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Abstract:	This document describes how SP10 will organise its research, engineering and Platform operations during SGA1 and beyond. It defines criteria for selecting scientific Use Cases as well as the strategy for physical robots in SP10. The document then describes how daily work of researchers can be organised to provide requirements for the development and evolution of the HBP Neurorobotics Platform. The role of a Scientific Coordinator is established to organise a KANBAN-like agile process for the research in SP10. This role complements the Product Owner of the agile SCRUM process, used by the software development team. Regular consultations, meetings and product reviews ensure that features and properties needed by the scientific users are implemented quickly and with the required quality.
Keywords:	Neurorobotics, brain simulation, virtual robots and environments, agile software engineering, agile science processes

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SP10 Neurorobotics Platform – Implementation Plan

1. Notes on the first revision

This document is the revised version of the Human Brain Project (HBP) SP10 implementation plan for SGA1, originally submitted in M6. Due to the tight planning (SGA2) and reporting (D10.7.2 at M12) schedule in the first half of 2017, much of this revision was prepared after the M12 report (D10.7.2). Consequently, this report includes some material that was developed *after* M6. This applies particularly to the pilot experiments which have been defined by users of the Neurorobotics Platform (NRP) from within SP10 and from other Subprojects (SPs).

2. Overview

The SP10 NRP develops and operates a web-accessible simulation system for neurorobotics experiments in which brain models (data-driven or top-down) can be connected to realistic robot models that operate in sensory rich dynamic environments.

During the Ramp-Up Phase (RUP), SP10 bootstrapped the NRP by integrating a variety of tools and preparing them for use over the web.

During SGA1, SP10 will develop the NRP into a reliable research infrastructure that supports both simulated and physical robots. The development and operation of the NRP will be driven by Platform users from within the SP (WPs 10.1-10.4), from the cross-cutting Co-Design Projects (CDPs 1, 4, and 5), as well as other researchers inside and outside the HBP.

SP10 therefore engages in three overlapping areas of activity: science, software development, and platform operation. This document describes how these activities are integrated and how they contribute to the goals and objectives of SP10 and the HBP. Figure 1 below illustrates how the different Work Packages (WPs) of SP10 integrate to support the goals of SP10 and the HBP as a whole. A comprehensive description of all WPs and Tasks is given in the last chapter of this report.

The following paragraphs give an executive summary of the different parts of the implementation plan. The subsequent sections elaborate the plan in detail. The material for this report was compiled in discussion with all SP members during the SP meetings in Munich (12 April 2016), Geneva (10-12 May 2016) and Pisa (17-18 October 2016). Material for this revision was compiled during the SP10 Performance Shows in January and May 2017, as well as from the Month 12 Deliverable D10.7.2.

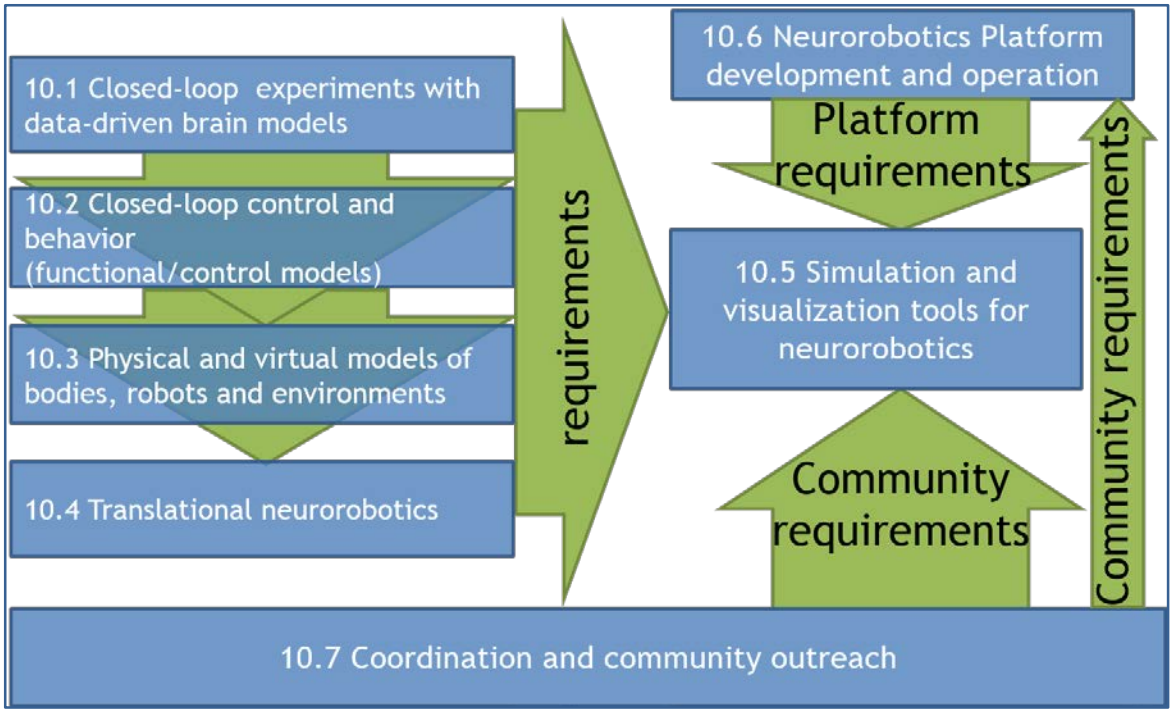

Figure 1: Diagram showing the relation between the WPs in SP10.

WPs 10.1-10.4 help to identify and define the requirements of the NRP developed in WP10.5. Additional requirements result from community requests (WP10.7) and operation and deployment (WP10.6).

2.1 Pilot experiments drive science and platform

Science and platform development in SP10 are driven by pilot-experiments, i.e. experiments which are prototypical for the type of research that the NRP should enable and support.

The most important set of Use Cases for SP10 are those where large-scale, data-driven brain models are investigated in the context of a closed sensory-motor loop. SP6 will, for the first time, allow researchers from all over the world to collaboratively investigate large-scale high-fidelity brain models. Similarly, SP10 will, for the first time, allow researchers from all over the world to collaboratively investigate such brain models under realistic stimulus-response conditions. A concrete Use Case is defined in CDP1, which aims to deliver a whole mouse brain model at the level of point neurons and the corresponding mouse brain atlas. The mouse brain model is then embedded into a virtual mouse body and investigated in a behavioural experiment related to stroke and post-stroke recovery. SP10 is committed to deliver an *in silico* model of the experiment setup along with the tools to formulate and execute the experiment in simulation.

In addition to those experiments, an extensive list of suggested candidates for pilot experiments has been gathered by the Science Coordinators and WP Leaders, which will be prioritised at the Performance Show / HBP Summit in Month 7. The list of candidate experiments is given in Appendix 3.

In parallel, SP10 is in contact with researchers from SPs 3, 4, 6, and 9 to help migrate legacy closed-loop experiments to the NRP or to help implement planned experiments. Concrete examples are the Shrewbot, developed in SP3, as well as the Myorobotics arm, controlled by a SpiNNaker board from SP9. Concrete instruments to inform and support existing and potential users in other SPs are NRP User Workshops and Install Parties, physical meetings where SP10 scientists and developers work together with the workshop participants to implement their Use Cases.

In addition, it must be noted that many groups in other SPs have legacy projects that need additional work to be migrated to the NRP. Particularly, the new SP3 has many interesting

neurorobotics projects, but was, by design, self-contained with no dependencies to other parts of HBP (the application rules did not allow prior connections to HBP). We tackled this challenge by reaching out to the relevant groups in other SPs to help them migrate their use-cases into the NRP.

As a result, several new pilot experiments, e.g. around the Shrewbot and Miro (SP3), have been added. The result of this effort is an extended list of pilot experiments which are described in Appendix 4. Moreover, concrete collaborative (cross-SP) tasks have been defined for SGA2. Science

SP10 has three scientific WPs. WP10.1 focuses on neurorobotics experiments with data-driven brain models, such as the whole mouse brain scaffold model developed in SP6/CDP1. WP10.2 investigates neurorobotics experiments with functional brain models, i.e. brain models where processing principles and algorithms are tested in a closed action-perception loop. Many of the models developed in SP3 also fall into this category. SP10 is now in close contact with SP3 to integrate their models into the NRP. Finally, WP10.4 investigates how principles of neurorobotic systems can be transferred to technical applications outside the NRP. These applications use physical robots (rigid or soft-bodies) controlled by abstracted brain models, running on neuromorphic hardware. This WP is therefore the link between neurorobotics and the adjacent fields of mobile robotics, embedded systems, and neuroprosthetics.

Table 1: Relation between SP10 WPs and the different SPs and CDPs.

WP No.	WP Name	SP10 FPA Operational Objective(s)	Contributes to SP SGA1 Objective(s)	Contributes to CDP(s)	Inputs from	Outputs to
WP10.1	Closed-loop experiments (data-driven brain models)	10.1: *In silico* models of behaviour, cognition and motor control	10a Initial version of Neurorobotics Platform 10c Pilot experiments using Platform capabilities	CDP1, CDP4, CDP5	SP1, SP2, SP3, SP4, SP5, SP6	SP4, SP6, SP9
WP10.2	Closed-loop experiments (functional/control models)	10.1: *In silico* models of behaviour, cognition and motor control	10a Initial version of Neurorobotics Platform 10c Pilot experiments using Platform capabilities	CDP4, CDP5	SP1, SP2, SP3, SP4, SP5, SP6	SP4, SP6, SP9
WP10.3	Components of closed loop experiments	10.2: *In silico* models of bodies, robots and environments 10.6 Community outreach	10a Initial version of Neurorobotics Platform 10b Capabilities to design virtual robots, environments and experiments and to link them to existing brain simulations	CDP1, CDP4, CDP5	SP3, SP4, SP9	SP3
WP10.4	Translational Neurorobotics	10.3 Future robotics technology	10b Capabilities to design virtual robots, environments and experiments and to link them to existing brain simulations 10c Pilot experiments using Platform capabilities	CDP5	SP4, SP6, SP9	SP3, SP6, SP9
WP10.5	Simulation and visualization tools for neurorobotics	10.4 Simulation and visualisation tools for neurorobotics 10.6 Community outreach	10a Initial version of Neurorobotics Platform 10c Pilot experiments using Platform capabilities 10a, 10b	CDP1, CDP4, CDP5	SP5, SP6, SP7, SP9	SP3, SP4, SP9
WP10.6	Neurorobotics Platform	10.5: Neurorobotics Platform 10.6 Community outreach	10a Initial version of Neurorobotics Platform 10b Capabilities to design virtual robots, environments and experiments and to link them to existing brain simulations 10c Pilot experiments using Platform capabilities	CDP1, CDP4, CDP5	SP1-10	SP1-10
WP10.7	Coordination	10.6 Community outreach	10a Initial version of Neurorobotics Platform 10c Pilot experiments using Platform capabilities	CDP1, CDP4	SP11, SP12	SP11, SP12

2.2 Strategy for physical and simulated robotics

During the RUP, SP10 started working with physical robots alongside simulated robots. Most notable were experiments with FZI's hexapod "Lauron" and TUM's Myorobotics robots. However, these experiments were not part of any SP10 Milestone or Deliverable.

In SGA1, SP10 will strengthen its support for physical robotics. This is done in two ways. First, physical robots become part of the neurorobotics pilot experiments, developed in WPs 10.1 to 10.3. Secondly, we introduce a new WP that aims to translate brain-derived control principles into (physical) robotics applications, also using SP9's neuromorphic hardware (WP10.4).

Finally, the NRP will develop and publish benchmark experiments to compare particular robots (physical) with their model implementation. This work is done in Tasks 10.3.3 and 10.3.4.

Robotics is a vast research field in its own right. SP10 must therefore be strategic with respect to the physical robot models it selects for research. The following five principles define the strategy for physical robotics in SP10:

1) Provide body models that help to investigate the development of cognitive functions (embodied intelligence). These models should be available in simulation and in reality.
2) Provide body models that help to understand how neural circuits control bio-mimetic motor systems, such as muscle-tendon based robots or soft-robots.
3) Provide body models that help to investigate the interplay of bio-mimetic sensors (for vision, touch, hearing, etc.) and its embodiment. To this end, SP10 works with neuromorphic sensory systems such as silicon retinas (DVS) and comparable systems.
4) Provide platforms to test neuromorphic hardware from SP9 in closed-loop neurorobotics experiments
5) Actively calibrate NRP virtual robot models against their physical references.

Details of the activities in physical robotics planned in SGA1 are described below.

2.3 Software development

WP10.5 is dedicated to developing the software tools for the NRP. The NRP integrates existing simulators for large-scale brain models and for robot/environment models into a web-application that can be run locally or on high-performance computing systems. In addition, the tools developed in WP10.5 include editor components that support the neurorobotics modelling workflow.

Software development in SP10 follows a stringent development, review and testing policy with clearly defined roles and responsibilities.

WP10.5 prepares and distributes installable packages of the NRP that can be downloaded from a public website such as github or dockerhub.

2.4 Software selection

During the second Periodic Review, the reviewers suggested that GAZEBO may not be the best choice for the world simulation engine. As many of the reviewers were new, we would like to use this opportunity to summarise again how the different foundation tools of the NRP were selected.

During the RUP, SP10 did an extensive comparison of the different available software components for neural simulation, world simulation (robot+environment), and visualisation and rendering. Each candidate tool was evaluated under different criteria, such as performance, interoperability with other tools, availability and community support.

For the neural simulation software, NEST (with PyNN) was an obvious choice as it is one of the core simulation engines in the HBP. For the world simulation engine, a large number of different tools were evaluated, including (semi-)commercial simulators such as Webots and VRep, 3D modelling tools with game engines such as Blender/MORSE, open source simulators for robotics such as GAZEBO, and bio-medical simulators such as OpenSim.

The final selection had to be a compromise somewhere on the Pareto-front (https://en.wikipedia.org/wiki/Pareto_efficiency) of the high-dimensional optimisation space. We selected GAZEBO for various reasons. The most important being: 1. GAZEBO is well integrated with ROS the *de facto* standard robot middleware. 2. GAZEBO provides a large number of robot models that are immediately available to the HBP. 3. GAZEBO has a

client-server architecture that allows us to run the simulation engine on a back-end server and the visualization on the user side. 4. GAZEBO has a very large and active user and developer community. Finally, GAZEBO supports different physics engines natively. This gives us the possibility to integrate OpenSim for neuromuscular simulations with very little extra work.

Choosing GAZEBO then almost forced us to use ROS as the middleware that connects world simulation, brain simulation, potential physical robots and user-interface devices. We mention this here, because there would of course have been a European alternative to ROS (YARP) which we could therefore not consider.

