in teaching

Since October 2017, 20 students at FZI have had an exclusive access to NRP servers from our pool of CSCS SP7 servers. After following the "Baseball tutorial" experiment, which gave the students a good understanding of the NRP, they imagined and developed from scratch three challenge experiments in perception, motion, and locomotion. The different groups then focused on solving one or more challenge experiments with creative solutions on the NRP. Some of the proposed solutions involved learning with the use of the virtual coach. The challenges developed by the students are open-source and available on our GitHub account [viewed 2018-03-27]:

- https://github.com/HBPNeurorobotics/hbpprak_perception
- https://github.com/HBPNeurorobotics/hbpprak_motion
- https://github.com/HBPNeurorobotics/hbpprak_locomotion

This has been a successful experience and paves the way for our more challenging educational session that will offer 106 NRP servers to 77 students at EPFL for training on a locomotion experiment at the beginning of SGA2. This training, run by the IJSPEERT laboratory, will have students work on Computational motor control. They will use the online Platform for the following exercises:

1) Integration of muscle models with simple pendulum. In this exercise, the students explore the dynamics of Hill-type muscle models.
2) Exploration of the locomotion of mouse hindlimb. In this exercise, the students receive a mouse model with the muscles attached to the hindlimbs.

A massive open online course (MOOC), using the NRP is in production at EPFL. The MOOC is expected to start in Summer 2018.

2.6.3 Achieved Impact

A full class of neurorobotics students has successfully used the online NRP, which is a key result and proves that we can now scale up to cover demanding user needs.

Figure 23: Prime Minister Alexi Tsipras from Greece is shown the robot mouse

Picture from the EU Digital Summit in Tallinn, September 2017.

The following dissemination and community engagement activities have been successfully organised in the past 12 months:

- Neurorobotics Developer Workshop, Munich (6-7 Apr)
- Interviews at the Deloitte Digital Series, Luxemburg (25 Apr)
- “Hack Roboy” Programming Event, Munich (29 Apr-1 May)
- Neurorobotics Booth at TUM event "50 Jahre Informatik“, Munich (12 May)
- Public talk at “Pint of Science”, Munich (15 May)
- 3rd Japan-EU workshop on Neurorobotics, Geneva, Switzerland (15 Jun)
- International Neurorobotics Symposium “Building Bodies for Brains and Brains for Bodies”, Geneva, Switzerland (16 Jun)
- Presentation at the 3. Zukunftskongress „Technik zum Menschen bringen“, Bonn, Germany, 26-27 Jun
- Workshop at the BMW Summer School 2017 on “Intelligent Cars on Digital Roads – Frontiers in Machine Intelligence”, Bad Wörishofen, Germany (9-14 Jul)
- Neurorobotics Platform User Workshop, Karlsruhe, Germany (24-26 Jul)
- 2nd Young Researchers Event, Geneva, Switzerland (12-13 Sep)
- CodeJam#8 (together with SP9, SP6 and SP8), Lausanne, Switzerland (13-15 Sep)
- Presentation of physical and simulated robots at the EU Digital Summit, Tallinn (29-30 Sep)
- HBP Innovation Day: “Neuroscience-driven Innovation and the Path Forward in AI and Robotics”, Garching, Germany (15 Dec)
- The Human Brain Project Neurorobotics sub-project workshop: “Does the Brain Need a Body to be a Brain?”, Barcelona, Spain (8-9 Mar)

- HBP Education workshop "HBP Curriculum: Cognitive systems for non-specialists" workshop (co-organised with SP12) in Munich, Germany (13-15 Mar)
- Neurorobotics Platform Workshop at the ERF 2018 in Tampere, Finland (15 Mar)
- NRP booth and keynote lecture by Alois KNOLL at the Künstliche Intelligenz , Handelsblatt – Euroforum, Munich, Germany (15-16 Mar).
- NRP booth at the HBP Innovation Expo in London, United Kingdom (23 Mar).

