Showcase 3 - DEMO3.1 and Showcase 4 - DEMO4.1 (D2.1 - SGA3)

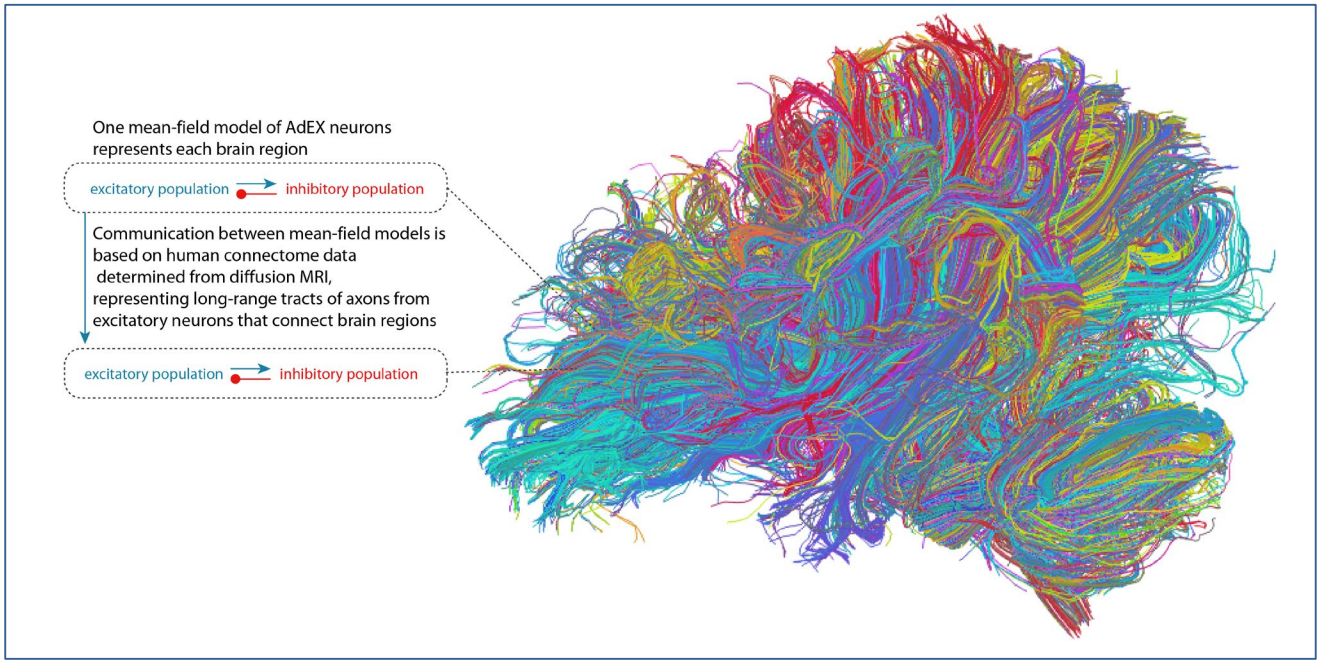

Figure 1: Showcase 3: Introducing TVB-AdEX

TVB-AdEX is a novel method for effectively simulating human brain states

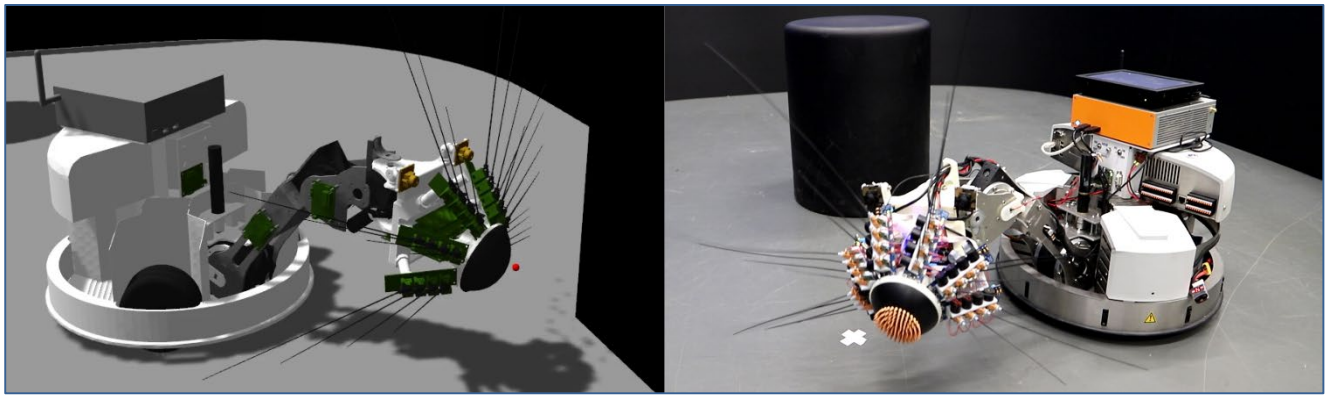

Figure 2: Showcase 4: WhiskEye a visual tactile biomimetic robot

Comments on Figure 2. The WhiskEye robot is integrated with a predictive coding model of primary and associative regions of the cortex that is available on the EBRAINS Neurorobotics Platform.