2.5 Platform operation

WP10.6 is responsible for deployment of the NRP software stack on HBP computing infrastructure. At the end of the RUP, the NRP was deployed on EPFL servers located in Geneva and Lugano. During the first half of SGA1, the NRP will mainly run on the CSCS based *Piz Daint* supercomputer.

Deployment of the NRP software stack has become increasingly difficult, due to incompatibilities of software installations on the development systems and the production servers (SP10 has no control over the foundation software on the production system and cannot anticipate version changes which may break the NRP software stack). To improve the speed of deployment as well as the robustness of the NRP installation, SP10, together with SP7, is prototyping the use of Docker on HPC infrastructures. The prototype is well advanced and once this system is operational, we will see a great improvement in the deployment and stability of the Platform.

2.6 Neurorobotics community outreach

The success of the HBP NRP depends on how well it is accepted by its research community, reaching from neuroscience to robotics. Therefore, WP10.7 “Scientific coordination and community outreach” puts a lot of emphasis on building active developer and user communities around the NRP Software and Infrastructure. A large user base will validate the usefulness of the NRP as a research tool. Turning users into developers will extend our resources, binds users to the NRP and at the same time ensures that the NRP will also in the future evolve in the right direction. This strategy is reflected in several Tasks and WPs: WP10.3 works with the community to build up and maintain a community library of models for robots, sensors and environments. WP10.5 develops the neurorobotics simulation and visualisation tools in close interaction with the communities of the respective foundation tools as well as with internal (WPs 10.1 and 10.2) and external users (CDPs 1,4, and 5). Making the software available to the scientific community on open source is also part of SP10’s user and community engagement strategy.

While SP10 included many new Partners in the FPA, not all partners could be given an active role in SGA1. SP10 is, however, committed to these Partners and wants them to play a role in the SP10 community. SP10 has therefore dedicated sufficient travel funds (T10.7.4) to allow all Partners to visit all SP10 meetings as well as the HBP Summits.

2.7 SP10 integration and coordination

The different fields of activities in SP10 are coordinated by WP10.7. The new and interesting challenge is to direct the newly established scientific activities and synchronise them with the engineering activities around the NRP. In short, scientists and engineers each use an agile process. The scientists use a Kanban-like process to deliver requirements for the engineering team and to evaluate the Platform releases. A *Scientific Coordinator* ensures that this process is properly implemented – in fact, SP10 has elected two Scientific Coordinators, one representing neuroscience and one representing robotics. The engineers use SCRUM to implement the requirements and features requested by the scientists and to

deliver regular releases of the NRP. The SCRUM team is coordinated by the *Product Owner* and the *SCRUM Master*. The Scientific Coordinators work closely with the SCRUM Master and the Product Owner to guide the development of the NRP software. The roles and responsibilities are defined in more detail in section "Software development: terms and roles". The list of people currently filling these positions are given in Appendix 2.

3. Implementation of the Neurorobotics Platform

3.1 Goals for SGA1

In SGA1, SP10 will further extend the NRP to be a reliable research infrastructure that supports both simulated as well as physical robots. As mentioned above, the development of the NRP will be driven by the Platform users. These users come mainly from within the SP (WPs 10.1-10.4), but also from the CDPs (1, 4, and 5), as well as from Collaboratory users.

The main goal of SP10 is to develop the Platform, based on the specifications and core development of the first version of the NRP during the RUP. To achieve this, we relied on agile programming methods, which are well suited for the development process. Based on our very positive experiences with this form of development, we will continue its application during the SGA1 period.

SGA1 includes new research Partners who will not directly participate in the development of the NRP. Instead, they play the role of Platform users. Their main responsibility is the development of pilot experiments that will help to identify useful novel features and necessary requirements. That way, the capabilities of the Platform will increase and cover all main requirements of scientists, and directly prove its validity as a research infrastructure. The main objective of all research conducted in SP10 is therefore to fuel the development of the NRP, aside from fostering new advances in neurorobotics and neuroscience.

At the end of SGA1, the Platform will have become a valuable research infrastructure that covers most possible needs of researchers in the fields of neuroscience, as well as traditional robotics and neurorobotics. Our new organisation reflects the separation of software development and scientific research to efficiently pursue this goal.

3.2 Task dependencies, risks, and mitigation strategies

The design, development and operation of a cloud infrastructure for neurorobotics is a complex scientific, technological, and operational endeavour that carries many inherent risks. The most obvious risks are:

1) Working in silos: the different groups work independently, rather than collaborating on the SP goals.
2) Platform features not available in time: features of the NRP not available when the scientists need them.
3) Science that does not contribute to Platform development: the scientific groups focus on the science only and neglect their role of co-designing Platform features.
4) Problems during Platform operation: any problem that disturbs the 24/7 operation of the NRP.

Risk 1 is organisational. We have therefore tried to choose an organisational structure that integrates groups, and is able to detect problems early and adapt itself to the evolving problem landscape.

As outlined in the following sections, the science and development parts of SP10 are each using an Agile[1] process. The science team uses a process called Kanban[2], while the software development uses a process called Scrum[3]. At the core of both methodologies is the idea of "inspection and adaptation"[4], that is, the processes are designed to be self-optimising according to the ever-changing requirements of the products to be developed and the environment in which these products are developed.

The organisational structure of SP10, outlined in the following sections, explains how SP10 is organising collaborative research on the *pilot experiments* and development on the NRP, and how these two processes are synchronised with each other.

Risk 2 originates from the different speeds of research and software development. For research, features must be available at the same time when their need becomes apparent. Implementing these features into a production system, however, may take weeks or months. Thus, by the time a new feature is available in the production system, it may no longer be needed by the researcher who requested it. Usually, the researcher will have found an alternative solution instead of waiting for the new feature to be delivered.

We solved this apparent conundrum by realising firstly that the "alternative solution" may actually be the best specification of the desired Platform feature and secondly that the production system - the NRP - has many other users, for which the new feature will be delivered on time. Thus, we therefore encourage our research team members to provide working prototypes to the development team which then serve as reference implementation of a new set of features.

Risk 3 is mostly a consequence of risks 1 and 2 and can be mitigated by proper management of these core risks.

Risk 4 is complex due to the many factors that are beyond our control, such as the production environment on which the Platform will be employed. We try to mitigate this risk by a) providing on-site installation as an alternative to the cloud version of the Platform, b) slowly scaling up the type and number of users that are admitted to the Platform, and c) by regularly assessing the current situation and quality of service of the NRP.

3.3 Organisational structure

The members of SP10 are organised into two groups with different goals: a) a Development Team and, b) Scientists, who work in close collaboration, but their operating principles differ significantly. Therefore, each team will apply different methods and their releases are synchronised at regular intervals. Figure 2 shows the basic organizational structure including the roles of stakeholders which will be defined below. The synchronization of the release cycles for the science and development teams are described in more detail in section "Development and Research Workflow".

[1] https://en.wikipedia.org/wiki/Agile_software_development
[2] https://en.wikipedia.org/wiki/Kanban_(development)
[3] https://en.wikipedia.org/wiki/Scrum_(software_development)
[4] see e.g. http://www.scaledagileframework.com/inspect-and-adapt/

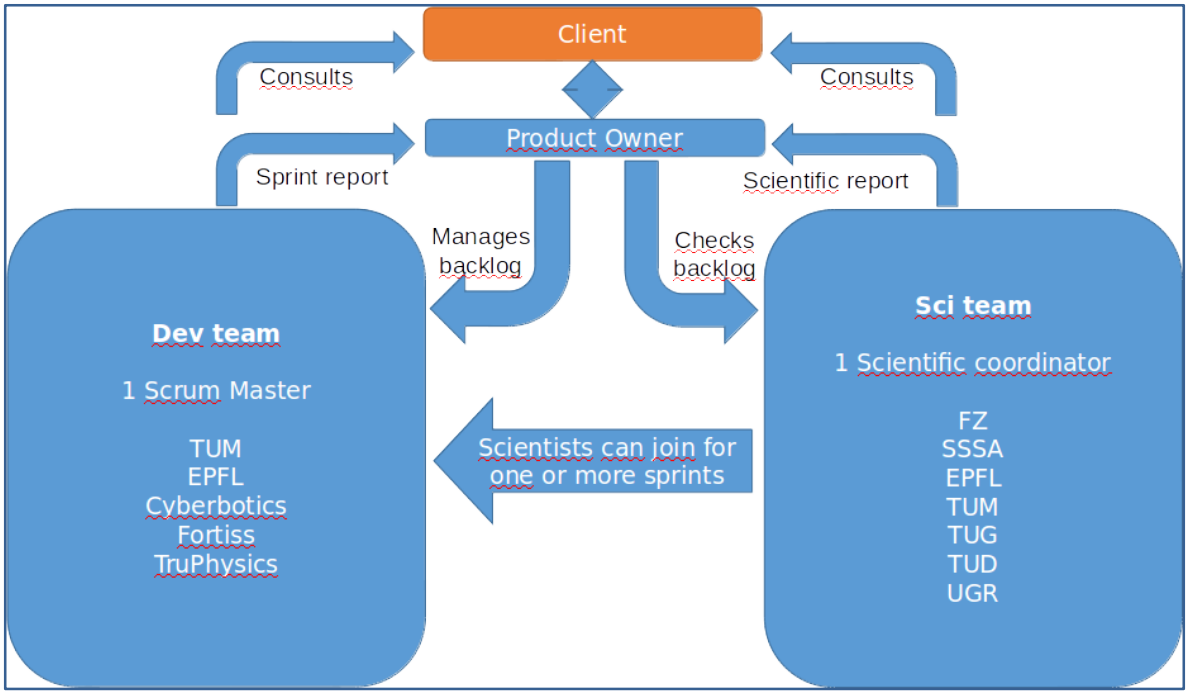

Figure 2: Organization of the Development Team and Scientists in SP10.

Scientists contribute to the Platform development by creating and conducting pilot experiments. As users of the Platform, they play a crucial role in identifying novel, useful features and defining the requirements of the Platform. This figure applies the terminology of SCRUM-based development, which is introduced in the text.

3.4 Software development: Terms and roles

The software development of the NRP as a research infrastructure adheres to SCRUM, an agile software development method based on iterative development cycles, a dynamic task, and flexible team organisation.

In this section, we introduce the most significant terms and how they map onto the development process of the NRP.

- Sprint:

  Sprint refers to the development cycles of the NRP. Each sprint lasts 3 weeks. They start and end with planning and review meetings. During these 3 weeks, a developer chooses tasks from the backlog which is prioritised by the Project Owner.

- Backlog:

  The backlog is a list of tasks ordered by priority and maintained by the Product Owner. A task can be the implementation of additional functionality or the investigation and resolution of bugs encountered by either the developers or the users.

- Client:

  In SCRUM terms, the Client defines the overall strategy of the product (i.e. the NRP). They are responsible for taking strategic decisions that influence the priorities of the functionality of the NRP. In SP10, this role is represented by the two SP Leaders. They also act as top-level consultants for the whole SP.

- Product Owner:

  The Product Owner maintains the Backlog, i.e. sets priorities to software features requested by the Client. In our case, the Product Owner defines these priorities based on a core development roadmap and additional requirements identified by the scientists. Therefore, this role is responsible for keeping research and development in sync. This is

done by reviewing reports from Scientific Coordinator, (see next section) in a 3-week cycle.

- Developers:

  Developers are committed to developing the Platform by implementing tasks from the backlog.

The current list of people fulfilling these roles is given in Appendix 2. A more comprehensive definition of SCRUM and its roles and responsibilities can be found in *Ken Schwaber's and Jeff Sutherland's* "The Scrum Guide" (PDF).

3.5 Scientific coordination: Terms and roles

Research conducted in SP10 aims to design and conduct pilot experiments that drive the development of the NRP as a research infrastructure. Scientists will be the first users of the Platform and their work will be substantial to identifying the functionality required to perform their experiments and reveal possible problems at already early development stages. Therefore, all research efforts have to be coordinated not only among the scientists but also tightly coupled to the development process.

In addition to those defined by the SCRUM process presented in the last section, additional roles are defined in SGA1, which reflect the aforementioned aspects.

- **Scientists:**

  In contrast to the RUP, there will be pure scientists in SGA1 who are not directly involved in the active software development. Their primary goal is to identify limitations of the NRP by designing and performing strategic pilot experiments that are representative for their respective research areas. They are therefore committed to include the NRP as their main research infrastructure. However, it is possible for them to act as developers during individual sprints to accelerate the development of required features. Scientists dedicated to research only will have an assigned liaison developer (see below) providing first-level support. Ideally, scientists should not have access to or require the source code of the NRP.

- **Liaison developers:**

  These are (regular) developers who are the assigned contact person to a single researcher. Apart from the development, they are expected to gain the researcher's perspective and support his feature requests.

- **Work Package Leaders:**

  Are responsible for their respective WPs. This includes the supervision of Milestones, Deliverables and reporting to the European Commission. In SGA1, the WPs and their exact implementation are of higher importance than during the RUP. WP Leaders are supposed to have detailed knowledge about development and/or research in their respective WP and the involved Partners' sites.

- **Science Coordinator(s):**

  The science coordination team will be elected by the SP and WPs during each release cycle. The team's role is to coordinate the research of all Partners and ensure that Milestones are reached, Deliverables are met and that research fuels the development of the NRP. In that sense, the Science Coordinators are the analogue of the Product Owner for research. In close collaboration with the Product Owner, the team is responsible for defining the main development and research. Another important responsibility is the reporting to the Product Owner, SP and WP Leaders. This role yields a lot of responsibility, therefore, and requires an excellent overview over the Platform.

To simplify the coordination, the science coordination team relies on tools typically used in Kanban (another industry-approved agile development process) without adapting it. Furthermore, the newly introduced Project-Lifecycle App (PLA) has proved to be a valuable tool to identify common goals and collaborations with other SPs.

Implementation of these tools

Based on the success of the development team, similar methods are used for the scientists. Every 3 weeks a scientific report is written, similar to the development reports. These reports contain tables from the Kanban board during this reporting period as well as freely written text to make them easier to read to document the bigger picture of the labs' ongoing projects. This text is obtained during regular meetings with scientists. That way, all the labs are always synchronised and an efficient cooperation can be guaranteed.

3.6 Development and Research Workflow

3.6.1 Release cycles

As shown in Figure 3, development and research operate in different low-level cycles but synchronise on every platform release. Software releases are scheduled in 6-month cycles. Scientists and developers participate in a common planning meeting at the beginning of a release cycle where they define scientific and development objectives.

The role of the Scientists foresees, shortly after each release, to evaluate the state of the platform and propose novel features for the next development cycle. Software releases should coincide with the general performance shows which occur four times a year with all WP Leaders, developers and scientists involved (i.e. similar to the Platform release event).