2.6.4 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
841	Web Cockpit	No	Main graphical client for the Neurorobotics Platform, it is the playground that students have used.
890	Virtual Coach	No	The tutorial included use of the virtual coach extensively.
905	User Support and Training	No	Users have been provided with a tutorial that has been developed as part of this component.
901	Integration, deployment and operation	No	Providing these dedicated servers has only been possible with the enhanced deployment and operation activities of the SP10 team.

3. Conclusion and Outlook

3.1 SP10 reorganisation

SP10 has continued to focus its scientific and development work around fewer internal use cases and stronger engagement of users from other SPs and from outside the HBP. In particular, we intensified our collaborations with SP1, SP3, SP6, SP7, and SP9.

During the reporting period, SP10 has undergone a light and an in-depth review by the EC and the reviewers. In response to the feedback, SP10 has submitted a significantly streamlined mission and work plan for SGA2.

For SGA2, we have reorganised the entire WP structure to sharpen SP10s goals and research profile, see Figure 24. The SP has now only five WPs instead of seven in SGA1. Moreover, the scientific WPs have been grouped around three key application domains of neurorobotics: the virtual rodent modelling, models of behavioural architectures, and learning and physical neurorobotics. The research in each WP either depends on the unique properties of the NRP or represents a strategic application domain for the NRP and therefore serves to define and validate new functions of the NRP.

The old NRP WPs have been consolidated into a single WP with the central mission to improve the features and utilities of the NRP for the benefit of the growing user community.

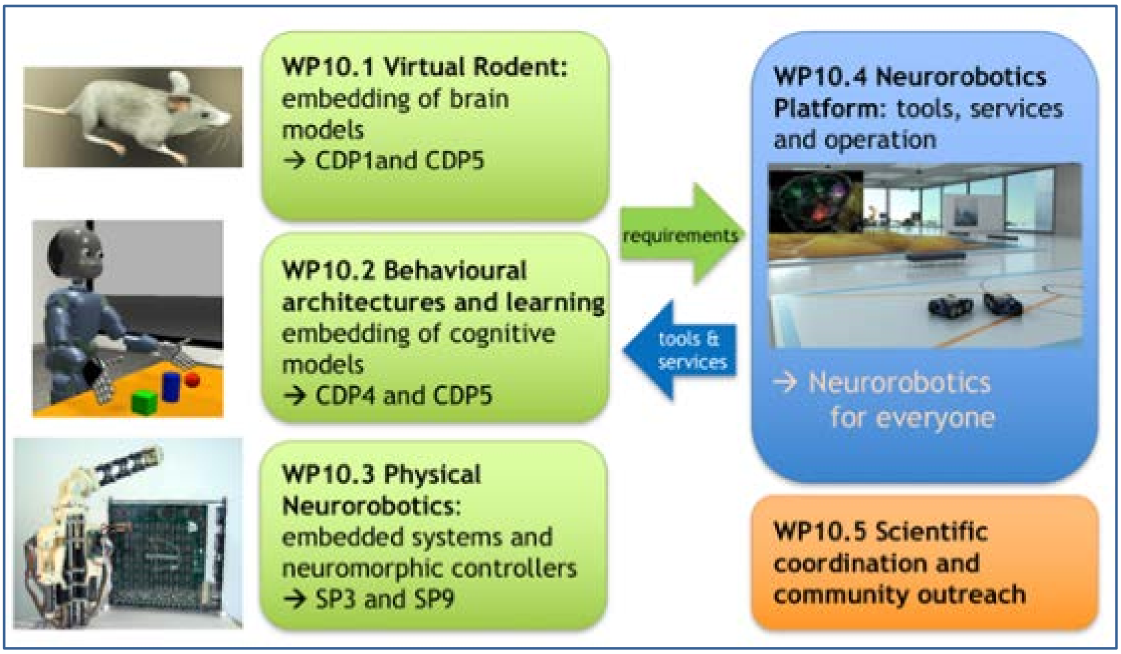

Figure 24: SP10s goals and research profile in SGA2

3.2 SP10 as driver for future computing and innovation

SP10 has also realised that it must play a more active role in driving HBP's innovation efforts. SP10 is at the intersection between neuroscience, robotics, and AI; it is, thus, in an ideal position to integrate knowledge from these disciplines and transfer it to different application domains. The main vehicle for this information transfer is the HBP NRP, which has a huge potential for simulation-based prototyping and application development in areas ranging from neurotechnology, robotics, and production to future AI. We have thus been actively working with Erdyn to leverage the ongoing HBP-level effort undertaken to facilitate technology transfer, and as a result the NRP will be present on the online platform this consulting company is creating for the HBP. From the end of SGA1, we also have been aiming to engage industrial elements of the innovation chain, and this effort will be sustained throughout SGA2.

