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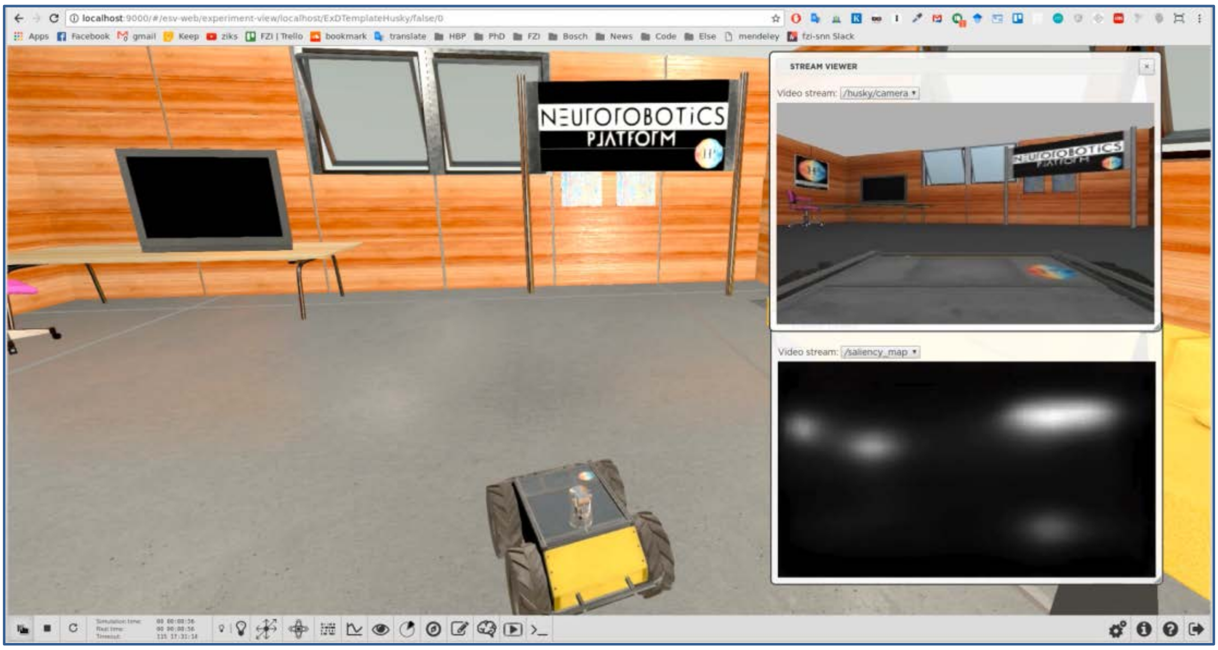
Abstract:

This deliverable is the annual compound of HBP deliveries and results (outputs and outcomes) from Co-Design Project CDP4 – Visuo-Motor Integration. The live complete catalogue of HBP deliveries is online accessible at the HBP portal.

The Key Results from April-2017 to March-2018 are:

1) Implementation of saccade target selection model
2) Implementation of image distortion based on retinal cell density
3) Embedding salience detection architecture (deep convolutional autoencoder), target selection and saccade generation model into robotic system as a closed loop
4) Publication of task-related changes in effective connectivity within large-scale model architecture
5) Publication of re-implementation of saccade generator model using the NEST simulator
6) Contribution of new neuron types to NEST simulator (release v 2.16.0)

Keywords: visuo-motor integration, deep learning, autoencoder, rate neurons, NEST, target selection, saccade generation, connectivity



A robot (husky UGV) computing salience, the degree to which an object stands out from its surroundings, over a simulated environment in the Neurorobotics Platform. A deep convolutional autoencoder, developed by Alexander Kroner at Maastricht University, computes salience (lower right inlay) in real time over the robot's visual field (upper right inlay). The salience detection architecture was embedded in a robotic system in collaboration with the developers of the Neurorobotics Platform, notably Jaques Kaiser.

Targeted users/readers	Researchers, Policy Makers
Contributing Work-Package(s):	SGA1 WPs 2.4, 4.4, 7.1, 10.1
Initially Planned Delivery Date:	SGA1 M24 / 31 03 2018

Authors:	Mario SENDEN, UM (P117)
Compiling Editors:	Mario SENDEN, UM (P117)
Contributors:	Rainer GOEBEL, UM (P117) Mario SENDEN, UM (P117)
SciTechCoord Review:	Science and Tech Coordination (SP11)
Editorial Review:	EPFL (P1): Annemieke MICHELS