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Description in GA:	Proof of concept demos of large scale, full brain simulation corresponding to different brain states and consciousness levels (Showcase 3) and robot demonstration and simulation of object and scene recognition v1 (Showcase 4).
Abstract:	Conscious and unconscious brain states differ both at baseline and in response to stimuli. Hallmarks of neural dynamics between brain states span spatio-temporal scales, from neuromodulators acting on ion channels to changes in communication between macroscopic brain regions. Developing a scale integrated understanding of neural computations performed in different brain states therefore remains challenging. Here, using conductance-based mean-field models constrained by human anatomy, we show that different scales spanning from cellular membrane conductances to state transitions in global brain dynamics associated with conscious and unconscious states can be simulated on a laptop using EBRAINS. Both spontaneous and evoked dynamics can be simulated for synchronous and asynchronous brain states, reproducing the typical brain-wide responses of these states, as found in experiments in human subjects (Showcase 3). Departing from such asynchronous, conscious brain states, cognition occurs. We perceive the world by attempting to match our predictions of how it should be against uncertain and incomplete observations through our 6 senses. Deep predictive coding networks are a machine learning approach that models this process at an algorithmic level of description. A novel multi-sensory network architecture based on interconnected but disparate primary sensory and associative cortices has been tested, using live data captured from a biomimetic robot and demonstrated as capable of place recognition comparable to conventional state-of-the-art machine learning approaches. The network model and robot have been

	included into the EBRAINS Neurorobotics Platform for long duration experiments, open science and access to other EBRAINS services (Showcase 4).
Keywords:	Mean-field model, AdEX neurons, full-brain simulations, human neural activity, human connectome, brain states, consciousness, predictive coding, neurorobotics, multi-sensory reconstruction, place recognition
Target Users/Readers:	Computational neuroscience community, computer scientists, consortium members, HPC community, neuroimaging community, neuroinformaticians, neuroscientific community, neuroscientists, platform users, researchers.

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History of Changes made to this Deliverable (post Submission)

Date	Change Requested / Change Made / Other Action
19.01.2021	Deliverable submitted to EC
15.02.2021	Changes requested in Review Report Main changes requested: • Change 1 (Before publication, it would be valuable to add a preamble section explaining the positioning of these showcases and related demos in the context of SGA3 and HBP.)
29.03.2021	Revised draft sent by SP/CDP to PCO. Main changes made, with indication where each change was made: • Change 1 (Before publication, it would be valuable to add a preamble section explaining the positioning of these showcases and related demos in the context of SGA3 and HBP.): Added section 1 (The showcases in the context of SGA3 & HBP) • Change 2 (Sections 2.3 & 2.5: added one reference to a preprint) • Change 3 (Section 3.1: minor improvements on the text) • Change 4 (Section 3.4: minor improvements on the text)
14.04.2021	Revised version resubmitted to EC by PCO via SyGMa

1. The WP2 Showcases in the context of SGA3 & the HBP

WP2 aims to model and understand the different functional states of the brain network and their multiscale nature, ranging from unconsciousness (sleep, anaesthesia, coma) to consciousness, a baseline state for cognition to occur. Such an objective is better approached in a highly collaborative framework like the HBP, which brings together systematically acquired multiscale data and models across different scales. Furthermore, WP2 aims to understand how neurons and networks respond to sensory stimuli at the cellular, meso-scale and whole-brain levels, and how to integrate information from different sensory modalities and perform cognitive tasks, such as multisensory object learning, perception and object-directed behaviour, and to use this knowledge to further explore the relationship between consciousness and cognition.

In this document, we include the first description of two Showcases that, although they do not illustrate all the ongoing work in WP2, are good representatives of our main research lines. Showcase 3 illustrates well the interactions with WP1, since it uses the brain connectome and full brain model of The Virtual Brain, and integrates the data-driven models of different brain states and involved mechanisms explored in WP2. Showcase 4 is a good illustration of the interactions with WP3, since it investigates cognitive functions and contributes to the cognitive architectures of WP3 and uses neurorobotics to explore the environment, gather sensory data and give a body to the data-driven models of cognition.