In December 2017, for example, we organised the first SP10 Innovation Workshop where we presented research from SP10 and HBP to representatives from SMEs and large industrial groups based around Munich in Germany. The response was very positive, with more than 90 registrations and about 70 participants from industry. In March 2018, SP10 was also involved in the First HBP Innovation Forum in London. The same month, SP10 members organised an NRP workshop at the European Robotics Forum, Tampere, Finland, which generated an overwhelmingly positive feedback from the audience. This indicates that the features of the NRP are in line with what the robotics community expects to see from an enabling technology for embodied AI, and motivates us to keep engaging this community.

In the future, SP10 will therefore not only continue, but also increase its effort to drive innovation in the areas of neurotechnology, robotics and future AI, based on the technologies developed in SP10 and HBP.

4. Component Details

The following is a list of the newly released internal Components for this deliverable.

4.1 NRP - Robot/Avatar library

Field Name	Field Content	Additional Information
ID	849	
Component Type	Model	
Contact	Reichard, Daniel	
Component Description	This library provides a strategical set of robots (industrial, humanoid, simplified human and rodents etc.) and biological avatars (rodent, human, etc.).	
Latest Release	18 - Community library of robots avatars	
TRL	TRL6	
Location	data hosted by other non-HBP 3rd party	Bitbucket
Format	model	
Curation Status	PLA registered	
Validation - QC	Pass	
Validation – Users	Yes	3551 experiments launched on the online development server
Validation – Publications	No	
Privacy Constraints	No Privacy Constraint	
Sharing	anonymous	
License	GPL2	
Component Access URL	https://bitbucket.org/hbpneurorobotics/models/	
Technical documentation URL	https://bitbucket.org/hbpneurorobotics/models/src/master/README	

Usage documentation URL	https://bitbucket.org/hbpneurorobotics/models/src/master/README	
Component Dissemination Material URL	Not available	

4.2 NRP - Sensor model library

Field Name	Field Content	Additional Information
ID	850	
Component Type	Model	
Contact	Reichard, Daniel	
Component Description	Library for various sensors to be simulated in the Neurorobotics Platform. Will be accessible from the web-based Robot Designer application.	
Latest Release	18 - Community library of sensors	
TRL	TRL4	
Location	data hosted by other non-HBP 3rd party	Bitbucket
Format	model	
Curation Status	PLA registered	
Validation - QC	Pass	
Validation – Users	Yes	3551 experiments launched on the online development server
Validation – Publications	No	
Privacy Constraints	No Privacy Constraint	
Sharing	anonymous	
License	GPL2	
Component Access URL	https://bitbucket.org/hbpneurorobotics/gazeborospackages	
Technical documentation URL	https://github.com/HBPNeurorobotics/gazebo_dvs_plugin	

Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/9746/nav/73391	
Component Dissemination Material URL	Not available	

4.3 Rodent Body Model for the Neurorobotics Platform

Field Name	Field Content	Additional Information
ID	845	
Component Type	Model	
Contact	CLOSTERMANN, Matthias	
Component Description	Rodent model for simulation in the Neurorobotics Platform. The development of the rodent body model is subcontracted. It requires a realistic model skeleton, which it encases.	
Latest Release	24 - Final version of the model	
TRL	TRL5	
Location	Online	Bitbucket
Format	Not available	
Curation Status	PLA registered	
Validation - QC	Pass	
Validation – Users	Yes: used in walking experiments in student course; used in the stroke rehabilitation experiment.	Process driven by EPFL Ph. D. students (Rodarie D, Ramalingasetty ST)
Validation – Publications	No	
Privacy Constraints	No Privacy Constraint	
Sharing	anonymous	
License	GPL2	
Component Access URL	https://bitbucket.org/hbpneurorobotics/models/src/acda7194151444478589c174ca732f463dfcda25/mouse_v2_model/?at=master	