3.6.2 Performance Shows

The members of SP10 – scientists, developers, WP and SP Leaders - meet on a regular basis to review the progress of the NRP development and research conducted in SP10. These meetings, called "Performance Shows", occur every three months and are hosted by the SP10 Partners.

The software releases of the NRP coincide with these meetings. The Platform releases occur shortly before such that the state of the pilot experiments representing the scientific progress can be demonstrated to the consortium.

In addition, at each performance show workshops for developers and scientists occur to foster the communication between SP10's Partners.

3.6.3 Science and Development Objectives

Scientific objectives are defined in terms of pilot experiments and intermediate goals. Both should be demonstrable on the Platform at the end of the release cycle.

Development objectives, on the other hand, are both defined by the development team itself (according to the specifications roadmap) and derived from requirements by the scientists.

At the end of a release cycle, the Scientific Coordinator ensures scientific objectives are met, the Release Manager releases the new version of the Platform and the new pilot experiments can be demonstrated in the next performance show. A new release cycle is then initiated with a collective planning meeting as described above.

3.6.4 Development cycles

Research is not constrained to a release cycle. The scientific coordinators report every third week to the Product Owner to make sure the progress in research and development is not diverging.

In the development, the Scrum process imposes iterative cycles (sprints) of 3 weeks, each starting with a planning and ending with a review including the developers.

In addition, a frequent interaction between the scientists and the liaison developers occurs to ensure continuous progress.

The overall workflow and procedure for the release cycle is depicted in Figure 3.

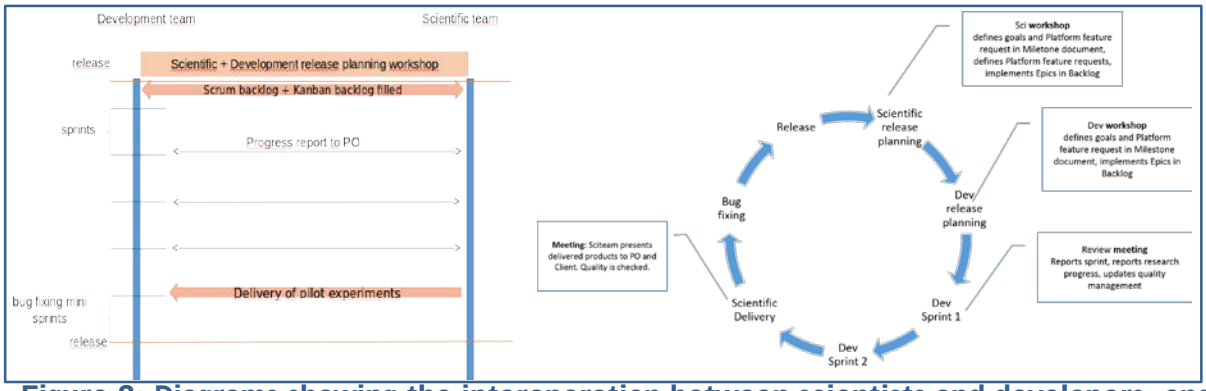

Figure 3: Diagrams showing the interoperation between scientists and developers, and the release cycle of the NRP.

3.6.5 Reporting and Planning of the next operational phase (SGA2)

On the project time scale, that is, the whole two years, the science coordinator monitors the progress of the project with respect to Milestones and Deliverables and, together with the Product Owner, SP and WP Leaders, develops the roadmap for the next operational phase (i.e. SGA2). The responsibility for reporting the monitored progress lies with the Science Coordinator while WP Leaders are responsible for reporting to the European Commission on time.

The planning for the second operational phase (SGA2) will commence at the yearly HBP Summit and continue on the Performance around Month 9.

3.7 Platform roadmap

In SGA1, the development roadmap remains filled with requirements from the specifications and the Client. It is completed with the requirements identified by the Pilot Experiments. The objectives are prioritised according to user needs and feedback and should help the first Pilot Experiments to get integrated into the Platform. As soon as the definition of Pilot Experiments leads to additional requirements for the Platform, these will be integrated into the roadmap thanks to the dynamic nature of Scrum's backlog and process.

The roadmap for SGA1 is of course less precise for the last release and leaves space for user requirements and roadmap delays.

Release 1.1 (M6):

- Better server discovery
- Rendering improvements
- User definable graphical settings
- UI improvements
- User debugging tools
- New template experiments

Release 1.2 (M12):

- Support for bigger brain models

- Graphical transfer functions editor
- Basic brain visualisation
- Python API for batch simulations (Virtual Coach)
- Object scaling
- New template experiments
- Camera Streaming
- Object Scaling
- Environment Enhancements

Internal milestone 1.2.1 (M15):

- Four pilot experiments (see the Pilot Experiments section for details)
- CDP1 experiment MVP (see the Pilot Experiments section for details)
- Basic user showcase experiments: dedicated servers for basic users (on amazon) continuously running simulations

Release 1.3 (M18):

- New pilot experiments (see the Pilot Experiments section for details)
- CDP1 experiment V1 (see the Pilot Experiments section for details)
- New virtual lab: full model available + collection of subparts accessible from the Environment Designer
- Bigger brains support (enhanced from Release 1.2), with use of MUSIC
- Migration of backend servers to SP7's Piz Daint in Lugano
- Replay of recorded simulations
- New interface design
- Full collab features on a local installation

Release 2.0 (M24):

- Pilot experiments in final version (see the Pilot Experiments section for details)
- CDP1 experiment V2 (see the Pilot Experiments section for details)
- Backend server on SP7's Jülich cluster
- Distribute simulation over a cluster (Virtual Coach)
- Other neural simulator support (Nengo)

3.8 Platform deployment and operation

Platform deployment will change a lot in SGA1. This section describes the deployment process as of the date of this document and the plan for SGA1. The new deployment scheme will allow migration to bigger resources from HBP.

3.8.1 Current deployment scheme

Development and deployment are interleaved by the toolchain we use. We use an industry-level process as described in Figure 4 below.

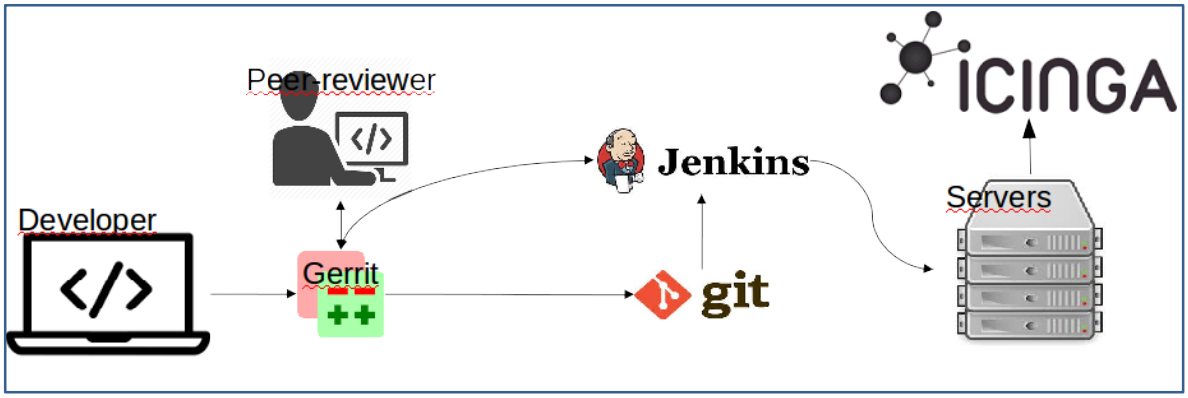

Figure 4: Industry-level process for deployment

Each developer atomic change is committed to Gerrit, which is a code-reviewing facility for Git. Every code change triggers a build on Jenkins and only if the build is green, the change can be merged to the repository. Changes are peer reviewed, validated by code reviewers, and finally merged to the master branch in Git. On demand, Jenkins triggers deployment on the servers. Icinga is a monitoring facility that logs runtime errors and failures on deployed servers.

We have two levels of deployment: development and staging (= production). For each level we provide separate servers: 6 for development and 20 for production (see Figure 5 below). These servers are situated both in Geneva and Lugano (CSCS BBP resources).

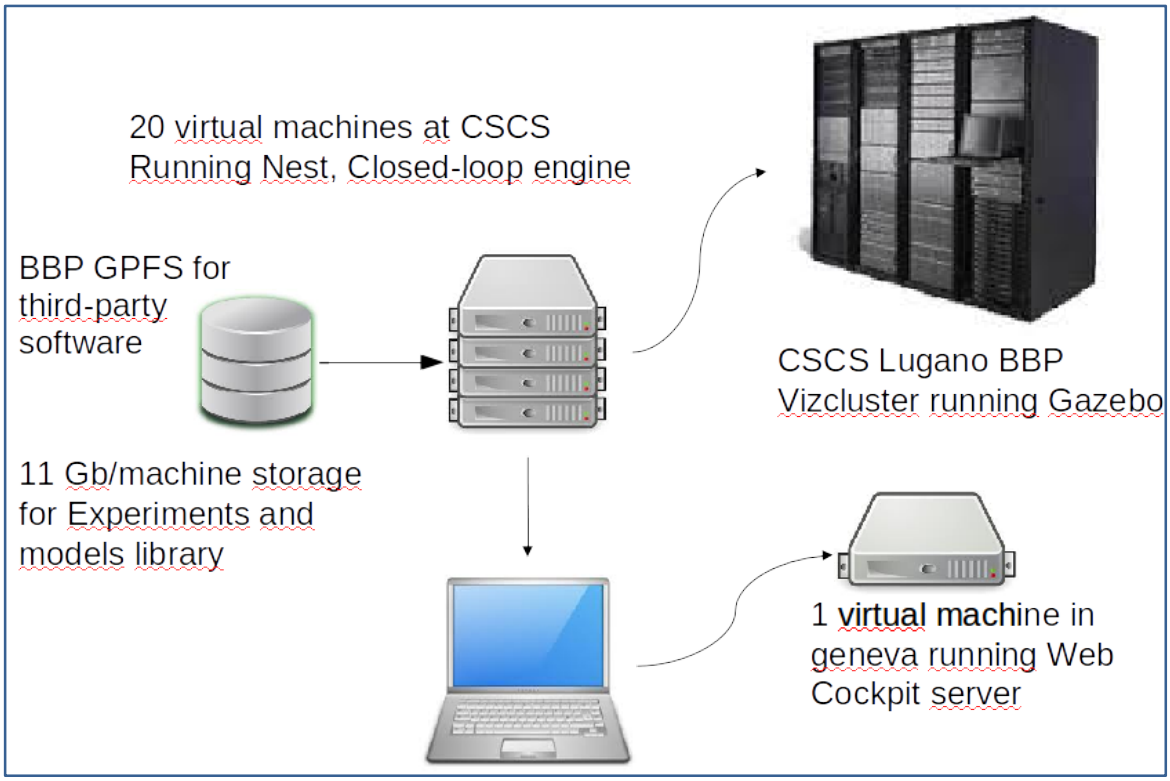

Figure 5: Servers for deployment and production

Dev deployments are for internal testing needs and are frequent (at least once per week). Production deployments are more scarce but happen at least at release time.

The current deployment process involves Jenkins as the build server. It generates software packages on specific package servers at EPFL (RPMS, Python packages, NPM package, modules) that are installed either by Jenkins or by puppet recipes on the deployed servers. The process is the same for dev and production deployments, only the puppet recipes are different. All servers run RedHat Enterprise Linux 6.

This deployment process is very systematic but has many drawbacks:

- Puppet recipes are difficult to maintain, because they rely on parent recipes that are subject to changes.
- The deployment servers have a very different system than the one developers work on (RHEL 6 vs. Ubuntu 14.04 LTS), so there is always a porting effort to synchronise libraries and dependencies.
- As the project gets more and more complex, dependencies are harder to maintain both on servers and on Jenkins, and the build process takes a long time on Jenkins. A single deployment usually takes a full day.

For these reasons we plan to move to a different deployment scheme described hereafter.

3.8.2 SGA1 deployment scheme

We are working on a completely different deployment scheme that should fix the problems reported in the first section. We plan to use Docker as a deployment tool, instead of Jenkins and package servers. Docker creates very lightweight "nearly-VMs", called containers. They build on top of the host operating system (OS), instead of having their own OS, and they can be assembled from building blocks, namely already existing containers. In our case, our container for Gazebo would base on the available ROS container and we would only have to configure our Gazebo-specific material. Note that the development process would be left unchanged and would still use Gerrit, Git and Jenkins. Docker will be used only for deployment.

The process is as follows: The responsible person builds Docker container images on their local up-to-date developer installation, running so-called Dockerfiles that automate completely the process. The NRP is built from source locally in the Docker images running Ubuntu 14.04 LTS, as the developer machines do. The images are then tagged as dev or staging (= production), depending on the destination. The images are uploaded to Dockerhub, a publicly available Docker online repository. Finally, images are downloaded and installed on deployed servers either by hand or by a scheduler (preferred). Deployed servers run a more recent Redhat Enterprise Linux 7 and have a very minimal puppet configuration to enable smooth running of the Docker containers, but the NRP runs inside the Docker containers under Ubuntu 14.04 LTS.

A possibility offered by this deployment scheme is also to use servers and clusters from the High Performance Analytics and Computing (HPAC) Platform (SP7) in Lugano (Piz Daint), which will support Docker containers.