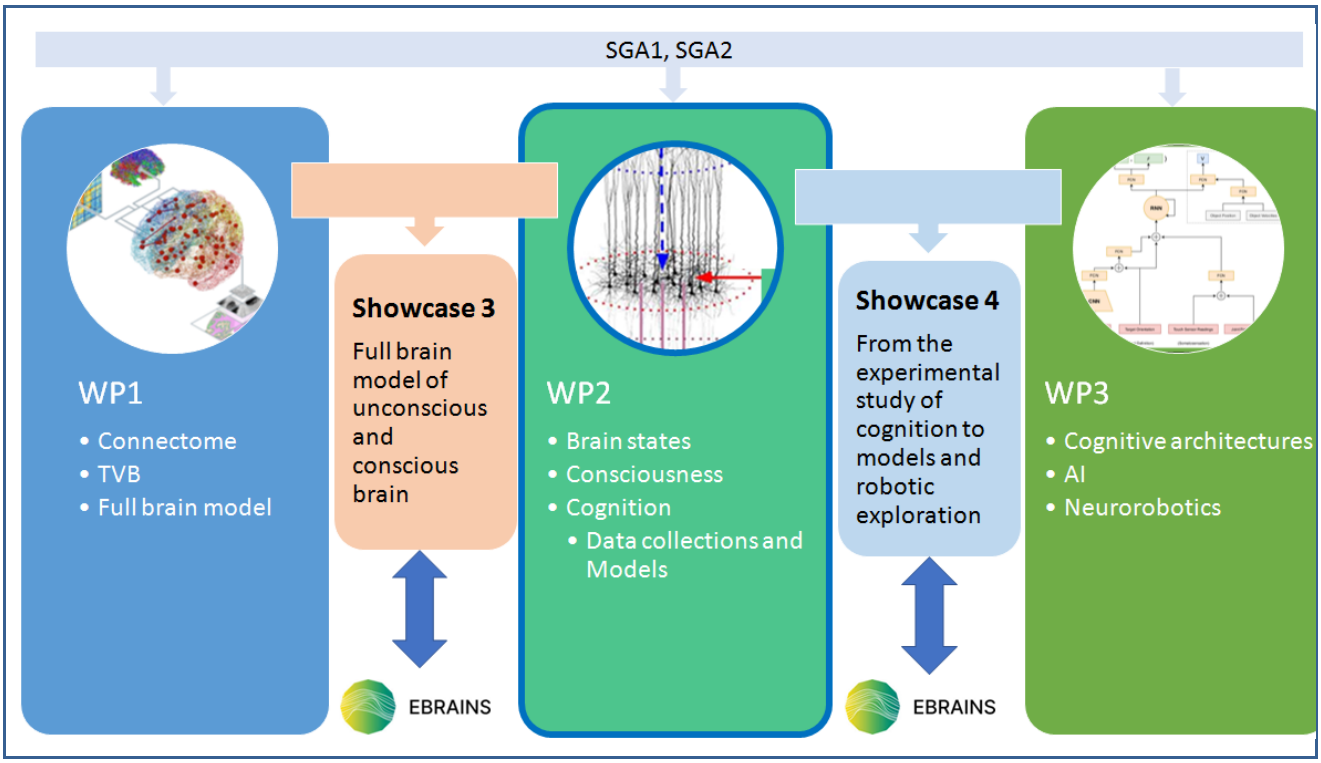

Figure 3: How Showcases 3 and 4 connect the work of WPs 1, 2 and 3.

2. Showcase 3: Brain Complexity and Consciousness

2.1 Introduction

Conscious and unconscious brain states differ, both at baseline and in response to stimuli, with hallmarks spanning spatio-temporal scales, from neuromodulators acting on molecular membrane channels to changes in global communication between brain regions. Developing a scale integrated understanding of neural dynamics and its effects on computations done by the brain in different

states will therefore require linking knowledge spanning ion channel currents (microscale) to the dynamics of brain-wide, distributed, transient functional assemblies (macroscale). Here, using mean-field models of conductance-based, adaptive exponential integrate-and-fire neurons with spike-frequency adaptation, constrained by human anatomy and empirically informed local circuit parameters, we report successful simulation of synchronous and asynchronous brain dynamics, thus connecting microscopic to macroscopic scales. Specifically, it has been previously observed that enhanced neuromodulation by acetylcholine during active brain states closes ion leak channels (blocking K+ M-currents), resulting in sustained depolarization of neurons and blocking spike-frequency adaptation. Neuromodulation-induced depolarisation promotes asynchronous, irregular action potential firing. In contrast, low levels of acetylcholine during unconscious brain states allow membrane leak channels to open, leading to waves of synchronous depolarisation and hyperpolarisation. In this Deliverable, we present a scale integrated model that considers neuromodulation-induced microscopic changes and show that the resulting macroscopic signals are comparable to empirical human data comprising different brain states. This model opens the doors to personalised modelling of human brain states in health and disease, including restful and active waking states, as well as sleep, anaesthesia, and coma.

Understanding consciousness is one of the grand challenges of contemporary neuroscience. Why does it fade and recover during transitions across physiological, pharmacological and pathological brain states? How can we determine whether a behaviourally unresponsive patient is conscious? Can we quantify consciousness levels? Can we use our multi-scale understanding of brain-state transitions to devise strategies to induce recovery of consciousness? A brain-based quantification of the levels of consciousness is of the utmost importance because, each year, intensive care medicine is called upon to treat millions of patients whose level of consciousness is difficult to assess due to severe brain injuries and disconnections. Detecting the fundamental mechanisms of consciousness is crucial, not only for better diagnosis, but also to guide recovery in an optimal manner. Finally, it is critical to provide tools - such as eye tracking or brain computer interfaces - to provide input and output channels for patients who have recovered consciousness but remain disconnected (e.g. locked-in patients). An equally urgent requirement comes from the field of anaesthesiology - pharmacologically induced alterations of consciousness – which is used in millions of patients every year. The effectiveness of this approach is limited by a lack of systematic understanding of the underlying circuit mechanisms and a lack of reliable brain-based measures of anaesthesia depth. Therefore, deeper understanding of consciousness also paves the way to engineering novel methods of tracking the results of pharmacological interventions, as well as engineering next-generation, non-pharmaceutical, direct methods for inducing states of non-responsiveness, with potentially fewer side effects and dangers.

This showcase consists of a DEMO showing simulations of full brain activity, during spontaneous activity and after stimulation. Stimulation results in perturbed or evoked activity, with spatiotemporal interactions between areas that have a different fingerprint, corresponding to different brain states. These brain states can be physiological (sleep or awake), pharmacological (e.g. anaesthesia levels), or due to disorders of consciousness (e.g. traumatic brain injury). For these reasons, we have used the simulation capabilities offered by the Human Brain Project's (HBP's) EBRAINS neuroscience research infrastructure to make access to the models as wide as possible. The simulations delivered here at SGA3 Month 9 (M9 – December 2020) illustrate how emergent patterns of activity can be reproduced *in silico* and shed light on their microscopic underpinnings. These simulations are presented with qualitative and quantitative analyses pioneered in empirical data, for direct comparison to activity recorded during different brain states in actual human subjects.