Technical documentation URL	https://bbpteam.epfl.ch/project/spaces/pages/viewpage.action?pageId=28443262 https://bbpteam.epfl.ch/project/spaces/display/HSP10/OpenSim+integration	
Usage documentation URL	https://www.youtube.com/watch?v=rvw9SibIrw4	Video tutorial for the CDP1 experiment
Component Dissemination Material URL	Not available	

4.4 Musculoskeletal models of rodents for the Neurorobotics Platform

Field Name	Field Content	Additional Information
ID	847	
Component Type	Model	
Contact	IJSPEERT, Auke	
Component Description	Develop an accurate musculoskeletal model of a rodent hindlimb. The developed model will be validated to reproduce biologically acceptable results from literature and animal experiments. The model will then be used for locomotion studies by integrating spinal cord circuits for closed loop simulation.	
Latest Release	12 - 1st version of the musculoskeletal mouse model	
TRL	TRL5	
Location	Online	Bitbucket
Format	Not available	
Curation Status	PLA registered	
Validation - QC	Unchecked	Currently checked by component user locally
Validation – Users	Upcoming	Due for release to students under MOOC course at EPFL
Validation – Publications	No	
Privacy Constraints	No	

Sharing	anonymous	
License	GPL2	
Component Access URL	https://bitbucket.org/hbpneurorobotics/models/src/acda7194151444478589c174ca732f463dfcda25/mouse_forelimb/?at=master	
Technical documentation URL	https://gitlab.com/HBPNeurorobotics-Mouse	
Usage documentation URL	https://gitlab.com/HBPNeurorobotics-Mouse	
Component Dissemination Material URL	Not available	

4.5 Sensory models

Field Name	Field Content	Additional Information
ID	899	
Component Type	Model	
Contact	LASCHI, Cecilia	
Component Description	This component aims at providing models of early sensory processing that will be used in sensory-motor integration tasks. Models of proprioceptive, visual, inertial and tactile sensors will be provided with suitable neural interfaces for brain models.	
Latest Release	20 - Sensory models	
TRL	TRL3	
Location	Online	Bitbucket
Format	Not available	
Curation Status	PLA registered	
Validation - QC	Pass	
Validation – Users	No	
Validation – Publications	Yes	DOI 10.3389/fnins.2017.00341
Privacy Constraints	No privacy constraint	

Sharing	anonymous	
License	GPL2	
Component Access URL	https://bitbucket.org/lore_ucci/musclespindle	
Technical documentation URL	https://bitbucket.org/lore_ucci/musclespindle	
Usage documentation URL	https://bitbucket.org/lore_ucci/musclespindle	
Component Dissemination Material URL	Not available	

4.6 Sensory-motor maps

Field Name	Field Content	Additional Information
ID	903	
Component Type	Model	
Contact	LASCHI, Cecilia	
Component Description	The main goal of this component is to provide a basic neural implementation of sensory motor maps and integrate them into a closed loop for the control of simulated agents (mouse or robotic platforms), using sensory models developed in this task, simplified brain models from T6.2.2 and T6.2.3, as developed in T6.2.7, and motor primitives provided by T10.1.1.	
Latest Release	24 - Sensory-motor maps	
TRL	TRL3	
Location	Not available	
Format	Not available	
Curation Status	PLA registered	
Validation - QC	Unchecked	Manuscript in preparation
Validation – Users	No	
Validation – Publications	No	

Privacy Constraints	No privacy constraint	
Sharing	Anonymous	
License	Not available	
Component Access URL	https://collab.humanbrainproject.eu/#/collab/9686/nav/73072	
Technical documentation URL	https://collab.humanbrainproject.eu/#/collab/9686/nav/73072	
Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/9686/nav/73072	
Component Dissemination Material URL	Not available	