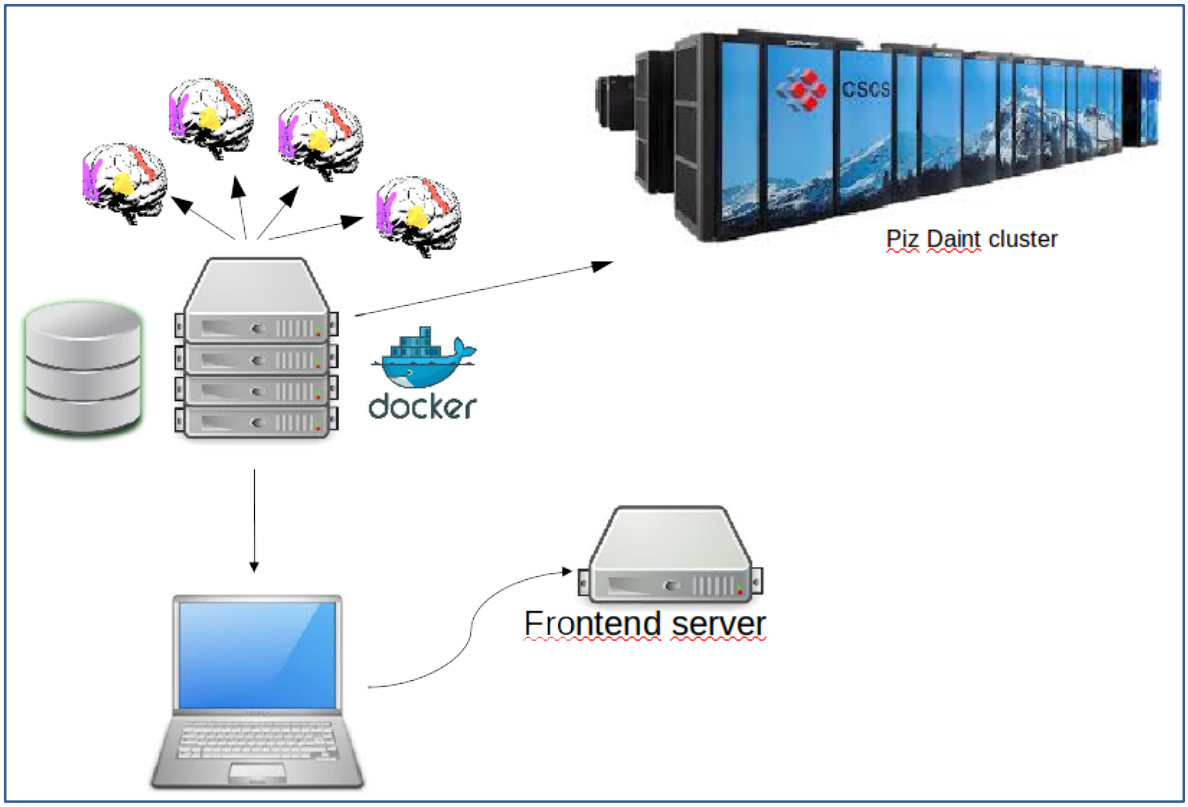

Figure 6: The new deployment scheme in SGA1

The advantages of this new deployment scheme are:

- Developers and servers share the same Ubuntu distribution, vastly simplifying dependencies maintenance
- Deployment build no longer happens on Jenkins, but on fast developer machines
- The person in charge can be any assigned developer, because the build no longer depends on restricted EPFL resources
- Docker containers contain everything they need (no more complex dependency installations)
- Docker containers can run on HPC resources
- In the future: Docker containers can be spawned automatically when needed, which allows flexible scalability
- Docker containers can run as well on deployed servers as on user machines, making user local installation easy

3.8.3 Risk analysis

The introduction of a new deployment strategy involves a lot of work and can be considered risky. But the following issues make this step unavoidable:

- As mentioned before, the current deployment strategies are reaching their limits in terms of maintainability
- The cost of developing the Docker-based deployment will be covered by the effort benefit of abandoning the costly Jenkins-based deployment
- Docker packaging is a mandatory requirement to deploy on SP7 clusters

3.8.4 Local installation and open source dissemination

On top of online deployment as described above, the Platform will be available for download and installation on users' local computers. We have a Bitbucket account (https://bitbucket.org/hbpneurorobotics/neurorobotics-platform), where the whole source code is available and updated frequently. A step-by-step installation guide will ensure that users can install the Platform flawlessly.

Moreover, to speed up the adoption of the Platform, we will organise install parties and user workshops, where the users have a chance to be accompanied in their Platform installation and first use.

3.8.5 Management

We try, as a Scrum team, to distribute the deployment and operation knowledge as much as possible within developers, but of course, there are people who have the final responsibility for them. For online deployment (former Jenkins, now Docker), the manager is Luc GUYOT (EPFL Gewaltig). For the locally installable open-source version, the preferred contact is Axel VON ARNIM (FORTISS).

4. Work Packages

4.1 WP10.1 Closed-Loop Experiments with Data-Driven Brain Models

This WP contains the majority of SP10's contribution towards CDP1. The main goals of CDP1 are to develop a whole mouse brain model at the point neuron level and the corresponding mouse brain atlas. These two goals are substantiated by using them in an *in silico* neuroscience experiment[5] in in the NRP.

For the end of the SGA1 period, we plan to replicate the mechanics (the protocol) of this experiment in the NRP. In other words, scientists should be able to experiment with a virtual mouse (and its virtual brain) inside a virtual experiment setup, use the same stimuli as in the original experiment and record the same quantities as in the original experiment. The physical reference setup of this experiment was developed at LENS and SSSA in Florence and Pisa, respectively[5]. A second use-case for the virtual mouse model is locomotion on a treadmill, based on a spinal-cord injury model, developed at EPFL.

Particularly noteworthy is the role of WP10.1 as SP-internal co-design driver. During the first few months of SGA1, the scientists in WP10.1 developed prototypes of the models that contribute to the two pilot experiments (treadmill locomotion and the stroke-rehabilitation experiment). These prototypes are then used in close collaboration with the development team of WPs 10.5 and 10.6 to define new NRP requirements and to implement them along a roadmap with user-defined priorities.

4.1.1 Key Personnel

Letizia ALLEGRA (LENS), Gregoire COURTINE (EPFL), Egidio FALOTICO (SSSA), Marc-Oliver GEWALTIG (EPFL), Auke IJSPEERT (EPFL), Silvestro MICERA (SSSA/EPFL), Eduardo ROS (UGR), Patrick VAN DER SMAGT (FORTISS)

4.1.2 Milestones

[5] Spaletti C, Lai S, Mainardi M et al. A robotic system for quantitative assessment and poststroke training of forelimb reaction in mice. Neurorehabilitation and Neural Repair 2014;28(2):188–196.

Table 2: Milestones for WP10.1 Closed Loop Experiments with Data-driven Brain Models

MS No.	MS Name	Leader	Expected Month	Achieved Month	Comments
10.1.1	Implementation plan for WP10.1	EPFL	M02	M06	This document
10.1.2	Draft model of mouse brain (SP6) connected to a mouse body (SP10) and its musculo-skeletal system integrated and accessible in the NRP	EPFL	M12	M12	Closed loop spinal cord stimulation experiment with mouse hind limb musculo-skeletal model. Currently installed on NRP on a local machine. Will be soon integrated with web Platform.
10.1.4	Draft implementation of the motor-rehabilitation experiment	EPFL	M12	M12	The initial version of the motor-rehabilitation experiment has been integrated in the NRP. Currently installed on NRP on a local machine, it will soon be integrated with web Platform (see https://hbpneuroroboticsblog.wordpress.com/2017/05/17/the-virtual-m-platform/). The CAD model of the main components (i.e. linear actuator, linear slide, handle) of the mouse stroke rehabilitation platform (M-Platform), was converted into a suitable format for the Gazebo simulator. Physical properties of the models have been set up according to the real characteristics of the slide. The modelled components of the M-Platform have been included in a simulated experiment with a closed loop involving a spiking neural network. In addition to this, a biological model of proprioceptive sensory information, implementing a computational model of neural activity of sensory fibres connected to muscle spindles, has been designed and tested with a simulated mouse in the NRP.

4.1.3 T10.1.1 Locomotion and posture

This Task aims to reconstruct the control of posture and locomotion using the rodent model developed in T10.3.1 and T10.3.2, as well as the corticospinal integration from T10.1.3.

The overarching goal of this Task is to ensure the convergence of the computational models of spinal circuits, the descending motor control inputs from supraspinal structures, sensory models of proprioception and light touch and musculoskeletal models of the mouse hind limbs. The integration of these inputs will support simulations of standing and locomotion in the mouse (and potentially other species).

We will initiate this work with assisted walking on a treadmill. We will then extend the model to unassisted walking onto flat surfaces. The model will be constrained and validated using muscle activity (EMG) recordings and high-resolution motion-capture data. Using this information, we will achieve the following goals:

GOAL 1: Provide comprehensive dataset on the kinematics, EMG and kinetics underlying locomotion in mice (and other species).

GOAL 2: Perform closed-loop simulations using a neuro-biomechanical model of the mouse hind limbs through the computational platform.

4.1.4 T10.1.2 Sensory-motor integration

This Task develops technologies to map sensors and motors to selected parts of SP6 scaffold brain models to enable sensory control voluntary movements. In particular, sensors and motors will be selected to support the strategic Use Cases: proprioceptive, visual, inertial and tactile sensors will be included in the implemented sensory-motor maps together with a set of actuation mechanisms defined in T10.1.1.

The main goal of this Task 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, see T10.1.6). Investigations will be performed in order to exploit learning mechanisms for adapting the maps to body changes (i.e. growth or lesion) or interaction with the environment (i.e. tool use). A possible approach may involve developmental robotics to analyse the impact of body development on the formation of sensory motor maps. This Task contributes to the following Use Case of CDP1: CDP1-P4, A virtual lab app.

4.1.5 T10.1.3 Cortico-spinal integration

The objective of this Task is to connect the neurorobotic models to the brain simulation. An interface module will have to be devised that can interpret cortical signals.

This will be achieved in two steps.

The first step will implement a 5-neuron-per-muscle model in Python, based on previous work by Loeb et al (2010; 2014) and using the open-source Musculo-Skeletal Modelling Software (MSMS) model. This will be integrated with the NRP that is developed in WP10.5. The model will include features as self-stabilising against external forces and motor limits (limits force/load in muscles), and thus mimic spinal cord control, which is necessary as an interface between the NRP and the brain simulation.

As a primary example for this implementation, the currently available mouse model is targeted. We intend to adapt existing joint and motor models to biologically correct models, and include our spinal model for joint movement generation. The output of the mouse brain model will be fed into the spinal cord to induce movement.

Once the model is running, in the second step, it will be replaced by a deep learning-based neural network model, which can mimic and then generalise the behaviour of the spinal cord model. The neural network will be bootstrapped from our spinal model. In particular, this will be used to extend the spinal cord model to its application to general robotic systems.

4.1.6 T10.1.4 Cerebellar Motor Control

This Task will develop and integrate a biologically relevant model of cerebellar motor control in a manipulation task. The model will be used to test the functional role of cell/network/synaptic plasticity properties according to a bottom-up approach from models in SP6.

Description:

- Three incremental cerebellar models will be implemented on NEST simulator:
  - The first will include a data-driven model of the cerebellar connectivity accounting for the experimental evidence of neuron density, morphological details of the axons/dendrites extension and connectivity ratios but only static synapses (no learning rules).
  - The second will add plasticity at the synaptic sites between the parallel fibres and Purkinje cells. This plasticity mechanism will be driven (supervised learning rule) by the complex spikes occurring in the Purkinje cells.
  - The third (distributed learning) will be extended with plasticity at the deep cerebellar nuclei, including the connections between mossy fibres (cerebellar main input) and deep cerebellar nuclei cells and between Purkinje cells and deep cerebellar nuclei cells.
- These three models will be integrated in the NRP to control the movement of a robotic arm in manipulation tasks. The influence of the plasticity mechanisms in the performed task will be evaluated.

4.1.7 T10.1.5 Sensory-guided neuromotor control

This Task will implement the spiking model of CDP4 in a neurorobotic engine achieving biologically-inspired closed-loop motor control. This aim is a comprehensive visuomotor and somatosensory brain model of complex motor control. The sensorimotor modelling will, in collaboration with other SPs, be integrated with the development of algorithms for multi-modal guidance of robotic motor control with feed-forward and feedback loops.

4.1.8 T10.1.6 Simulation of motor rehabilitation experiment in rodents

This Task will define and replicate a robot-based rehabilitation scenario for rodents able to simulate real experiments performed with the M-Platform in the NRP. The M-Platform is a robotic device able to train mice to perform a retraction movement with their forelimbs (pulling experiment) and this experiment is the core use-case of the CDP1 in the SGA1.

4.2 WP10.2 Closed-Loop Experiments with Functional Models

This WP focuses on the development of a set of strategic top-down models of sensorimotor processing used to control virtual and physical body models. In particular, this WP aims to develop control models through a set of functional components that can be implemented by means of basic neural networks or classic control techniques and can be functionally replaced by data-driven brain models. The work is composed of three functional parts:

1) Models of visual perception (T10.1.2) including a cortical model for early visual processing;
2) Models of sensory-motor coordination using incremental functional models (T10.2.2) including models for the control of eye-head coordination in gaze stabilisation tasks;
3) Learning models of body representation (T10.2.3) including models of short-term visual prediction, learning body model and force control.

The final goal is to have a library of models (functional components) that can be selectable and usable in the NRP. These models will be integrated during the second year of SGA1 in

order to generate complex behaviours. All the developed models and implementations are innovative and lead to submissions of articles in journals or international conferences. This work will be carried out by collaboration among SP10 partners (i.e. the gaze stabilisation model developed in the framework of T10.2.2) or across SPs (i.e. neural model for short-term visual prediction implemented in the framework of T10.2.3).

4.2.1 Key Personnel

Rüdiger DILLMANN (FZI), Cecilia LASCI (SSSA), Michael HERZOG (EPFL), Egidio FALOTICO (SSSA), Stefan ULBRICH (FZI)

4.2.2 Milestones

Table 3: Milestones for WP10.2. Closed-Loop Experiments (Functional / Control Models)

MS No.	MS Name	Leader	Expected Month	Achieved Month	Comments
10.2.1	Implementation plan for WP10.2	SSSA	M02	M06	This document.
10.2.2	First version of the functional components library	SSSA	M12	M12	A first functional framework composed of functional models for brain mechanisms, perception mechanisms and robotic controllers has been defined. This framework allows users to design basic and complex functional behavioural models. We implemented some basic behavioural models using building blocks that have now been embedded in the framework. The behavioural models have been tested with simulated and real experiments, including visual perception, gaze stabilization, balancing, and grasping tasks. Further details on the experiments can be found in the last semester report. More details about the framework architecture and some examples and demos of the experiments are available on the HBP Neurorobotics blog https://hbpneurorobotics.wordpress.com/2017/05/05/functional-components-for-control-and-behavioural-models.

4.2.3 T10.2.1 Early sensory processing

T10.2.1 continues work on a cortical model for early visual processing that started during the RUP (Laminart model). The model is a multi-layered biologically plausible neural network that uses recurrent processing to segment a visual stimulus into several separated perceptual groups. The main goal of the Task is to integrate the model in the NRP as part of

a closed-loop simulation of perceptual-cognitive-motor systems. Once embedded in a virtual experiment, the model will project its output to higher cortical areas to generate a motor response, recurrently updating the visual stimulus. The model contains hundreds of thousands of neurons, and is (to date) the largest simulation in the NRP. It is a benchmark that the Platform can operate a model with such many neurons and simulate a complex cortical model and human performance in a closed loop fashion.