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1. Introduction

Human vision is characterised by a central region of high resolution (high visual acuity) and a continuous resolution drop-off with increasing distance from the centre of fixation. This creates the need for an exploration of a visual scene in the form of quick snapshots. The rapid eye movements (saccades) by which this exploration occurs are of major interest for understanding visuo-motor integration. The Co-Design Project 'Visuo-Motor Integration' (CDP4) is dedicated to build a large-scale network architecture of visuo-motor integration following a teleological approach. As such, CDP4 pursued two goals within the period determined by the first specific grant agreement (SGA1). The first was scientific and was subdivided into four milestones. First, the identification of functional components relevant for a “saccades for object recognition” loop. This was largely based on reviewing the existing literature over the first six months of SGA1. Second, development and testing of computational models of these individual components. This occurred in collaboration between Maastricht University and HBP members in Germany and Spain. Third, integrating these components into a single architecture. Finally, embedding the architecture in a closed-loop robotic system. To achieve this goal, we have worked tightly with robotics researchers in Germany. The second goal was platform oriented and involved an extension of the NEST Platform with rate neuron models as well as extending the Neurorobotics Platform with deep learning capabilities.

2. Results

This is the list of Key Results, the outputs and outcomes from Co-Design Project CDP4 – Visuo-Motor integration. Each Key Result is presented together with the list of the corresponding HBP Components which constitute/contribute to this element, and a table is provided for each newly released (brand new or new version) Component. Key Results can also be a major integration of existing HBP or external Components or the achievement of a CDP’s objective or related major Use Case.

2.1 Saccade target selection model

One of the areas we focused on during the last 12 months was to build a retinotopically organised (neighbouring points in the visual scene are represented by neighbouring neurons of the model) multiple-choice competitive decision-making model of “movement neurons” in the frontal eye fields. The model consists of a sheet of laterally connected rate neurons mutually competing for activity. Each model neuron receives input from a retinotopically aligned “visual neuron” coding for salience at the neuron’s location.

We implemented a first version of the model in Python 2.7 which we subsequently made available to robotics experts for internal testing on the Neurorobotics Platform. A second version of the model has recently been implemented in the NEST simulator and makes use of NEST’ s new rate neuron capabilities.

This model is important as it constitutes one critical component of the eye-movement architecture forming the link between salience computation and saccade generation. Target selection and its interaction with other components has important implications for perceived visual stability in light of visual displacement. It is likely that the activity of visual neurons in the frontal eye fields is modulated by upcoming saccades through a corollary discharge. How the resulting shifts as well as distortions affect selection of upcoming saccade targets remains an open question with implications for transsaccadic perceptual continuity. As such, the target selection model constitutes a potential starting point for developing hypotheses of how the brain achieves visual stability.

2.1.1 Achieved Impact

Through the development of the target selection model we were able to strengthen our collaboration with neuroroboticists at the Forschungszentrum für Informatik in Karlsruhe who used our model to build a closed-loop embedded visual memory model able to fixate highly salient targets, recognise objects at fixation, and store their location in memory. Furthermore, our model inspired the robotics group in Munich to provide their virtual iCub robot with an increased range of eye movements. Originally, the virtual iCub was limited to horizontal eye movements.

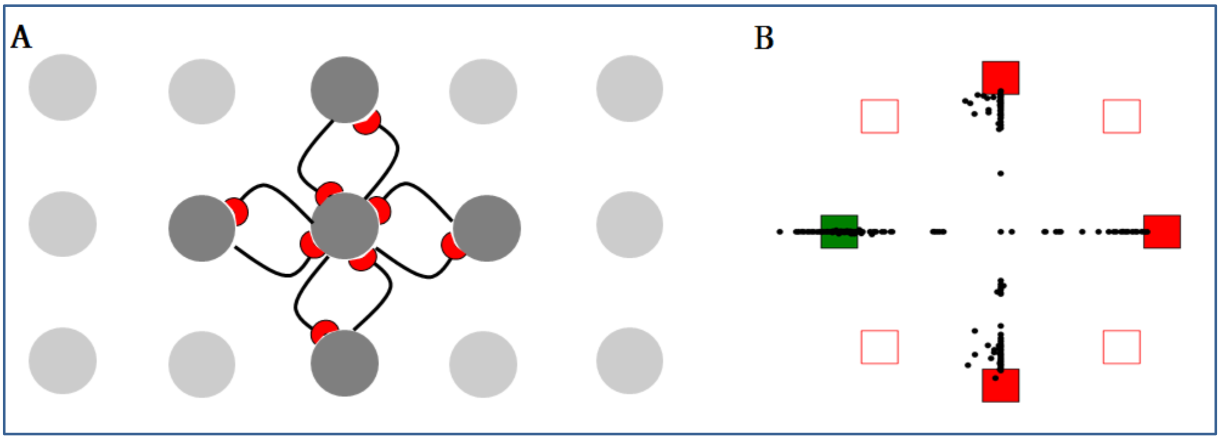

Figure 1: Target selection model.

Panel A) shows a schematic overview of the sheet of interacting movement neurons. For clarity, only connections between a central neuron and its four neighbours are shown. The lateral interaction pattern extends in the same vain across the entire sheet. All lateral interactions are exclusively inhibitory with exact strength decaying with distance between neurons. Panel B) shows selected targets in a visual search task with 8 possible locations (square boxes), three visible distractors (filled with red), and one target (filled with green).