This work contributes to several areas of active work in the HBP. Firstly, it contributes to modelling, because it is the first time biophysical network models (with sophisticated biophysical features such as adaptation and conductance-based interactions) have contributed to "biologically-realistic" mean-field models (displaying several activity states) and are integrated in EBRAINS to simulate, with computationally non-demanding methods, large-scale network-level (whole brain) simulations. Three distinct scales of modelling are thus integrated here: microscopic (network of neurons), mesoscopic (mean-field), and macroscopic (whole-brain). Secondly, this Showcase contributes to knowledge of Brain States, because the models simulate two fundamentally different brain states, asynchronous (wake-like) and synchronised (sleep-like) dynamics. Thirdly, this Deliverable contributes to research in Cognitive Function because the model captures how information about

stimuli are integrated by different brain areas, a situation which occurs uniquely in asynchronous states, consistent with the high-level sensory integration displayed by the brain in the awake state. Finally, the model delivered here is useful for contributing to knowledge of changes in dynamical complexity between brain states and helps identify mechanisms relating changes in relationships between structural and functional connectivity between different states.

This work is of broad interest to computational neuroscientists, anaesthesiologists, neurologists, cognitive neuroscientists, and physicists. The generality of the tools offered by this Deliverable are due to the enormous flexibility of the models displayed in the showcase that offer the means to connect knowledge of brain function across spatio-temporal scales and identify microscopic mechanisms as key to physiological changes in global brain networks.

This showcase is relevant for several downstream purposes. Firstly, this work is delivered in a manner consistent with the requirements of high-performance computing (HPC), allowing the scaling up of models to more detailed, higher-resolution representations of human brain activity, representations of personalised multi-scale brain activity, as well as parameter exploration and bifurcation analyses. These downstream HPC applications will enrich specific knowledge of individual variation in brain activity related to healthy and abnormal brain states. As such, this work will also bear clinical interest, as we will use the models delivered here to investigate states of consciousness, which will be used as a companion to better understand the results of empirical analyses of spontaneous human brain activity as well as that evoked by sensory stimuli and TMS stimulation in various states of sleep, anaesthesia, coma, and stroke (in conjunction with the HBP Work Package WP1).

2.2 Technical Specification

In the M9 version of Showcase 3, we deliver commented code and supporting documentation to simulate and analyse two different human brain states, first a state of asynchronous activity, which is close to the brain dynamics in EEG-activated states, often called “desynchronized brain state”, such as typically seen in an awake subject. The second state simulated is slow-wave activity, which is more synchronised across the brain, and is reminiscent of slow-wave sleep (SWS). The showcase is written in Python and it is delivered in commented Jupyter Notebooks that will be made publicly available via EBRAINS and GitHub.

This Deliverable is divided into two parts, both showing asynchronous and synchronous dynamics. The first part offers code to simulate spontaneous, ongoing, background dynamics in the absence of stimuli. In part one, the EBRAINS user can visualise the qualitative features of signals through figures embedded in the code, including the signals from one brain region alone and all brain regions together. Furthermore, plots of the firing rates are made in anatomical space, showing the activity of the 76 brain regions simulated here. The code ends by producing a Gif of firing rate dynamics through time. Further, quantitative features of the simulated spontaneous activity are examined through analyses also embedded in the code. These analyses show shifts between synchronous and asynchronous states consistent with empirical findings. The included analyses are histograms of the firing rates of excitatory and inhibitory mean-fields, power spectral analysis, correlation between structural and functional connectivity, functional connectivity matrices, Hilbert transform and calculation of Phase Lag Index.

In Part 2 of the M9 Showcase 3, stimuli perturb the spontaneous activity of synchronous and asynchronous states, showing qualitative differences reminiscent of evoked human brain activity in different states of consciousness. In particular, stimuli evoke changes in brain dynamics that propagate relatively further in space and time during conscious compared to unconscious brain states. This phenomenon can be quantified using the Perturbational Complexity Index (PCI). One form of PCI [1] has been programmed into Part 2 to demonstrate similarities between the simulations and empirical data.

The model is a bottom-up construction which started in SGA1 by conceiving spiking (AdEx) models of excitatory and inhibitory networks of the human brain [2-4]. These models were constrained based on micro-electrode data in humans. Population models were then derived for AdEx networks in SGA2 using mean-field techniques. These mean-field models were shown to accurately capture the excitatory and inhibitory interactions in cerebral cortex. In SGA3, the mean-field models were

integrated in the Virtual Brain (TVB) using its EBRAINS implementation. The AdEx mean-field model can simulate asynchronous states (based on asynchronous irregular firing of neurons) and Up/Down states (which is the cellular correlate of slow waves). The TVB implementation of the mean-field models can thus simulate either desynchronised activity or slow-waves at the level of the entire human brain (whole-brain simulations).

These TVB simulations can reproduce the main features of the TMS stimulation in human: brain responses tend to be stereotyped and with little propagation during sleep, which gives a low PCI value, while in awake subjects, the response is typically complex and propagates all across the brain, a situation which corresponds to high PCI values. The Showcase 3 TVB-AdEx simulations qualitatively reproduce these observations (Figure 4 & Figure 5). These simulations can be run interactively in EBRAINS, where the user can change all parameters and simulate asynchronous awake-like and synchronous sleep-like brain responses.