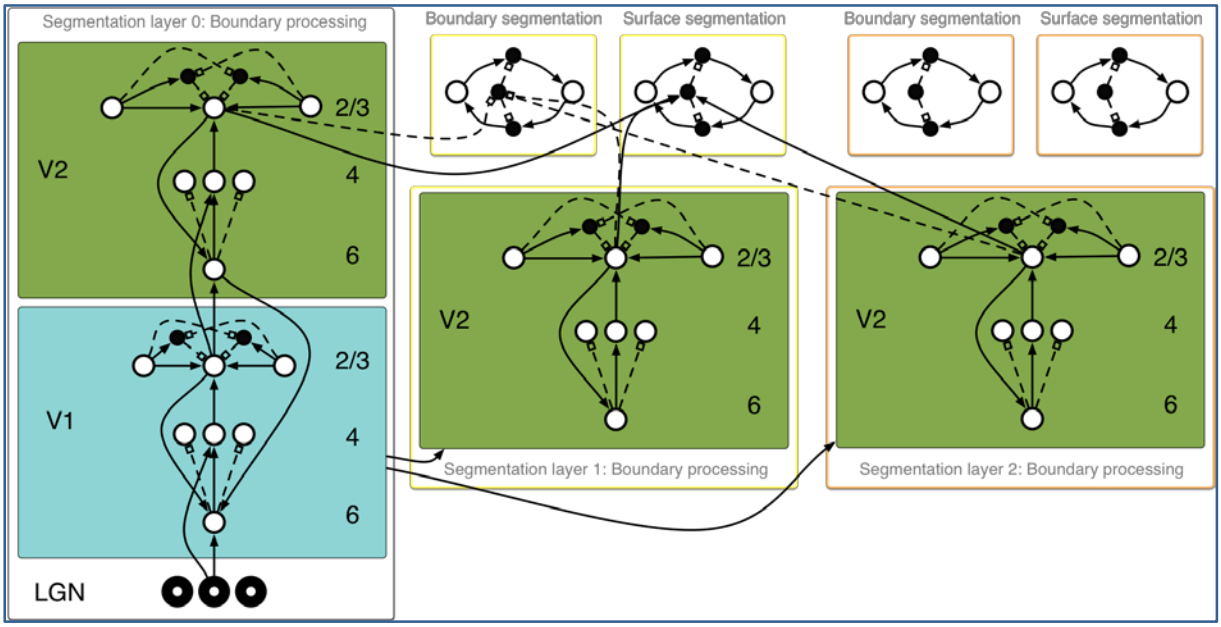

Figure 7: Laminart model.

Neurons in V1 (blue) project to three segmentation layers in V2 (green), each representing different perceptual groups. Boundary and surface segmentation networks segment the visual field into perceptual groups and allow activity to spread within the segmentation layers. Segmentation is initiated by top-down signals. V2 activity projects to three different copies of V4 (not shown), which generate the output of the model.

4.2.3.1 Aims:

- Integrate the model in the NRP.
- Connect the cortical model to a retina model to increase physiological realism, by taking into account the retinal magnification factor for central and peripheral vision and pre-processing the input with a basic gain control (Weber's law).
- Connect the model to higher cortical models to generate a motor response.
- Design visual experiments to test and explore the models in realistic conditions within the NRP.
- Based on the model's performance in the NRP, implement the adequate modifications to the model, so that it detects objects in realistic scenes.

4.2.3.2 Platform Use Cases:

- Visual tracking experiment: the iCub robot, equipped with the cortical model, tracks a moving target. The robot is expected to keep a stable, non-retinotopic representation of the target object, through the computation of illusory contours and a constantly active and adapting segmentation process, even if the object is moving in the retinotopic space or is partially occluded by non-target objects. The future plan is to connect the Laminart model to a model for gaze stabilisation, to ensure that the segmentation signals are shifted according to the robot's eye movements.
- Catching experiment (collaboration with Tasks 10.2.2 and 10.2.3): start from the visual tracking experiment and connect the output of the Laminart model to higher visuo-motor

cortical areas (saliency detection, saccade generation, smooth pursuit generation, object related movement prediction, target detection, decision making, predictive coding), to track and predict the pathway of a moving target object to catch.

4.2.4 T10.2.2 Behaviour generation

This Task focuses on the development of functional components needed to allow the agent to generate a proper behaviour in response to complex sensory stimuli. Such behaviours will include incremental functional models; starting from the basic perception and action functions of the robot, specifically the visual, proprioceptive, vestibular and tactile sensory systems and the actuators for the eye, head, body and limb movements.

4.2.4.1 Cognitive models for complex behaviours

This Component will provide integration of previously developed functional and data-driven models in order to generate complex behaviours. A set of experiments will guide the selection of the mentioned models and their integration (i.e. spinal cord models for locomotion, basal ganglia and cerebellum models for manipulation or gaze control). This Component can take advantage of sensory and motor models developed in T10.1.1 and T10.1.2.

4.2.4.2 Reactive perception-action loops

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 brain models provided by T10.1.2.

4.2.4.3 Anticipative perception-action loops

This Component will provide functional behavioural models of anticipative perception-action loops. These behaviours will be tested on simulated robotic platforms (humanoids or modular) or simulated human models. The models will have a modular structure, so that parts of them can be substituted by brain models provided by T10.1.2.

4.2.5 T10.2.3 Learning body and movement representations for grasping and manipulation

The main goal of this Task is to develop a small library of brain models (i.e. spiking neural networks) dedicated to the control of classical robots. In contrast to the majority of models handled in WP10.1, their development is much lesser data-driven and instead, they are rather engineered for functionality based on well understood and reliable principles. In the N, such *functional* models offer new insights into the process of conceptualization, design and execution of meaningful and challenging experiments that were designed to develop and evaluate novel, brain-based technologies.

Consequently, previously unpredicted requirements for the platforms could already be identified during the design of our experiments and the development of the neural controllers. We designed the controllers and experiments to be easily integrable into the NRP once these features are implemented. During the remainder of SGA1, we will continue this research and transform it into pilot experiments that serve as showcases of the NRP, mainly targeting engineers.

Our pilot experiments will be centred around early grasping and manipulation experiment in the platform and feature an industrial arm with an anthropomorphic hand (Schunk LWA arm and SVH hand) and neuromorphic sensors (Dynamic Vision Sensor cameras) both physically available to the consortium. We designed the experiments to be able to demonstrate and evaluate learnable body and movement representations, and in order to achieve this, we identified several necessary building blocks each of which is represented by a Component in T10.2.3.

- Functional brain model for visual perception
- Learnable body model representations
- Neuromorphic visual motor coordination
- Functional brain model for humanoid grasping
- Functional body and movement learning
- Functional model of Symbolic perception
- Library for Human Motion Data

4.3 WP10.3 Components for Closed-Loop Experiments

WP10.3 prepares and provides the components required for the closed-loop experiments of WP10.1 and 10.2, the CDPs, and even beyond research conducted in the human brain project. The WP focuses on the directly needed robot models and sensors, the preparation of community-driven model libraries and initial validation, calibration and benchmarks.

Of particular importance is the work on the virtual rodent, which plays a crucial role in WP10.1 and CDP1. Tasks 10.3.1 and 10.3.2 focus on realistic reconstruction and appearance of the rodent musculoskeletal apparatus. T10.3.3 refines already existing robots and creates novel models of robots and sensors required for research in WP10.2. The fundamental mechanisms for creating large-scale models libraries for experiments that go beyond SGA1 will be implemented. Initial benchmarks and validation of the NRP models against their real counterparts are topic of T10.3.4.

4.3.1 Key Personnel

Matthias CLOSTERMANN (EAS, subcontracted by TUM), Auke IJSPEERT (EPFL), Rüdiger DILLMANN (FZI), Olivier MICHEL (Cyberbotics, third party to EPFL)

4.3.2 Milestones

Table 4: Milestones for WP10.3 Components for Closed-Loop Experiments

MS No.	MS Name	Leader	Expected Month	Achieved Month	Comments
10.3.1	Implementation plan for WP10.3	FZI	M02	M06	This Deliverable 10.7.1.

10.3.3	First version of the NRP core library of robots, sensors, and environments	FZI	M12	M12	Initial version of library facilities of robots, sensors and environments. These allow users to add their own models and combine them into an experiment with help of a "wizard" user interface. The way users can add new sensors, for instance, is documented on the example of a strategically relevant neuromorphic sensor (Dynamic Vision Sensor Camera) on the Neurorobotics Blog: http://neurorobotics.net/researchBlogEntry.html?id=5. The same blog entry also displays a new robotic head for saccadic eye movement and demonstrates how additional strategic robots can be added to the Platform.

4.3.3 T10.3.1 Rodent Body Model

4.3.3.1 Key Personnel

Task Leader: Matthias CLOSTERMANN (EAS, subcontracted by TUM)

4.3.3.2 SGA1 DoA Goals

This Task develops a photo-realistic model of the mouse body, to be combined with the musculoskeletal model developed in T10.3.2. The body model will be calibrated using MRI and other quantitative data on the mouse body, and will include whiskers and fur. Different versions of the model will be developed, depending on the desired simulation speed and visual realism. Finally, the combined body/musculoskeletal mouse model will be added to the core library of the NRP (T10.3.3).

4.3.4 T10.3.2 Musculo-skeletal models of rodents

4.3.4.1 Key Personnel

Task Leader: Auke IJSPEERT (EPFL)

4.3.4.2 SGA1 DoA Goals

To develop an accurate musculoskeletal model of a rodent hind limb. 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.

Description of Component:

- Simulate a single hind model of mouse with three degrees of freedom - hip, knee and ankle.
- Each joint is actuated by a pair of flexor and extensor muscles. Knee and ankle joints also have bi-articular muscles. Each hind limb consists of eight muscles, six mono-articular and two bi-articular.

- Muscles are modelled as Hill-type muscles for which muscle properties are obtained from the literature[6].
- Extension of single hind limb model to two hind limb model with rigid spine and fore limbs.

4.3.5 T10.3.3 Models of robots, sensors and environments

4.3.5.1 Key Personnel

Task Leader: Rüdiger DILLMANN (FZI)

4.3.5.2 SGA1 DoA Goals

The aim of this Task is the creation of a core library of strategic models for robots, sensors, environment and their Components required for the simulation in the NRP. On the one hand, this library will contain a selection of Components that are strategically important to implement the pilot experiments as requested by WPs 10.1 and 10.2 but also from other SPs. They will be curated by the consortium of SP10. On the other hand, the library will additionally be opened to the public so that offering access to simulations of the world's robots becomes a community-driven effort.

A basic set of models immediately required for the pilot experiments will be created and integrated into the NRP, and existing models will be refined (e.g., by adding better sensors or visualisations). Furthermore, the methods required for the expansion towards an open and community-driven effort will be investigated.

The building blocks required are each represented by a Component

- Environment model library: This library contains models of complex environments (mazes, laboratories, outdoor scenes) for the use in the NRP.
- Sensor library: This Component represents a library for various sensors to be simulated in the NRP. These sensors are accessible from the RobotDesigner application where they can be assigned and connected to a virtual robot or avatar.
- Robot avatar library: This library provides a strategical set of robots (industrial, humanoid, simplified human and rodents, etc.) and biological avatars (rodent, human, etc.).

4.3.6 T10.3.4 Benchmarking and validation of NR models

4.3.6.1 Key Personnel

Task Leader: Olivier MICHEL (Cyberbotics, third party to EPFL)

4.3.6.2 SGA1 DoA Goals

To develop a series of benchmarks allowing the evaluation of the quality of the neurorobotics simulation models, including robots, sensors and actuators. Benchmarks for neuro-muscular robotics models should be developed, as well as benchmarks for standard, off-the-shelf robotics systems.

The simulation models of robots, including all sensors and actuators, will be calibrated accurately against their real counterparts, i.e. real robots. This process involves a series of precise measurements on the real devices performing standard robotics operations and the adjustment of the simulation models so that the simulation behaviour matches the behaviour of the real robot. As a result, the simulation parameters will be refined regarding the mass distribution of each component, the motor positional limits, maximum velocity, maximum

[6] Charles JP, Cappellari O, Spence AJ, Wells DJ, Hutchinson JR. Muscle moment arms and sensitivity analysis of a mouse hindlimb musculoskeletal model. Journal of Anatomy. 2016;229(4):514-535. doi:10.1111/joa.12461.

torque, the sensors properties, including noise, non-linear response function, range, etc. Eventually, the models will be improved to better capture the physical properties of the real devices, for example motor backlash. Benchmarks will be defined to validate the calibrated models. These benchmarks will include several metrics based on standard error (SE) measurements involving both analytical models and real hardware. The benchmark will define different compliance classes, depending on the type and application of the model. A minimal compliance class for all models of the NRP core library will be defined. All models in the NRP core library will be required to pass the calibration benchmarks in order to be validated. The benchmark will be released to the scientific community so that models in the NRP community library and external models can be validated and compared.

- Benchmarking of the swimming salamander robot (including simulation of fluid dynamics).
- Benchmarking of the artificial muscle based humanoid walker.
- Benchmarking of existing commercial robotics systems.

4.4 WP10.4 Translational Neurorobotics

4.4.1 Key Personnel

WP Leader: Jörg CONRADT (TUM)

WP10.4 develops multiple real-world robotic platforms and performance demonstrators, that are connected to real-time neuronal controllers. Several of these systems are linked to neuronal simulation software (PyNN) or real-time neuro-computing hardware systems (predominantly the SpiNNaker neuro-computing hardware, WP9). This WP explores metrics such as achievable task complexity for given software/hardware constraints in multiple robotics domains, and continuously extends and revises neuronal models to more complex scenarios.

The WP addresses the timely creation of more “ready-to-use” systems (both as physical robot instances and as simulated robots in NRP), so that users from other SPs apply and test neuronal models on their robots of choice in both, simulated and real-world scenarios.

More coherent and more complete integration of existing sensors and physical robots into the NRP will be a high priority in WP10.4.

4.4.2 Milestones

Table 5: Milestones for WP10.4 Translational Neurorobotics

MS No.	MS Name	Leader	Expected Month	Achieved Month	Comments
10.4.1	Implementation plan for WP10.4	TUM	M02	M06	This Deliverable 10.7.1.
10.4.2	Instantiation of robotic sensors and actuators and neuro-robotics control algorithms in NRP	TUM	M12	M12	Within this Milestone, we integrated different simulated and real-world robotic sensors, robotic actuators and bio-inspired robots into the NRP. From a sensor perspective, we integrated real-world tracking sensors and a simulated Dynamic Vision Sensor to the NRP. The real-world tracking integration enables the interaction between the simulated NRP world and the

					real world. This integration is especially important for WP10.4, which focuses on bringing the NRP simulations and algorithms to real-world robotics. Additionally, we implemented a simulation of the Dynamic Vision Sensor (DVS) within the NRP such that users can use the spiking output of the biologically inspired DVS as input for their visual brain models. This simulation computes the change in the simulated frames to approximate the change of brightness and triggers a corresponding spike event once a certain threshold of brightness change is reached. From an actuator perspective, a baseline for musculoskeletal actuators has be added to the NRP. In this first step, the tendon routing models have been created as plugins to Gazebo. Currently, we are working on calibrating the simulation models with the physical robot actuators to guarantee simulation fidelity. From a robot perspective, the Myorobotics anthropomimetic robot Roboy and the 6-DOF NST Robot Head have been setup within the NRP and are usable within experiments.