4.7 NRP interface for motor actuated robots

Field Name	Field Content	Additional Information
ID	927	
Component Type	Software	
Contact	LASCHI, Cecilia	
Component Description	This component will provide suitable interfaces for motor actuated robots. These interfaces will comply with the Neurorobotics Platform currently adopted robotic middleware (ROS). Possible candidate robotic platforms for such a component are the iCub robot and the biped humanoid robotic platform named SABIAN.	
Latest Release	12 - Prototype of the interfaces for motor actuated robots	
TRL	TRL4	
Location	Online	Bitbucket
Format	Not available	
Curation Status	Not Applicable	
Validation - QC	Pass	Agile Quality Assurance, Axel von Arnim

Validation – Users	Yes	Internal users
Validation – Publications	No	
Privacy Constraints	No privacy constraint	
Sharing	Anonymous	
License	GPLv2/GPLv3	
Component Access URL	https://bitbucket.org/hbpneurorobotics/cle	
Technical documentation URL	https://collab.humanbrainproject.eu/#/collab/9545/nav/72009	
Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/9545/nav/72009	
Component Dissemination Material URL	Not available	

4.8 Real-time closed-loop neurorobotics systems for real motor-actuated robots

Field Name	Field Content	Additional Information
ID	928	
Component Type	Software	
Contact	LASCHI, Cecilia	
Component Description	The aim of this component is to provide a suitable version of the NRP able to achieve real-time performances in conjunction with neuromorphic hardware for controlling real motor-actuated robots.	
Latest Release	24 - Prototype for neurorobotics experiments using real motor-actuated robots	
TRL	TRL4	
Location	Online	Bitbucket
Format	Not available	
Curation Status	Not Applicable	

Validation - QC	Unchecked	Still under testing with internal users
Validation – Users	No	In progress
Validation – Publications	No	
Privacy Constraints	No privacy constraint	
Sharing	Anonymous	
License	GPLv2/GPLv3	
Component Access URL	https://bitbucket.org/hbpneurorobotics/cle	
Technical documentation URL	https://collab.humanbrainproject.eu/#/collab/9545/nav/72009	
Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/9545/nav/72009	
Component Dissemination Material URL	Not available	

4.9 Reactive perception-action loops

Field Name	Field Content	Additional Information
ID	908	
Component Type	Model	
Contact	LASCHI, Cecilia	
Component Description	This component will provide functional behavioural models of reactive perception-action loops (i.e. reflexes and feedback-based actions, based on cerebellar motor control). These behaviours will be tested on simulated robotic platforms (humanoids or modular) or simulated mouse and human models. The models will have a modular structure, so that parts of them can be substituted by other brain models.	
Latest Release	24 - Library of functional behavioural models of reactive perception-action loops	

TRL	TRL3	
Location	Online	Bitbucket
Format	Not available	
Curation Status	PLA registered	
Validation - QC	Pass	
Validation – Users	No	
Validation – Publications	Yes	DOI 10.1088/1748-3190/aa8581 DOI 10.1109/BIOROB.2016.7523593 DOI 10.1007/978-3-319-42417-0_31
Privacy Constraints	No privacy constraint	
Sharing	Not available	
License	Not available	
Component Access URL	https://bitbucket.org/hbpneurorobotics/experiments/src/master	
Technical documentation URL	https://collab.humanbrainproject.eu/#/collab/9539/nav/71999	
Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/9539/nav/71999	
Component Dissemination Material URL	Not available	

4.10 NRP Environment Designer

Field Name	Field Content	Additional Information
ID	*878*	
Component Type	Software	
Contact	HINKEL, Georg	
Component Description	Tools in the Neurorobotics Cockpit to construct and to represent different environments. Reusable Software components (packages) which are helpful will be adapted from external resources. The involved environmental models do not describe only static environments but also	

	dynamic scenes and outdoor scenes. The user will be enabled to modify and extend the environmental models graphically in an interactive manner. This component has been updated with snap-to-grid and snap-to-object functions, extended library of ready-made 3D objects, object duplicate function.	
Latest Release	24 – Release of ExDFrontend 2.0	
TRL	TRL 6	
Location	data hosted by other non-HBP 3rd party	Bitbucket
Format	Software, JavaScript application	
Curation Status	Not Applicable	
Validation - QC	Pass	Agile Quality Assurance, Axel von Arnim
Validation – Users	Yes	Internal users
Validation – Publications	Yes	
Privacy Constraints	No privacy constraints	
Sharing	Anonymous	
License	GPLv2/GPLv3	
Component Access URL	https://bitbucket.org/hbpneurorobotics/exdfrontend	
Technical documentation URL	https://bbpteam.epfl.ch/documentation/#exdfrontend	
Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/71/nav/1610	
Component Dissemination Material URL	Not available	