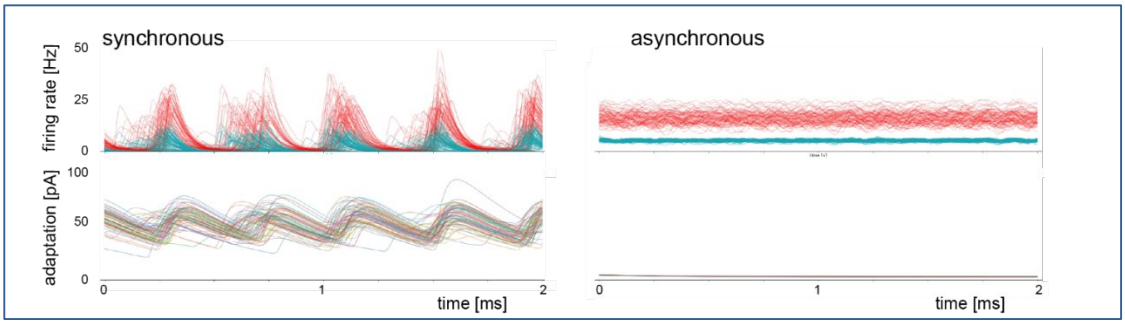

Figure 4: Spontaneous whole-brain activity in synchronous and asynchronous states

Spontaneous whole-brain activity in synchronous and asynchronous states simulated with the EBRAINS implementation of AdEx mean-field models connected through TVB.

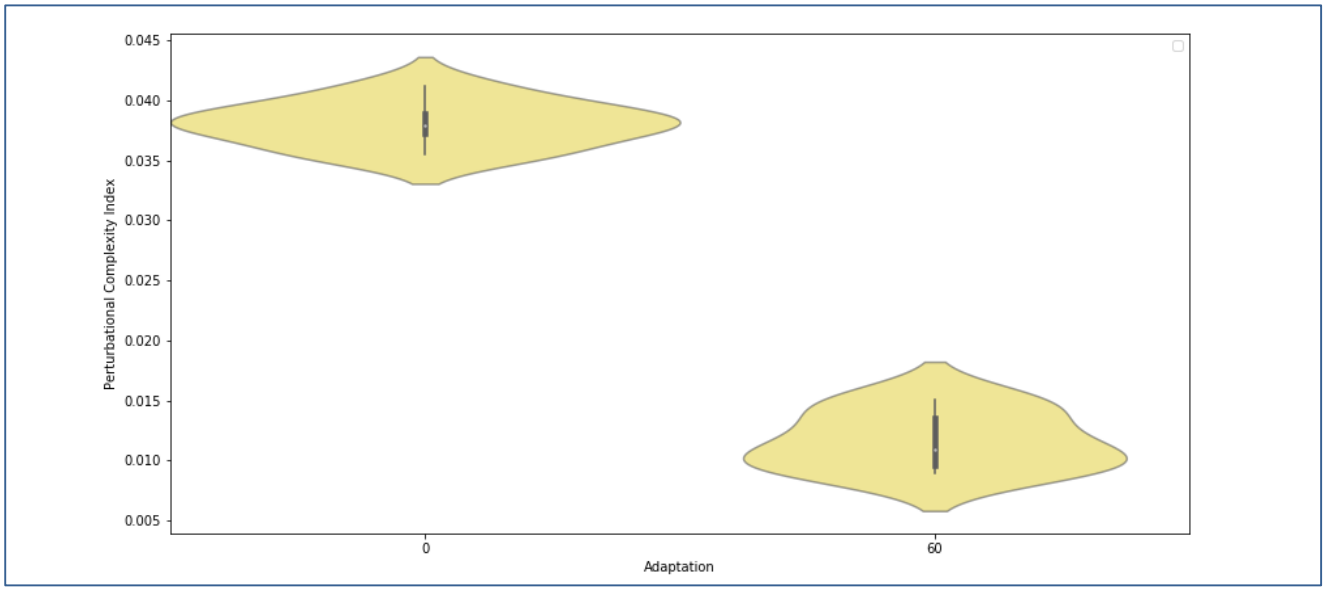

Figure 5: AdEx-TVB simulations produce evoked activity and PCI measurements that change with simulated brain state

Asynchronous activity (left) produces more complex brain responses with higher PCI values, while synchronized slow-wave activities (right) gives simpler brain responses and lower PCI.

A brief summary of the input, protocol and output of the showcase is outlined below:

2.2.1 Input

A human connectome determined from diffusion magnetic resonance imaging collected in the Human Connectome Project, which can be found in:

https://zenodo.org/record/4263723#.X9vvhulKg1J (berlin subjects/DH_20120806)

and biophysically informed neuronal parameters are introduced into mean-field populations of AdEX neurons in the The Virtual Brain framework [5-6].

2.2.2 Protocol

- Run TVB-AdEX in a Jupyter notebook.
- Part 1: Spontaneous activity. All parameters can be varied, but here we explicitly change the spike frequency adaptation to generate asynchronous and synchronous states.
- Part 2: Evoked activity. Perturbations are introduced into the model to understand differences in the brain responsiveness. In this code, we perturb the right pre-motor cortex and calculate the Perturbational Complexity Index, for qualitative and quantitative comparison to the experiments of Marcello Massimini and colleagues [7-9].

2.2.3 Output

Part 1: Synchronous and asynchronous signals representing simulated spontaneous whole-brain neural dynamics, produced by varying levels of spike-frequency adaptation (b_e), representing physiological, molecular changes in neuromodulation between brain states.