4.4.3 T10.4.1 Design and control of musculo-skeletal robots for the NRP

4.4.3.1 Key Personnel

Task Leader: Alois KNOLL (TUM)

4.4.3.2 SGA1 DoA Goals

Integrate the musculoskeletal Robotics toolkit Myorobotics and Roboy into the NRP as well as improving the simulation models of the real hardware to enable realistic experiments.

Description of Component:

- Adapt Roboy and the Myorobotics framework to use ROS and Gazebo, so the robots are compatible with the NRP;
- Implement a controller that makes the physical muscles behave like hill-muscles, enabling the brain-derived controllers to work with a standardised muscle model;
- Implement different controllers facilitating calibration as well as joint angle deduction for joints without direct sensing based on tendon configuration;
- Validate the controllers' accuracy through an external tracker-based measuring system;
- Build bio-inspired legs based on the two platforms;
- Update Roboy to use the Myorobotics electronics to unify the software frameworks and validate their inclusion into the NRP.

4.4.4 T10.4.2 NRP and motor-actuated robots (iCub)

4.4.4.1 Key Personnel

Task Leader: Cecilia LASCHI (SSSA)

4.4.4.2 SGA1 DoA Goals

The aim of this Task is to provide tools for the control of motor-actuated robots through the NRP framework. Such tools will allow:

- Communication with the robot through the use of a robotic middleware compatible with the NRP;
- Provision of a suitable version of the NRP able to achieve real-time performances in order to exploit the compatibility with the neuromorphic hardware from T10.4.3 and use the synchronisation mechanisms implemented in the NRP for brain and robot simulation;
- Provision of a robot configuration interface to access and adjust sensors and motor parameters based on the task to be executed.

Possible candidate robotic platforms for such a task are the iCub robot and the biped humanoid robotic platform named SABIAN. Both these Platforms are available at SSSA.

4.4.5 Real-time closed-loop neurorobotic systems for real motor-actuated robots

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.

Behavioural models, provided by T10.2.2, will be used to test the effectiveness of the developed technology.

4.4.6 NRP interface for motor actuated robots

This Component will provide suitable interfaces for motor-actuated robots. These interfaces will comply with the NRP 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.

4.4.7 T10.4.3 NRP and Neuromorphic Hardware

4.4.7.1 Key Personnel

Task Leader: Jörg CONRADT (TUM)

4.4.7.2 SGA1 DoA Goals

This Task addresses the development of infrastructure for neuromorphic sensors, neuromorphic actuators (e.g. T10.4.1), and neuromorphic computing systems (SP9, SpiNNaker) to allow real-time closed-loop robot control in simulation (NRP) and real-world robots. It will develop interfaces to connect such neuromorphic hardware (sensors, actuators and computing substrate) to the NRP.

4.4.8 T10.4.4 Self-adaption in modular robots

4.4.8.1 Key Personnel

Task leader: Henrik H. LUND (DTU)

4.4.8.2 SGA1 DoA Goals

To develop a bio-inspired motor control and motor learning system for modular robots. The model will integrate cerebellar-like learning mechanisms, the Locally Weighted Projection Regression (LWPR) machine learning algorithm and an adaptive feedback controller to control a modular robot. The nucleus of the control system will reproduce the modularity of the anatomy of the cerebellum. It will consist of a set of adaptive cerebellar modules, which are capable of learning the input-output relationship of dynamic processes. The cerebellar modules mimic the input-output characteristics of the motor apparatus of the modular robot. They adapt the corrections by means of a teaching inverse reference signal. Their

activation is triggered every time a change is experienced. The self-adaptation will allow the modular robot to achieve task-fulfilling behaviours regardless robot complexity. The biomimetic learning architecture will be validated both into the NRP and with available physical robots.

The system will be tested in context switching experiments changing the morphology of the robot.

4.4.9 T10.4.5 Real-time control with reservoir networks

4.4.9.1 Key Personnel

Task Leader: Joni DAMBRE (UGENT)

4.4.9.2 SGA1 DoA Goals

This Task will apply reservoir computing as a stepping-stone to establish robust embodied neural models realising spinal cord functionality for real-time gait motor control in quadruped robots with passive compliance. A major difficulty in robots with passive compliance is the fact that their dynamics and kinematics cannot be described exactly by analytical models. Instead, control policies must be robust to morphological variability (e.g. the exact value of joint friction or spring constants) between individual robots as well as through time for each single robot. We will develop a generic approach for learning tunable embodied neural building blocks for real-time motor control and validate them on the NRP mouse model and a physical quadruped robot platform with passive compliance. The models will be made available through the Collaboratory. A secondary aim of this Task is to provide a test case for using the NRP in compliant robot design and optimisation. Detailed goals are the development of a generic approach for generating embodied neural building blocks for real time tunable motor control for locomotion, and its demonstration for the NRP simulated mouse and for a physical quadruped robot with passive compliant elements.

4.5 WP10.5 Simulation and Visualization Tools for Neurorobotics

4.5.1 Key Personnel

WP Leader: Axel VON ARNIM (FORTISS)

4.5.2 WP Leader's Overview

The first year of SGA1 will focus on improvements in the NRP, in terms of stability and availability. During the first period, feature development will be reduced to a minimum and we will refactor to improve the NRP architecture.

In the second period we will catch up on user features and requirements (our pilot experiments use cases):

- Support for bigger brain models (requirement from CDP1)
- Graphical transfer functions editor
- Basic brain visualization (requirement from CDP1)
- Python API for batch simulations (Virtual Coach) (requirement from DTU)
- Object scaling
- New template experiments
- Camera Streaming (requirement from FZI)
- Object Scaling
- Environment Enhancements

4.5.3 Milestones

Table 6: Milestones for WP10.5 Simulation and Visualization Tools for Neurorobotics

MS No.	MS Name	Leader	Expected Month	Achieved Month	Comments
10.5.1	Implementation plan for WP10.5	FORTISS	M02	M06	This Deliverable 10.7.1.
10.5.4	First release of the Neurorobotics Platform Software	FORTISS	M12	M12	The first version of the NRP was released on 10 May 2016, version 1.1 was released on 13 October 2016 and the next version (1.2) will be released in a few days.

4.5.4 T10.5.1 Simulation of physics (mechanics, light, sound, etc.)

4.5.4.1 Key Personnel

Task Leader: Fabian AICHELE (TruPhysics, subcontracted by TUM)

4.5.4.2 SGA1 DoA Goals

This Task will improve the physics simulation of the World Simulation Engine (T10.5.2) to make it suitable for the simulation of soft robots and skeleton-muscle systems. These require the simulation of deformable materials (e.g. muscles or skin) and high geometric detail, a feature that is not provided by state-of-the-art robot simulators such as Gazebo. This Task will therefore improve available collision detection algorithms to deal with highly detailed deformable 3D models and kinematic assemblies and to provide the high degree of geometric detail and physical plausibility that is required by the NRP.

4.5.5 T10.5.2 World Simulation and Closed-loop engine

4.5.5.1 Key Personnel

Task Leader: Marc-Oliver GEWALTIG (EPFL)

4.5.5.2 SGA1 DoA Goals

This Task adapts different software modules to the needs of the NRP and integrates them into a coherent system: The World Simulation Engine. The most important modules are the robot simulator (e.g. Gazebo), a physics engine (e.g. Bullet, ODE or SOFA.) as well as the Closed-loop engine, which synchronises the robot/environment simulation with the brain simulation. This Task also develops and documents the application program interfaces between the different modules of the NRP software and also between the NRP software and the tools running on other HBP Platforms, such as the Brain Simulation Platform and the Neuromorphic Computing Platform.

4.5.5.3 NRP Web cockpit (ExDFrontend)

The NRP Web cockpit, ExDFrontend, is the front end of the NRP. This is where you can launch and watch a neurorobotics simulation. It is tightly integrated into the Collab portal.

Repository: https://bbpcode.epfl.ch/code/#/admin/projects/neurorobotics/ExDFrontend

4.5.5.4 NRP Brain-Body Integrator (BIBI)

The NRP Brain-Body Integrator, BIBI, is the framework which allows neuroscientists to connect brain models to sensors and actuators of robot models within the NRP. 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.

4.5.5.5 NRP Closed Loop Engine (CLE)

The NRP Closed Loop Engine (CLE) is the Component which allows simulation of a brain wired to a robot evolving in a virtual environment. The CLE runs two simulators, the brain and the robot simulator, and keeps them synchronised.

Repository: https://bbpcode.epfl.ch/code/#/admin/projects/neurorobotics/CLE

4.5.5.6 NRP Services (ExDBackend)

The NRP Services software, ExDBackend (Experiment Designer Back-end), is the set of web services offered by the NRP to set up, launch and interact with an *in silico* neurorobotics experiment. A neurorobotics experiment is a scenario in which a brain model embodied in a robot model are simulated.

Repository: https://bbpcode.epfl.ch/code/#/admin/projects/neurorobotics/ExDBackend

4.5.6 T10.5.3 NRP User Experience (NRP Cockpit)

4.5.6.1 Key Personnel

Task Leader: Gudrun KLINKER (TUM)

4.5.6.2 SGA1 DoA Goals

This Task develops innovative tools for immersive high-fidelity rendering and real-time user interaction, enabling life-like neurorobotics experiments with users in the loop.

The Neurorobotics Cockpit is the central user interface to the NRP. The NR Cockpit will give the user full access to the underlying simulation data while the experiment is running and the virtual robot is performing assigned tasks. It will allow users to control the experiment and to visualise all simulation data. For this purpose, the cockpit will consist of a freely (ad hoc) configurable combination of display and interaction devices - some stationary and others mobile - to present inter-related visualisations of all relevant aspects of an experiment as 3D (VR)-type renderings in combination with magic lenses to explore details. The cockpit will provide a multi-modal interaction interface extending regular WIMP-based schemes with touch and 3D input based on tracked tangible objects, displays and users' limbs.

4.5.6.3 NRP Cockpit - Online user interaction

Online user interaction / input interpretation within experiments during runtime: Some experiment scenarios might directly involve users or depend on human interaction. In order to make these experiments possible, a system will be developed that integrates user input directly into the Platform during runtime of an experiment, with the possibility for the input to influence all parts of the NRP (environment, robot, brain).

4.5.6.4 NRP Cockpit - Dynamic reconfiguration

Dynamic (re)configuration of in-/output devices and interactivity between devices. In order to make full use of different display modalities the devices in use should be easy to integrate into the workflow and the NRP should have the capability to visualize interdependencies between the devices, e.g. the effect/results of changing parts of the experiment (brain) should be visible throughout other views on experiment data. This will not only ease the process of debugging experiments but also help to identify causes and effects during simulations.

4.5.6.5 NRP Cockpit – Input devices

Depending on Use Case scenarios described in Component 1 (desktop, multi-user, VR, etc.) an NRP user needs to have access to input devices suited for the working environment. Furthermore, specialised user tracking devices like Kinect, Myo, LeapMotion, etc. offer possibilities of more complex/natural input by the user that allows non-standard ways of interacting with simulations.

4.5.6.6 NRP Cockpit – Output devices

Users of the NRP Cockpit should have access to different screen configurations depending on the situation. Possible scenarios: desktop cockpit/operator views for managing experiments - displaying relevant aspects of the simulation distributed over multiple screens/devices, multiple users working collaboratively in the same physical space, VR environments of simulation This includes user interfaces tailored to the situation/devices used.

4.5.7 T10.5.4 Environment and experiment designer

4.5.7.1 Key Personnel

Task Leader: Rüdiger DILLMANN (FZI)

4.5.7.2 SGA1 DoA Goals

This Task develops the tools to construct and to represent different environments on possibly multiple screens. Hereby all reusable software components (packages) that are helpful will be imported from external resources. The environmental models involved describe not only static environments but also dynamic scenes. So for example a complex dynamic situation can be constituted by a group of mobile robots. In addition, also outdoor scenes will be considered which are often non-static. The user will be enabled to modify and extend the environmental models graphically in an interactive manner. The experiment designer utilises the environmental models and complements it with an appropriate experiment, which is roughly predefined and finally selected by a user. The detailed execution of an experiment will be done with state machines, where the user can define small experimental changes. The experiment designer will allow planning experiments with one or several robots, including interactions between robots. Another type of experiment is represented by the performance of closed loop experiments where, e.g. camera pixel-based pulse-coded output is given to the visual cortex and then via the motor cortex such trains of pulses go out.

4.5.7.3 NRP - Experiment Library

This Component represents a library of experiments where researchers can access and upload experiment templates used in their experiments. It links to the NRP Environment model library.

4.5.7.4 NRP - Experiment Designer

The experiment designer is tool embedded into the NRP cockpit. It utilises the environmental models and complements it with an appropriate experiment description, chosen roughly predefined from a library and finally selected by a user. The detailed execution of an experiment will be done with state machines, where the user can define small experimental changes. The experiment designer will allow planning experiments with one or several robots, including interactions between robots. Another type of experiment is represented by the performance of closed loop experiments where e.g. camera pixel-based pulse-coded output is given to the visual cortex and then via the motor cortex such trains of pulses go out.

4.5.7.5 NRP – Environment Designer

Tools in the Neurorobotics Cockpit to construct and to represent different environments. Reusable software components (packages) that are helpful will be adapted from external resources. The involved environmental models describe not 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.

4.5.8 T10.5.5 Robot Designer

4.5.8.1 Key Personnel

Task Leader: Alois KNOLL (TUM)

4.5.8.2 SGA1 DoA Goals

This Task develops the tools needed to construct robots from reusable parts and to import models from external resources.

The user will be able to modify and extend robot models graphically in an interactive manner. Available software packages will be used and imported from external resources. This designer considers the kinematic and dynamic restrictions of different types of robots (stationary or mobile, individual or multiple) together with basic muscular-skeletal models (e.g. from T10.3.2). The evaluation and validation of the different robot designers will be performed by benchmarks in the virtual world of NRP and partially with real, hard robots. The validation of soft robots (e.g. mouse) can only be done by simulation (see T10.5.1) where we can integrate the interplay of muscles (dynamics), e.g. for gripping, and represent the corresponding skin deformations. The input and the output of each brain model are analogue pulses. This sounds simple but the interpretation of the pulse code e.g. of a retina even for elementary features or even more for the recognition of human faces is till now not well known. Conversely the output of the motor cortex, e.g. to move the hand, is not exactly known. Therefore, we will collect all available software, e.g. from SP4 and SP6, to implement bidirectional interfaces which we also call transfer functions.