4.11 NRP Standalone Robot Designer

Field Name	Field Content	Additional Information
ID	884	
Component Type	Software	

Contact	Feldotto, Benedikt	
Component Description	Standalone version of the RobotDesigner realised as a Blender Plugin. This continues the effort of the Ramp-Up-Phase to design sophisticated complex robot models outside of the Neurorobotics Platform. This component has been updated with the ability to attach muscles to robot parts and with the automated creation of joints based on imported Blender rigs.	
Latest Release	24 – Release of BlenderRobotDesigner 2.0	
TRL	TRL 5	
Location	Online	GitHub
Format	Software, Python application, Blender plugin	
Curation Status	Not Applicable	
Validation - QC	Pass	Agile Quality Assurance, Axel von Arnim
Validation – Users	Yes	Internal users
Validation – Publications	Yes	
Privacy Constraints	No privacy constraints	
Sharing	Anonymous	
License	GPLv2/GPLv3	
Component Access URL	https://github.com/HBPNeurorobotics/BlenderRobotDesigner	
Technical documentation URL	Not available	
Usage documentation URL	https://github.com/HBPNeurorobotics/BlenderRobotDesigner	
Component Dissemination Material URL	Not available	

4.12 NRP Closed Loop Engine

Field Name	Field Content	Additional Information

ID	*830*	
Component Type	Software	
Contact	GUYOT, Luc	
Component Description	The NRP Closed Loop Engine (CLE) is the component which allows to simulate a brain wired to a robot evolving in a virtual environment. The CLE runs two simulators, the brain and the robot simulator, and keep them synchronised. This component has been updated with the integration of OpenSim for the simulation of muscle systems, in combination with robotics system. More precisely, an extension of Gazebo (the robotics simulator which the CLE depends on) has been implemented and released to enable the simulation of musculoskeletal apparatus, such as the mouse of CDP1.	
Latest Release	24 – Release of CLE 2.0	
TRL	TRL 6	
Location	Online	Bitbucket
Format	Software, JavaScript application	
Curation Status	Not Applicable	
Validation - QC	Pass	Agile Quality Assurance, Axel von Arnim
Validation – Users	Yes	Internal users
Validation – Publications	Yes	
Privacy Constraints	No privacy constraints	
Sharing	Anonymous	
License	GPLv2/GPLv3	
Component Access URL	https://bitbucket.org/hbpneurorobotics/CLE	
Technical documentation URL	https://bbpteam.epfl.ch/documentation/#hbp-nrp-cle	
Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/71/nav/1610	

Component Dissemination Material URL	Not available	

4.13 Model of Spinal Cord using reservoir computing for real time computing

Field Name	Field Content	Additional Information
ID	739	
Component Type	model	
Contact	DAMBRE, Joni	
Component Description	Model of the spinal cord built upon existing first results in which gait actuator signals were generated directly from a combination of the physical body and conventional untrained feedforward artificial neural networks (ELM), and explicit memory of the body feedback. For this model, the approach is augmented by the body feedback with a 'reservoir' consisting of rate based neuron population models with parameter settings that are plausible for spinal cord neurons.	
Latest Release	Not Applicable	
TRL	4	
Location	data hosted by Collaboratory storage	
Format	Programming model	
Curation Status	Not Applicable	
Validation - QC	Unchecked	Manuscript under review
Validation – Users	Yes	Internal users
Validation – Publications	No	Manuscript under review
Privacy Constraints	Not available	
Sharing	Not available	
License	Not available	
Component Access URL	https://collab.humanbrainproject.eu/#/collab/9105/nav/68856	
Technical documentation URL	https://collab.humanbrainproject.eu/#/collab/9105/nav/68856	

Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/9105/nav/68856	
Component Dissemination Material URL	Not applicable	

4.14 NRP-Robot/Sensor validation

Field Name	Field Content	Additional Information
ID	816	
Component Type	service	
Contact	DAMBRE, Joni	
Component Description	Calibration of the simulation models of robots, including all sensors and actuators, against their real counterparts, i.e., real robots.	
Latest Release	Not applicable	
TRL	Not applicable	
Location	data hosted by subproject providing dataset	
Format	service - validation	
Curation Status	Not applicable	
Validation - QC	Unchecked	Manuscript under review
Validation – Users	Yes	Internal users
Validation – Publications	No	
Privacy Constraints	Not available	
Sharing	Not available	
License	Not available	
Component Access URL	Not applicable	
Technical documentation URL	Not applicable	

Usage documentation URL	Not applicable	
Component Dissemination Material URL	Not applicable	

4.15 Robot Demonstrator - Robot Arm

Field Name	Field Content	Additional Information
ID	858	
Component Type	hardware	
Contact	CONRADT, Jörg	
Component Description	A neurocontrolled robot arm for demonstrating and evaluating translational neurorobotics on a real system	
Latest Release	24 – Prototype for experiment with NRP and SpiNNaker	
TRL	TRL4	
Location	TUM / Munich	
Format	hardware	
Curation Status	Not applicable	
Validation - QC	Unchecked	In progress
Validation – Users	Yes	Internal users
Validation – Publications	No	
Privacy Constraints	No Privacy Constraints	
Sharing	Anonymous	
License	Not applicable	
Component Access URL	Not applicable	
Technical documentation URL	Not applicable	
Usage documentation URL	Not applicable	

Component Dissemination Material URL	Not applicable	

4.16 SpiNNaker IO Board

Field Name	Field Content	Additional Information
ID	1338	
Component Type	hardware	
Contact	CONRADT, Jörg	
Component Description	This component is a set of electronics interfaces between the NRP and neuromorphic computing hardware (such as SP9's SpiNNaker), and between existing neuromorphic sensors/actuators and neuromorphic computing hardware. It uses high-speed high-bandwidth electronics, and a software environment to translate between the existing systems.	
Latest Release	18 – Prototype for neurorobotics incorporating real robots and neuromorphic sensors	
TRL	TRL6	
Location	TUM / Munich; UGent / Gent	
Format	hardware – neuromorphic	
Curation Status	Not Applicable	
Validation - QC	Pass	
Validation – Users	Yes	Internal users
Validation – Publications	Yes	DOI 10.1109/MRA2016.2535081 Citation count: 7
Privacy Constraints	No Privacy Constraints	
Sharing	Anonymous	
License	Not applicable	
Component Access URL	Not applicable	

Technical documentation URL	https://wiki.tum.de/display/nst/NST+SpiNNaker+Interface+Board+Documentation	
Usage documentation URL	https://wiki.tum.de/display/nst/NST+SpiNNaker+Interface+Board+Documentation	
Component Dissemination Material URL	Not applicable	

4.17 Laminart with segmentation and retina into the NRP

Field Name	Field Content	Additional Information
ID	658	
Component Type	Model	
Contact	BORNET, Alban	
Component Description	Laminart – The Laminart is a spiking cortical model for early-stage visual segmentation. This component integrates the Laminart model to the neurorobotics platform, to connect it to a retina model. The Laminart model is able to parse its visual input into several segmentation layers, and project its output into higher cortical areas to generate a motor response, recurrently updating the visual stimulus.	
Latest Release	03.2018	
TRL	TRL4	
Location	Data hosted by other non-HBP 3rd party	Bitbucket
Format	Programming model	
Curation Status	PLA registered	
Validation - QC	Yes	Continuous feedback and code review by Prof. Gregory FRANCIS
Validation – Users	Yes	Internal users
Validation – Publications	Yes	Francis, G., Manassi, M., & Herzog, M. H. (2017). Neural dynamics of grouping and segmentation explain properties of visual crowding. Psychological review, 124(4), 483.