- Histograms
- Power spectra
- Correlation between structural and functional connectivity
- Functional connectivity matrices
- Hilbert transform and Phase Lag Index (PLI)

Part 2: Signals representing simulated evoked activity resulting from the perturbation of a model node.

- Generation of averaged signals from several seeds to resemble event-related potentials (ERPs).
- Calculation of Perturbational Complexity Index in synchronous and asynchronous states.

2.3 How to access the Showcase

The Showcase 3 is located in the following EBRAINS Wiki Collaboratory:

https://wiki.ebrains.eu/bin/view/Collabs/showcase-3-tvb-adex

If you don't have access to it, please contact one of the following: Alain Destexhe (destexhe@unic.cnrs-gif.fr), Jennifer Goldman (jennifer.goldman.mcgill@gmail.com) or Arnau Manasanch (manasanch@clinic.cat).

To access the Showcase Demo 3.1 video:

https://youtu.be/B9RlXpv8hEg

If order to execute the DEMO, please follow these steps:

- Go to lab.ebrains.eu and log-in with your EBRAINS account.
- On the left, navigate to the following directory:
- Drive/Shared with Groups/Showcase3; TVB-AdEX/tvb-adex-showcase3-git
- To run the notebook for **spontaneous** activity, open the notebooks:
  - "Showcase3_part1_synchronous_TVB_AdEX_example_and_analysis.ipynb"
  - "Showcase3_part1_asynchronous_TVB_AdEX_example_and_analysis.ipynb"
- To run the notebook for **evoked** activity:

- Open the notebook "Showcase3_part2_EvokedActivity_PCI.ipynb"

- Follow the guidelines in each of the notebooks.
- More information regarding the models, equations and parameters used can be found in the following preprint: https://www.biorxiv.org/content/10.1101/2020.12.28.424574v1. [10]

2.4 Looking Forward

The specifications of the Showcase 3 to be delivered in M21 are described in Output 2.3 (release date M9)

Here, we show that known differences at the molecular and global levels in brain dynamics between brain states are easily relatable through mean-field models that represent local populations of neurons, connected based on experimentally-determined human structural connectomes. This region-based brain model replicates several qualitative and quantitative experimental observations of human brain states and shows that synchronous or asynchronous macroscopic dynamics can emerge at the whole-brain level from microscopic changes in neuronal membrane channels that promote or inhibit spike-frequency adaptation.

The delivery of this model represents the first in a series of advances made possible by the implementation and sharing of this model. These simulations can next be scaled up and made more accurate by scaling down the size of model nodes representing hundreds of thousands of individual cortical columns in the human brain, instead of the rough 68 regions anatomical parcellation delivered here. Connecting this model with HBP HPC tools will further allow the exploration of phase space and further characterisation of transitions.

The model presented here roughly reproduces synchronous and asynchronous states that have been previously observed experimentally to vary with consciousness. We will next explore more deeply changes between healthy brain states, including active and restful waking, REM and NREM sleep. The model will also be used to reproduce the dynamics of abnormal brain states associated with loss of consciousness, including coma and anaesthesia, as well as other dynamic diseases including epilepsy. In all simulations made possible by the delivery of this model, physiological phenomena including changes in functional connectivity and neural coding can be probed to further promote the harmonisation of experimental results and the foundations for future empirical discoveries. Beyond the ability to study commonly used, but often poorly understood, analysis methods for human neuro-imaging, the delivery of this model also makes possible a new generation of methods that is informed from deep insight into the mechanisms generating transitions between brain states, and their consequences for neural information.

The present model is a generalisation of brain activity that can be further used to study individual variability. Human connectivity data and corresponding spontaneous and evoked dynamics are provided by the Human Connectome Project and by Marcello Massimini's group, as well as inter-region heterogeneity provided by The Big Brain. These data will serve as bases to study the variation of statistics within human populations and between populations within individual human brains for personalised brain modelling purposes.

Finally, the anatomical backbone and functional parameters of this model can be substituted to study other animals. The Allen Institute offers a rich database of neuronal connectivity from axonal tracing studies in mouse, providing a ground truth to anchor connectivity determined in neuroimaging experiments, as well as providing models adapted to better understanding experiments performed in mice. In conclusion, this model delivers a biophysically-informed model that summarises microscopic to macroscopic dynamics and their differences between brain states that serves as precedent for the scale-integration of evolving neural network models, including those describing detailed neuronal morphologies.

2.5 References

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3. Showcase 4: Perception and Recognition of Objects and Scenes

3.1 Introduction

We experience changes in the world through our six senses. As we move, we predict how the changes in our multi-sensory experience should proceed. Perception is essentially a reconstructive process, by which the brain generates representations about what goes on in the world and improves these by comparisons to actual sensory inputs. If our predictions are wrong, then we attend to these inconsistences and act accordingly. Adopting the general principle of the brain as a prediction engine is attractive, as it potentially unifies many aspects of cognition such as perception, planning and attention. However, more concrete investigation is still required. In this showcase, we focus on an algorithmic-level description of the predictive brain, so called predictive coding networks, and in this first demonstration, we look at how they can be used to solve the real-world problem of multi-sensory place recognition.

A novel "Multi-modal deep Predictive coding Network" (MultiPredNet) has been constructed within the HBP and has been integrated with a mobile biomimetic robotic model of a rat - the "WhiskEye" - that can combine physical whisker tactile data and visual data from head mounted cameras to perform place recognition in a real-world arena. The network model contends the inter-relationship between visual, somatosensory and associative cortices and is inspired by an experimental neuroscience investigation into cross-modal object recognition in rat, also conducted within the HBP.