4.5.8.3 NRP – Robot Designer in the NRP Cockpit

The robot designer will be partially integrated into the web-based cockpit of the NRP. This version will not allow the user to create complex models from scratch. Rather, it allows adding sensors to an existing model of the robot library and minor modifications. Another aspect is the assembly of robots from predefined parts.

4.5.8.4 NRP – Standalone Robot Designer

Standalone version of the Robot Designer realised as a Blender Plugin. This continues the effort of the RUP to design sophisticated complex robot models outside of the NRP.

4.5.9 T10.5.6 Brain-Body Integrator

4.5.9.1 Key Personnel

Task Leader: Cecilia LASCHI (SSSA)

4.5.9.2 SGA1 DoA Goals

The Brain Interface and Body Integrator enables the user to connect brain models to the robot sensors and actuators, providing the tools to specify a brain model within the Brain Simulation Platform and connect it with the robot sensors and actuators.

This feature is partially available inside the NRP. It will be extended and enhanced with a larger library of transfer functions (developed as part of WP10.1 and WP10.2) and a user-friendlier graphical interface.

4.5.9.3 NRP – Transfer Library

A library of Transfer Functions (TFs) mediating between brain models and robot actuators. It will include TFs elaborating on different sensor inputs, and driving a wide spectrum of robotic actuators. Third party libraries such as the COREM retina framework will be added in order to embed state-of-the-art models within the Platform. The user will be able to select TFs from the library and, possibly, adapt them to design custom neurorobotics experiments.

4.5.9.4 NRP – Transfer Function UI

Web interface for editing Transfer Functions. In this Component, the interface will be enhanced so to provide the user with a better experience. The user will be able to pick and adapt transfer functions from a library in order to design interactively the behaviour featured in the experiment.

4.5.10 T10.5.7 Virtual Coach

4.5.10.1 Key Personnel

Task Leader: Alois KNOLL (TUM)

4.5.10.2 SGA1 DoA Goals

The aim of the Virtual Coach is to make the NRP support running learning experiments by enabling multiple experiment runs, re-suing parameters and brain models, running experiments without having to visualise them, and comparing different experiment results at the end.

Develop a software tool allowing researchers to define and execute multi-stage training protocols for robots (specification of timing, stimuli, correct and incorrect behaviours, and reward signals for each stage). These are necessary in the context of behavioural and reinforcement learning experiments.

4.5.11 T10.5.8 Benchmarking and validation of physics and light simulation

4.5.11.1 Key Personnel

Task Leader: Olivier MICHEL (Cyberbotix, third party to EPFL)

4.5.11.2 SGA1 DoA Goals

This Task will develop tools and progressive benchmarks to measure and improve the accuracy of physics simulations and rendering engines. It will also define quality scales to measure the progress of new versions of the physics and rendering engines.

The physics and the light models will be calibrated accurately to match the real physical behaviour. The physics calibration relies on the comparison between analytical models of physics behaviour and the numerical models resulting from the simulation physics engine. Based on this comparison, numerical models are improved to better match the analytical models. Several analytical models from the state-of-art literature will be used, related to rigid body dynamics, fluid dynamics, soft bodies, friction, etc. The light calibration involves the comparison between real world pictures and the images resulting from the 3D rendering of the simulation engine. Thanks to the recent progress in real time 3D rendering with powerful GPUs, OpenGL shaders, GPU computing, etc., significant progress can be achieved in the accuracy of 3D rendered images for all current light models, e.g. directional lights, point lights and spot lights. They include shadows, light textures, ambient occlusion, focus, motion blur, anti-aliasing, etc. A series of benchmarks will be defined for both physics and light simulation with metrics based on standard error (SE) measurements involving both analytical models and real world pictures. The simulation models will be required to pass the benchmarks in order to be validated.

4.5.12 T10.5.9 Software integration, packaging and release

4.5.12.1 Key Personnel

Task Leader: Axel VON ARNIM (FORTISS)

4.5.12.2 SGA1 DoA Goals

This Task will ensure the coherent integration of all software parts, the packaging and release of the Platform to the end users, using industry-level and widely spread tool chains.

Together with T10.6.1 and T10.6.2, it will provide a robust and standard release process that will guarantee the quality defined by the aforementioned Tasks. The software integration step will make sure that all software parts can communicate securely together, have loose dependencies with each other, and can be tested separately as well as together with integration tests. Packaging will make sure that the software will be available for deployment (T10.6.1) as autonomous packages in well-defined formats with support for versioning and automatic package generation. The release will follow a well-defined plan defining all steps and guaranteeing quality and transparency to the user. This will be achieved by connection with T10.6.3. The release frequency will follow an explicit roadmap and be high enough to ensure continuous user involvement.

The NRP software packages comprise all the packages a user needs to install and use the Neurorobotics tools on her/his computer or with her/his own infrastructure.

4.6 WP10.6 Neurorobotics Platform

4.6.1 Key Personnel

WP Leader: Alois KNOLL (TUM)

4.6.2 Milestones

Table 7: Milestones for WP10.6 Neurorobotics Platform

MS No.	MS Name	Leader	Expected Month	Achieved Month	Comments
10.6.1	Implementation plan for WP10.6	TUM	M02	M06	This Milestone has been achieved with the submission of Deliverable 10.7.1.

4.6.3 T10.6.1 Platform integration, deployment and operation

4.6.3.1 Key Personnel

Task Leader: Alois KNOLL (TUM)

4.6.3.2 SGA1 DoA Goals

The goal of this Task is to reliably deploy and operate the NRP in a stable production environment.

This Task is responsible for operating the NRP servers, installing/deploying the NRP software and operating the Platform. It will plan, provide and maintain the NRP servers, plan storage and compute capacity based on the projected user numbers, and will also provide services such as user registration, sign-in and fine grain access right management.

4.6.4 T10.6.2 Platform testing, profiling and quality assurance

4.6.4.1 Key Personnel

Task Leader: Marc-Oliver GEWALTIG (EPFL)

4.6.4.2 SGA1 DoA Goals

This Task ensures that the NRP delivers reliable and responsive software while offering an optimal user experience.

This Task monitors the NRP infrastructure. It measures key performance statistics such as uptime and utilisation of the NRP servers (CPU and memory) as well as of the network. The performance statistics will be used to improve the NRP software and to determine the requirements and capacity for the next generation infrastructure. The Task will provide user analytics to improve usability of the NRP software.

4.6.5 T10.6.3 Documentation, user support and user training

4.6.5.1 Key Personnel

Task Leader: Alois KNOLL (TUM)

4.6.5.2 SGA1 DoA Goals

The goal of this Task is to provide comprehensive end user documentation, support, and training.

This Task develops comprehensive the user level documentation for the NRP and its software. It supports users by answering user questions and providing community forums and mailing lists, and trains users through workshops and educational online material, such as webinars.

4.7 WP10.7 Scientific Coordination and Community Outreach

4.7.1 Key Personnel

WP Leader: Florian RÖHRBEIN (TUM)

4.7.2 Milestones

Table 8: Milestones for WP10.7 Scientific Coordination and Community Outreach

MS No.	MS Name	Leader	Expected Month	Achieved Month	Comments
10.7.1	SP10 strategy report on ethics, innovation, and community engagement	TUM	M05	M06	This Milestone has been achieved with the submission of Deliverable 10.7.1 "Release Plan for the NRP for SGA1 and Project Implementation Proposal" and the contributions to the SP12 document "Ethical Advisory Board & Rapporteurs: Identified SP Ethical Issues" (see EMDESK document manager). For the innovation aspect, we successfully identified a suitable candidate that will be employed by TUM in February 2017.
10.7.2	First NRP user workshop	TUM	M12	M12	The first NRP user workshop was held on 11/12 January 2017 in Munich, for details see www.neurorobotics.net.

4.7.3 T10.7.1 Subproject Leader (a)

4.7.3.1 Key Personnel

Task Leader: Alois KNOLL (TUM)

This Task involves no personnel costs, it is only budgeted with travel costs for the SP Leader. For a report see SP Leader's Overview at the beginning of this document.

4.7.4 T10.7.2 Subproject Leader (b)

4.7.4.1 Key Personnel

Task Leader: Marc-Oliver GEWALTIG (EPFL)

This task involves no personnel costs, it is only budgeted with travel costs for the SP Leader. For a report see SP Leader's Overview at the beginning of this document.

4.7.5 T10.7.3 Scientific coordination and WP lead

4.7.5.1 Key Personnel

Task Leader: Florian RÖHRBEIN (TUM)

4.7.5.2 SGA1 DoA Goals

This Task will coordinate SP reporting and writing of Deliverables, monitor scientific progress within the SP, organise SP-wide meetings, organise one BoD meeting, coordinate with the External Relations Team on issues related to innovation, coordinate with the Ethics Manager and with SP12 on issues related to ethics, provide support to Partners on issues related to administration, innovation and ethics, act as a point of contact with the HBP Administration. Additional funds (other goods and services) are reserved to organise meetings such as SP meetings and SIB meetings.

4.7.6 T10.7.4 Dissemination and community engagement

4.7.6.1 Key Personnel

Task Leader: Marc-Oliver GEWALTIG (EPFL)

4.7.6.2 SGA1 DoA Goals

The goal is to make our SP and its progress public, to advertise our Platform so we can get new users and possibly new Partners.

T10.7.4 will be responsible for supporting community activities elsewhere in the SP. This will include organisation of community workshops, acting as a point of contact between the SP and community users, and communications towards participating communities. The Task operates and maintains the SP10 web sites and develops brochures and info material.

In order to engage with users and entice them into using the Platform a variety of tools are used.

The Neurorobotics website has been updated to make it cleaner and easier for users to navigate. The blog has been integrated into the website as well as onto our Twitter account. The blog is available for a number of researchers to post onto allowing them to connect their work directly with users.

In terms of social media, as well as our blog posting directly onto our Twitter account, news and events related to the NRP are also highlighted there. Videos showcasing the Platform and tutorials are also available on the YouTube channel.

In order to support users we encourage the use of the Human Brain Project forum (https://forum.humanbrainproject.eu/c/neurorobotics), as well as our issue tracker hosted on Bitbucket (https://bitbucket.org/hbpneurorobotics/neurorobotics-platform/issues) where we have our open-source software repositories. These allow users to interact with us directly while also allowing them to see other people's questions, answers and feature requests. Furthermore, we have a Google group allowing us to make important announcements to users about the Platform.

To help users understand and use the Platform (and to allow us to gain direct feedback) various events have been organised. The first NRP User workshop takes place in January 2017

with the second planned for July. An install party takes place in April to help users install the platform locally on their own machines and to set up new experiments on the Platform. The neurorobotics team is also taking part in the HBP CodeJam which will take place in September. These events not only help users getting started with the Platform but also give the NRP development team a chance to better understand the needs and wishes of users.

To reach more users within SGA1, we plan to set up a continuously running backend server which basic users (the ones with "read-only" rights) can connect to anytime and watch demo simulations. This server will be easily maintainable (probably from Amazon Web Services) and will allow a large number of simultaneous user connections.

Susie MURPHY (EPFL Gewaltig) is our Community Manager and as such takes care of handling new user account requests, giving them information about Platform access and installation. She also moderates all our social media. She, as well as Axel VON ARNIM (FORTISS), will organise the first install party. Alexander KUHN (TUM Knoll) is, as a Science Coordinator, taking care of SP10 researcher's requirements.

4.7.7 T10.7.5 Innovation and Technology Transfer

4.7.7.1 Key Personnel

Task Leader: Alexander KUHN (TUM)

Other Researcher: Evgeny KALECHITS

4.7.7.2 SGA1 DoA Goals

The Task will be devoted to assessing economic potential of innovation opportunities and intellectual property available at / expected to result from SP10, developing commercialisation and technology transfer strategies for select options, identifying and structuring specific business and technology transfer initiatives and projects, assessing institutional environment for technology transfer and establishing industry and partner contacts required for technology transfer.

We expect contacts and cooperation with industrial partners, especially SMEs, looking to use the NRP for the testing of brain-inspired solutions in industrial robotics. Beyond that, industry will have the opportunity to benefit from the accumulated knowledge generated within the research done by Platform users who opt to contribute the results of their experiments to the community.

A short-term work plan was developed with the aim of launching the process of identifying existing and prospective technology transfer options within SP10. We also conducted a preliminary screening of immediately observable technology transfer options within SP10, resulting in the selection of Agricultural robotics and Autonomous driving as the first two options to explore in the near term. Next steps include a structured assessment of technologies and solutions available / expected from SP10 using the framework developed.

4.7.8 T10.7.6 Preparation of Grants and Report Documents

4.7.8.1 Key Personnel

Task Leader: Marc-Oliver GEWALTIG (EPFL)

4.7.8.2 SGA1 DoA Goals

To support the preparation of periodic reports as well as the proposal for SGA2.

5. Appendix 1: Summary of Co-Design Project 1

This chapter summarises the main ideas of Co-Design Project (CDP) 1: Mouse Brain Model and Mouse Brain Atlas. This CDP aims to provide a working example of simulation-based neuroscience, using the Neuroinformatics Platform, the Brain Simulation Platform, and the NRP.

5.1 CDP1: Mouse Brain Model and Mouse Brain Atlas

The goal of CDP1 is to deliver a mouse brain model at the level of point neurons as well as the corresponding mouse brain atlas. To make these two targets tangible and concrete, it was decided to implement an *in silico* version of a concrete neuroscientific experiment in which brain activity is recorded while the mouse is in a behavioural task. The extended goal of CDP1 is therefore to replicate in simulation *the mechanics* of the experiment, or phrased differently: we want to be able to investigate the brain model under the same experimental conditions as in the reference experiment – only in simulation.

Clearly, we cannot expect to obtain the same results as in the reference; however, we will be able to record the same type of data and compare them to the reference data. This is useful, because it allows the scientists to determine where and how the model can be improved in the next iteration.

The contribution of SP10 to this CDP is to develop *in silico* versions of the mouse, experiment setup and the experiment protocol. SP6 (Brain Simulation) will provide a whole mouse brain scaffold that is then connected to SP10's virtual mouse.

The first part is a paradigm for motor learning in healthy animals. In the second part of the experiment, a photothrombotic stroke is induced, leading to a loss in motor function. Then, the re-training of the motor task is studied. This part of the experiment is a paradigm for motor rehabilitation after stroke. This pilot experiment is in close cooperation with SP1 in the context of CDP1. SP10 will develop an *in silico* version of the experiment. The details of CDP1 can be found in the corresponding description of action.

5.1.1 Mouse Experiment: Motor learning and rehabilitation-induced cortical remapping after stroke

The first strategical experiment is linked to CDP1.

The first part is a paradigm for motor learning in healthy animals. In the second part of the experiment, a photothrombotic stroke is induced, leading to a loss in motor function. Then, the re-training of the motor task is studied. This part of the experiment is a paradigm for motor rehabilitation after stroke. This pilot experiment is in close cooperation with SP1 in the context of CDP1. The actual experiment with real-life mice will be reproduced in the NRP during SGA1.