Privacy Constraints	No Privacy Constraint	
Sharing	Anonymous	
License	GPLv2/GPLv3	
Component Access URL	https://project-lifecycle.herokuapp.com/component/658/	
Technical documentation URL	https://bitbucket.org/albornet/laminartcomponent	
Usage documentation URL	https://bitbucket.org/albornet/laminartcomponent	
Component Dissemination Material URL	None	

4.18 Virtual coach

Field Name	Field Content	Additional Information
ID	890	
Component Type	Software	
Contact	KNOLL, Alois	
Component Description	This component is meant for researchers to design reinforcement learning experiments. It tied to the main product of SP10, the Neurorobotics Platform. It allows to run batch simulations in an ipython notebook and script the whole process in python. Users can use any python package to visualize and analyse simulation data.	
Latest Release	24 – Release of CLE 2.0	
TRL	TRL 6	
Location	Online	Bitbucket
Format	Software, Python application	
Curation Status	Not Applicable	
Validation - QC	Pass	Agile Quality Assurance, Axel von Arnim
Validation – Users	Yes	Internal users

Validation – Publications	Yes	
Privacy Constraints	No privacy constraints	
Sharing	Anonymous	
License	GPLv2/GPLv3	
Component Access URL	https://bitbucket.org/hbpneurorobotics/VirtualCoach	
Technical documentation URL	https://bbpteam.epfl.ch/documentation/hbp-nrp-virtual-coach-1.3.9	
Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/71/nav/1610	
Component Dissemination Material URL	Not available	

4.19 NRP Brain-Body Integrator (BIBI)

Field Name	Field Content	Additional Information
ID	838	
Component Type	Software	
Contact	GUYOT, Luc	
Component Description	The NRP Brain-Body Integrator, a.k.a. BIBI, is the framework which allows neuro-scientists to connect brain models to sensors and actuators of robot models within the NRP platform. The communication between the brain and the body is implemented by means of the so-called "transfer functions" which read and write data via ROS topics.	
Latest Release	24 – Release of BIBI 2.0	
TRL	TRL 6	
Location	Online	Bitbucket
Format	Software, Python (back-end) and JavaScript (front-end) applications	
Curation Status	Not Applicable	

Validation - QC	Pass	Agile Quality Assurance, Axel von Arnim
Validation – Users	Yes	Internal users
Validation – Publications	Yes	
Privacy Constraints	No privacy constraints	
Sharing	Anonymous	
License	GPLv2/GPLv3	
Component Access URL	https://bitbucket.org/hbpneurorobotics/CLE https://bitbucket.org/hbpneurorobotics/brainsimulation https://bitbucket.org/hbpneurorobotics/brainvisualizer	
Technical documentation URL		
Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/71/nav/1610	
Component Dissemination Material URL	Not available	

4.20 NRP Web Cockpit

Field Name	Field Content	Additional Information
ID	841	
Component Type	Software	
Contact	GUYOT, Luc	
Component Description	The NRP Web cockpit, a.k.a. ExDFrontend, is the front-end of the NRP platform. This is where you can launch and watch a neurorobotics simulation. It is tightly integrated into the HBP Collab portal.	
Latest Release	24 – Release of BIBI 2.0	
TRL	TRL 6	
Location	Online	Bitbucket

Format	Software, JavaScript application	
Curation Status	Not Applicable	
Validation - QC	Pass	Agile Quality Assurance, Axel von Arnim
Validation – Users	Yes	Internal users
Validation – Publications	Yes	
Privacy Constraints	No privacy constraints	
Sharing	Anonymous	
License	GPLv2/GPLv3	
Component Access URL	https://bitbucket.org/hbpneurorobotics/exdfrontend	
Technical documentation URL	Not available	
Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/71/nav/1610	
Component Dissemination Material URL	Not available	

References

[1]Moraud EM, Capogrosso M, Formento E, Wenger N, DiGiovanna J, Courtine G, Micera S. Mechanisms underlying the neuromodulation of spinal circuits for correcting gait and balance deficits after spinal cord injury. *Neuron*. 2016;**89**:814-28. doi: 10.1016/j.neuron.2016.01.009