The WhiskEye robot is driven using a neural cognitive architecture based on functional models of basal ganglia, superior colliculus and cerebellum resulting in a tactile attention-driven behaviour in the robot inspired by observed rat behaviour. Visual-tactile views of the world are captured by the robot in synchrony with the whisking phase to initially train the MultiPredNet and then to infer location through the joint latent representations generated by the network.

To measure performance in place recognition, we adopt Representational Similarity Analysis whereby the rank order of pose and representation distance between samples in a data set are compared. This has revealed that the MultiPredNet has equivalent performance in place recognition to state-of-the-art multi-modal variational auto encoders (a method used in AI). This is interesting to the neuroscience, machine-learning and robotics communities, as we demonstrate that a brain-inspired model of self-learning can be applied to a hard robotics problem. Furthermore, the distributed and local learning rules of the MultiPredNet make it amenable to implementation in parallel computing such as neuromorphic hardware. MultiPredNet is also linearly extensible to integrate additional sensory input channels, directly addressing a current challenge in the training phase of multi-modal VAE systems allowing for self-contained learning and retrieval.

To enable longer duration experiments for further validation and to provide access to the WhiskEye platform for other research groups, a virtual model has been instantiated into the Neurorobotics Platform (NRP) of EBRAINS. The whisker dynamics were approximated due to constraints of the current NRP world simulator; however, statistics from the physical whiskers have been incorporated into the model to improve realism. The code base for the multi-modal deep predictive coding network and data analysis tools are also available on the EBRAINS Knowledge Graph (KG), such that data sets gathered from the virtual WhiskEye can be used to train models and compare performance using the tools developed in this study.

The goals of the next phase of this Showcase will be aimed at the development of different computational models at different levels of biological realism, and models with extended cognitive capacities. These models can serve as connection between the computational strategies used by the WhiskEye robot and the ones associated with behaviour during a multisensory task in rats. More specifically, a spike-based model of a predictive coding network will be evaluated, and will be extended to architectures for e.g. categorisation, feature integration and view-invariance. Moreover, an interactive demo will be built, integrating experimental data from electrophysiology and human brain imaging with model simulations in a video. This will require further use of EBRAINS, including both the NRP and KG as used here, but the High-Performance Analytics and Computing Platform and Neuromorphic Computing Platform will also be required.

3.2 Technical Specification

The Multisensory Predictive Coding Network (MultiPredNet) combines three predictive coding networks: a visual sensory network, a tactile sensory network and a joint-modal associative network. Each is composed of the same basic components and network architecture, but with a different number of layers and neurons in each. The MultiPredNet will be trained using datasets captured from the WhiskEye robot as it explores the environment driven by the model of rat behaviour described above. Once trained, the network can be validated against datasets captured by the WhiskEye as it explores novel environments that have structural similarities to the original training environment. To measure the performance of the network in place recognition, we compare the rank order of ground-truth pose distance between samples in the dataset with the rank order of distance between inferred joint representations across the sampled dataset. A summary of the interaction with EBRAINS and the workflow for the demonstrator is visualised in Figure 6 below.

To generate data from the WhiskEye to train and test MultiPredNet, a virtual model of the WhiskEye has been ported into the EBRAINS NRP. The user can clone an instance of the full WhiskEye experiment into their own experimental folder to explore the control architecture and modify parameters. The WhiskEye platform can be situated in the standard arena used to gather the initial data set or into custom made environments defined by the user. The control architecture of the physical WhiskEye has been mapped into the Closed Loop Engine of the NRP, such that it has a synchronous time coupling with the world simulator. This will allow for extensions to the architecture including interfacing with the NEST simulator and the SPINNAKER neuromorphic platform. To collect

a dataset, the user simply needs to press record in the NRP user GUI; this will gather the messages passed on the required ROS topics into a timestamped data archive called a ROSBAG.

The raw ROSBAG data files gathered from the WhiskEye experiment on the NRP then need to be converted into training and test sets for the MultiPredNet. The scripts to do this will be available for download from the EBRAINS KG, alongside existing baseline datasets for comparison. The MultiPredNet training and test code will also be available on the KG, hosted as git repositories along with the analysis scripts to generate figures and performance metrics.