5.1.2 Spatio-temporal coordinated activity during motor learning.

We want to investigate to what extent the fundamental relationship between motor cortex activity and movement is shaped by learning. To this aim we will study the remodelling of activation maps both *in vivo* and *ex vivo*. In detail, we will perform longitudinal mapping of cortical activity using calcium indicators coupled with a multi-level imaging system based on both a wide-field macroscope and a cellular-resolution two-photon microscope. In parallel, we will analyse whole-brain cell-resolution activation maps by detecting early gene expression *ex vivo*. The mouse will learn a motor task driven by milk reward in a robotic platform. The platform is integrated in a wide-field one-photon fluorescence macroscope. This configuration allows obtaining functional maps (via calcium indicators) in the awake mouse during execution of the motor task (i.e. pulling a handle) in the whole cortex. Cortical connectivity will be dissected by integration of optogenetic tools with genetically encoded indicator of activity.

5.1.3 Robotic platform for the study of rehabilitation-induced cortical remapping after stroke.

Brain remapping after stroke is supposed to underlie the recovery of limb functionality. We will examine in a mouse model of stroke the features of neuronal plasticity relevant for functional motor recovery. We will assess impairments and motor recovery in a quantitative way by training mice on a robotic platform that mimics a human robotic device for upper limb stroke rehabilitation. The platform is integrated in a wide-field one-photon fluorescence macroscope. This configuration allows obtaining functional maps (via calcium indicators) in the awake mouse during execution of the motor task (i.e. pulling a handle) in the whole cortex. Cortical connectivity will be dissected by integration of optogenetic tools with genetically encoded indicator of activity. Differences in early gene expression will be evaluated *ex vivo* to assess differences in whole-brain activation profiles induced by robotic rehabilitation.

6. Appendix 2: Roles and their personnel

Scientific Coordinators	Stefan ULBRICH, FZI Letizia ALLEGRA, LENS (SP1, CDP-1) Alexander KUHN, TUM
NRP Product Owner	Axel VON ARNIM, FORTISS
NRP SCRUM Master	Luc GUYOT, EPFL
NRP Client	Marc-Oliver GEWALTIG, EPFL
Liaison Developers	Axel VON ARNIM, FORTISS Luc GUYOT, EPFL Kenny SHARMA, TUM Jacques KAISER, FZI

as of March 2017

7. Appendix 3: List of brainstormed experiments

This Appendix contains a list of all experiments that were discussed during the planning stage of SGA1. Only few experiments were then selected as *pilot experiments* for SGA-1. More details about this list is accessible with full details at:

https://bbpteam.epfl.ch/project/spaces/display/HSP10/Scientific+experiments

The pilot experiments are described in Appendix 4.

1) MOUSE 1 [Mouse] Knocking on Display Wall
2) MOUSE 2 [TUM] Simulation of Basic Musculoskeletal Reflexes
3) MOUSE 3: [BioRob] Forelimb Neuroprosthetic Setup
4) MOUSE walking in hamster treadmill
5) MOUSE 5: Freewalking
6) MOUSE 6: [UGent] Evolving mouse and brain model
7) ROBOTIC-MOUSE (SSSA) Gaze-guided locomotion for a biped robot
8) ROBOTIC 1. (FZI manipulation) Grasping: hand movements for different grasping types
9) ROBOTIC 2. (FZI vision) Visual object recognition
10) ROBOTIC 3. (FZI) Serial working memory and recall
11) ROBOTIC 4. (FZI vision) DVS: Object motion prediction
12) ROBOTIC 5.(Japan) Parkinson disease simulation
13) (Cross-SP) integrating MiRo from Consequential Robotics (Sheffield)
14) (FZI) DVS: Prediction of affordances
15) (FZI manipulation) Grasping: benchmark scenario
16) (FZI manipulation) Model learning of robotics arm
17) (FZI manipulation) Reinforcement learning: Target reaching task for robotic manipulator
18) (FZI) Reinforcement learning: Mouse learning to survive
19) (FZI vision) DVS: Drone with automatic neuronal stabilization
20) (Japan) Motion recognition and generation with text
21) (Japan) Neural maze solving
22) (Japan) Parkinson simulation
23) (Mouse) Mouse Whiskers Detect Collision
24) (Mouse) Real mouse vs. virtual mouse
25) (Mouse) Suspended mouse walking on moving walkway
26) (Mouse) Turning Mouse Head Using Muscles with Visual Representation
27) (Mouse) Turning Mouse Head Using Tendon-driven Concepts with Visual Representation
28) (Mouse) Walking mouse in glass box
29) (SSSA) Emotion-based emergent decision-making on a humanoid robot
30) (SSSA) Implementing visual attention models on virtual humanoid robots
31) (SSSA) Invariant object recognition for motor sequence generation on a humanoid robot

32) (SSSA) Learning motor coordination for visually guided bimanual manipulation(Step by step design of a walking mouse) (feature)

33) (TUM, Conradt) Cleaning up a cluttered scene

34) (TUM, Conradt) Compliance control

35) (UGR) Gain adaptation in distributed cerebellar learning

36) (UGR) Interfacing the cerebellar network with a robotic arm

37) (UGR) Supervised learning rules in the cerebellar model

38) [TUM, Weber] Human+Robot cooperative task solving & imitation learning

39) [TUM] Behavioural Mouse Experiment with Deep Reinforcement Learning

40) [TUM] Differential Extrinsic Plasticity Experiments

41) [TUM] End to End Learning of Sensorimotor Mapping in Autonomous Driving

42) [TUM] Evolving Neural Controllers for Autonomous Vision-based Robots (Redo Physical Experiment)

43) [TUM] Mouse Navigation with Deep End-to-End Learning

44) [TUM] Robustness Evaluation of Walking Algorithms

45) [TUM] Self-Organized Emergence of Cortical Maps

46) [TUM] Walking using CPGs and/or CMA

47) Walking Benchmark Playground

48) ROBOTIC 6 (TUM) Geijtenbeek walking algorithms

49) [TUM] Integrating Roboy

50) [TUM - UCI] Validating evolved retrosplenial cortex activity

51) [TUM - UCI] Using evolved navigation networks to control simulated robotics maze running experiment

52) [TUM - UCI] Modelling episodic memory and memory consolidation using simulated robotics experiment

53) [UCI, TUM] Neurobiological Model of Outdoor Path Planning

8. Appendix 4: List of pilot experiments

8.1 CDP1: Motor learning and rehabilitation-induced cortical remapping after stroke

This experiment is the core Use Case for the mouse brain model and mouse brain atlas developed in CDP1. During SGA1, SP10 has committed large parts of its resources to implementing this use base. The target for the end of SGA-1 is to implement the *protocol* of the experiment in the NRP. Researchers will thus be able to apply the same type of stimuli and perform the same types of measurements as in the real experiment. The details are described as Product 1 of CDP1 and are outlined in Appendix 1. Briefly, the reference experiment is an *in vivo* motor rehabilitation task in which a mouse learns to move a manipulandum. Activity from the mouse and the mouse brain can be recorded before, during and after learning. The experiment has two parts, each representing an important research paradigm in their own right.

The first part is a paradigm for motor learning in healthy animals. In the second part of the experiment a photothrombotic stroke is induced, leading to a loss in motor function. Then, the re-training of the motor task is studied. This part of the experiment is a paradigm for motor rehabilitation after stroke.

The implementation of this CDP1 experiment has been programmed in three steps: the Minimal Viable Product scheduled for M15, the Version 1 for M18 and finally Version 2 for M24.

8.1.1 CDP1 MVP

In this very first version of the CDP1 experiment we want the following features:

- first version of muscle simulation
- basic muscle visualisation in frontend
- mouse model with one limb equipped, passive muscle support
- simplified mouse brain
- basic spinal cord support
- M sled in empty world

8.1.2 CDP1 Version 1

Version 1 will be the first functional version of this experiment. It will include the following features:

- extended muscle visualisation
- full dynamics CDP1 simulation (active muscles)
- faster muscle simulation
- robot designer supporting muscle attachment points
- textured and scaled m-sled
- mouse skin animation
- 3D visualisation of neurons in the mouse brain with activity
- support for large-scale mouse brain model (not real-time)

8.1.3 CDP1 Version 2

Version 2 will be the complete implementation of this experiment.

- full model of M-platform
- modular spinal cord integration
- both forelimbs equipped
- faster mouse brain simulation
- real-time replay of experiment in the front-end

8.2 Mouse locomotion

This experiment is derived from MOUSE walking in hamster treadmill in the experiment list in Appendix 3.

In the first instantiation, a single mouse hind limb is hung in the air in a close-to-empty environment, and is controlled by the OpenSim muscle system. In forthcoming versions, we add the treadmill or a moving walkway, the full mouse skeleton, more muscle-equipped limbs and finally the whole experiment setup.

8.2.1 Mouse-Locomotion MVP:

The Minimal Viable Product is scheduled for M15 and will include the following features:

- one hind limb equipped with muscles, hung in the air
- a spinal cord module loaded as an external ROS node
- the spinal cord controls a realistic movement of the hind limb, through the OpenSim muscle system
- the environment is minimalistic

8.2.2 Mouse-Locomotion V1:

In this version, scheduled for M18, the full mouse is supposed to be standing (without collapsing) and the four legs equipped.

- full mouse skeleton
- two legs equipped with muscles
- mouse stands without collapsing
- a coordinated leg movement is not necessary yet, but some minimal connection with the mouse brain is implemented
- the treadmill/moving walkway is loaded in the environment, but the mouse is standing outside of it
- realistic physical properties (friction, forces)

8.2.3 Mouse-Locomotion V2:

The final experiment (scheduled for M24) is here better described in textual English.

The mouse model is placed in the treadmill (or moving walkway) on which angular speed can be regulated by the experimenter. That way, it can be observed how a neural controller can adapt to changing speeds. This experiment corresponds to experiments conducted with paralyzed mice[7] and will allow the evaluation of functional or data-driven brain models (T10.1.1, T10.1.3) and classical controllers.

[7] Van den Brand R, Heutschi J, Barraud Q et al. Restoring voluntary control of locomotion after paralyzing spinal cord injury. Science 2012;336(6085):1182-5.

The experimental setup including the treadmill/walkway is implemented in the virtual laboratory. The user can interact with the parameters of the experiment, for instance, by changing the speed of the treadmill by adequate user interface elements. Brain and muscular activity can be displayed to the user and be recorded for further offline processing and evaluation.

Suspension or impairment can be induced on the virtual robot mouse and avatar models to observe the controller's' behaviour under the changed conditions. Therefore, either the musculoskeletal system is modified, sensory information such as visual is removed or connections between neurons are cut off.

8.3 Optimizing CPG neuro-controllers for compliant quadruped locomotion

This experiment is derived from MOUSE 6: [UGent] Evolving mouse and brain model in the experiment list in Appendix 3.

8.3.1 MVP

The experiment is scheduled for a minimal integration in M18 and will include:

- a basic model of a quadruped robot using springs in the NRP
- a PyNN model inspired from LSM to drive the motors, as well as an optimisation flow using the Virtual Coach
- a compliant quadruped robot (real platform) to validate the controllers obtained in the NRP (transfer learning)

8.3.2 V1

This version is the final one scheduled for SGA1. It will include transferring the SNN model and optimisation approach detailed in the MVP on the mouse model using bio-inspired muscles.

8.4 Object motion prediction with a Dynamic Vision Sensor (DVS camera)

This is derived from experiment ROBOTIC 4. (FZI vision) DVS: Object motion prediction from the list in Appendix 3. It is scheduled to be integrated in the NRP by M15 and includes:

- a robotic head equipped with two DVS cameras
- support for DVS image stream to the NRP frontend
- an iCub robot waving the hand, which the robotic head can track and head in the direction of

8.5 LWPR and Purkinje/Cerebellar neuron controlled ball balancing

This experiment is scheduled to be integrated in M15.

In this experiment, we use a cerebellar-like model for the motor control and motor learning of the iCub humanoid robot during a ball balancing task.

The cerebellar-like model combines the LWPR algorithm and an analytical implementation of the Purkinje and Deep Cerebellar Nuclei cell layers.

The goal is to move the green ball towards the centre of the table held by the iCub once it appears within camera's field of view. For this aim, the iCub makes use of its right camera, the sensory information from its joints and actuates the joints of its wrist.

The environment is a custom version of the empty world.

8.6 SP3 Miro

This is derived from (Cross-SP) integrating MiRo from Consequential Robotics (Sheffield) in the experiment list in Appendix 3.

This experiment will feature the MiRo robot in a simple set up.

The integration into the Platform is scheduled for M18 and will enable controlled prototyping of a proposed model of spatial memory and navigation based on hippocampal place cell functionality. A multi-choice maze will be explored by the simulated Miro robot to parametrise the real-world experiments being conducted at BRL in SP3.

8.7 SP3 Shrewbot

This experiment will be similar to the previous one, except for the robot which will be the Shrewbot, a robot featuring whiskers developed in SP3. It is inspired by (Mouse) Mouse Whiskers Detect Collision in the experiment list in Appendix 3.

The integration is scheduled for M24 and will enable exploration of the parameter space for the whiskered Shrewbot and the visuo-tactile platform being developed during SGA1 within SP3 (called Whiskeye). Both of these platforms will be used to perform tactile object recognition and visuo-tactile sensory integration based on models of V1, S1 and perirhinal cortex models, being developed at various levels of abstraction, empirically based on multi-ensemble recordings taken from behaving rats.

8.8 Roboy

This is derived from [TUM] Integrating Roboy in the experiment list in Appendix 3.

A first version, called MVP, is scheduled for M18 and a final integration for M24.

Roboy is a tendon-driven humanoid robotic boy currently in further development by a student team at TUM. After integrating the control hierarchy into the standardized ROS framework in iterative development cycles, new versions of Roboy will be built that improve in terms of a more biologically realistic musculoskeletal system as well as integrating additional sensor modalities. http://roboy.org

The development is based on the modular toolkit for tendon-driven robots developed in the Myorobotics project (http://myorobotics.eu/).

8.8.1 Roboy MVP

This minimal integration will include:

- Gazebo muscle plugin that imitates the physical characteristics of Myorobotics muscle units and can be controlled via ROS interface
- Two simulated muscles antagonistically attached to a Myorobotics arm model that consists of two bones connected with a revolute joint, enabling first neural network-based control experiments with a musculoskeletal robot

8.8.2 Roboy V1

The final outcome in SGA1 will include:

- Muscle simulation integrated into the OpenSim muscle simulation framework

- a full Roboy model with muscle actuated arms, example experiment of neural network controlled arm motions