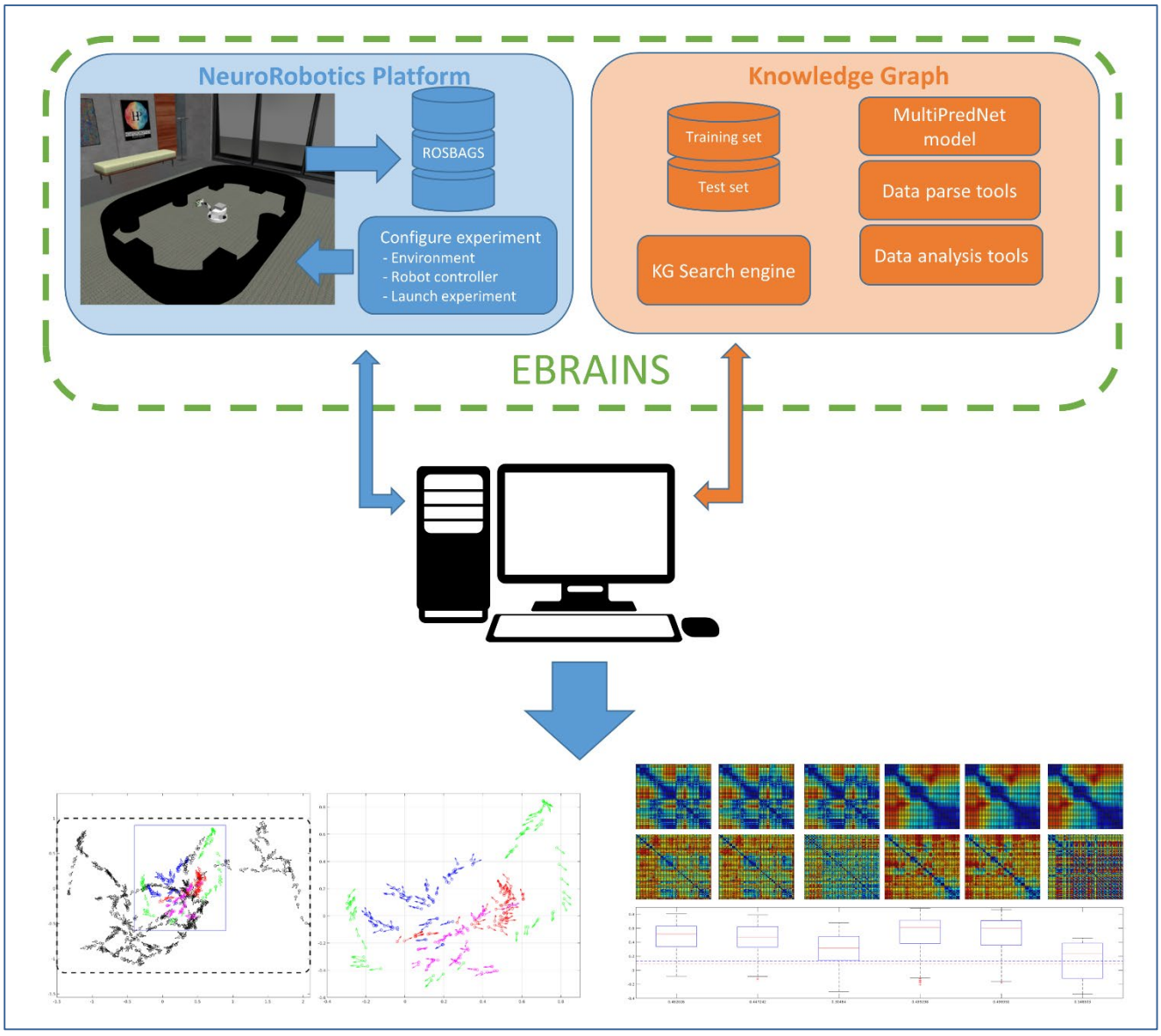

Figure 6: Workflow diagram of Demo 4.1

Comments on Figure 5. WhiskEye experiments launched on the EBRAINS NRP to generate datasets. MultiPredNet source code referenced from the KG can be trained, tested and evaluated. Analysis tools will generate figures illustrating, for example, place recognition performance (lower right) and ground truth pose of WhiskEye (lower left).

3.3 How to access the Showcase

To access the Showcase Demo 4.1 video:

https://youtu.be/0blgdAE1cbk

To access the WhiskEye experiment on the EBRAINS NRP:

https://neurorobotics.net/access-the-nrp.html

(*Note: WhiskEye experiment will be included in NRP release 3.1 due M9-10)

To access the model code base (data parse scripts, MultiPredNet code and analysis tools) for Showcase 4:

https://kg.ebrains.eu/search/instances/Model/2164c2b9bbb66b42ce358d108b5081ce

3.4 Looking forward

The specifications of the Showcase 4 to be delivered in M21 are described in Output 2.3 (release date M9).

In the next stages of SGA3, Showcase 4 will increasingly focus on the development of computational models able to provide predictions and insight at different levels of biological and behavioural complexity, including models with a strong focus on neural dynamics, biologically plausible architectures and learning rules, and cognitive and/or behavioural aspects from the point of view of the predictive coding framework. These models will be linked to the ones developed for Showcase 4.1 and will make increasing use of experimental data from rats and humans which has been or is being collected; for example, in the Pennartz and Düzel labs.

A first step in this direction will consist of developing brain-based deep neural network architectures for visual and tactile predictive coding for constructing sensory representations from sensory inputs. These architectures mimic the overall structure of the visual and somatosensory cortical systems. The current version of this model is constituted by a three-layered spiking neural network, trained using biologically plausible (Hebbian) learning rules to classify visual images (MNIST data set) and generate internal top-down predictions which match the bottom-up sensory input, or which generate the corresponding prediction errors to drive further learning. The network includes a fast route relaying coarse-grained information on the gist of a scene, which triggers image-specific priors in top layers of the hierarchy.

As a direct expansion to the previous model, we will build a model with an ability for view-invariant object categorisation and recognition in a predictive coding framework. This model will first reach preliminary levels of translation and possibly rotation or translation-invariance, to later progress to include two simultaneous modalities (corresponding to visual and tactile stimuli) and different stimulus features. This module will provide a computational framework to be used by the Whiskeye robot in the EBRAINS NRP.

Finally, we will develop a more biologically realistic spiking cortical column model, constrained by available connectivity data from the literature and the KG. The model will include details on different neuron types, postsynaptic receptors, and cortical layers. For the final stages of the showcase, biologically plausible learning rules will be introduced to perform predictive coding for multisensory tasks, and different patterns of activity such as multi-stability or oscillations will be analysed.

3.5 References

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