2.1.2 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
209	NEST - The Neural Simulation Tool	No	Model is implemented in NEST simulator
510	Continuous dynamics code in NEST	No	Individual components of the large-scale architecture are implemented using spiking neurons at different rates. It is thus necessary to ensure that communication between components remains functional.
809	Measurements from Cognitive Experiments Performed *In Silico* on the Neurorobotics Platform	No	The target selection model is one component of a large-scale visuomotor architecture and forms the basis for cognitive experiments performed *in silico* (as well as *in vivo*).

2.2 Biologically plausible image distortion

Another aim during the last 12 months was to develop an algorithm which distorts images in accordance with properties of the human retina and early visual cortex. The algorithm is based on a mathematical description of the relationship between the density of ganglion cells in the retina and eccentricity (retinal distance from fixation). Image distortion also takes into account: i) viewing distance, ii) typical receptive field sizes in early visual cortex, and iii) filter size in computational models/convolutional architectures.

A first version of the model implemented in Python 2.7 was released for internal use.

This algorithm strongly increases the biological realism of the visuomotor architecture as it implements an important constraint faced by the visual system. In this regard it also forms the raison d'être for saccadic eye movements as it captures the sharp drop-off in visual acuity with increasing eccentricity making eye movements necessary for object recognition.

2.2.1 Achieved Impact

This work resulted in a new contact for a future collaboration between Maastricht University and the Ecole Polytechnique Fédérale de Lausanne on the development of biologically realistic models of the retina. This collaboration highlights the complementary nature of different forms of biological realism. While the retina model includes realistic neuron dynamics, the distortion algorithm provides realistic sampling of the visual field.

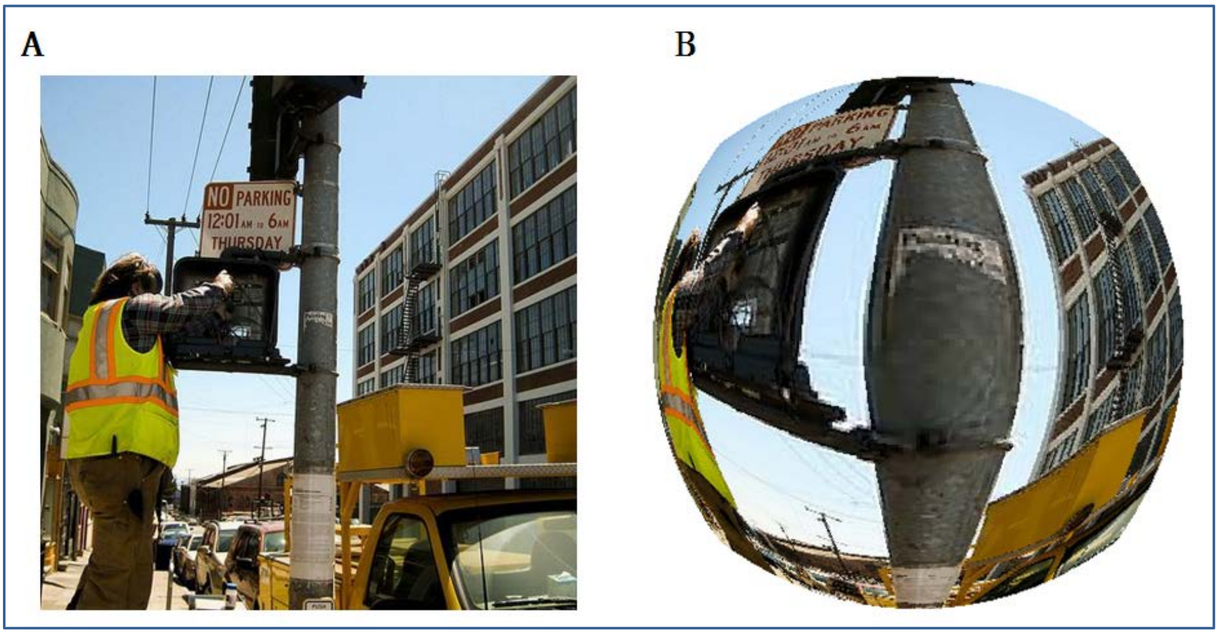

Figure 2: Image distortion.

Panel A) shows an image of a street worker in a busy street. Panel B) shows a distorted version of the same image reflective of the input the early visual cortex receives from the retina.

2.2.2 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
809	Measurements from Cognitive Experiments Performed *In Silico* on the Neurorobotics Platform	No	The visual distortion will affect all subsequent stages of the visuo-motor loop and will be a source of a range of *in silico* experiments.

2.3 Task-related effective connectivity

Since our goal is to build an architecture comprising several modules which in turn comprise of several distinct cortical (and subcortical) brain regions, a period during the last 12 months was devoted to investigating communication between a large set of cortical regions under different task demands. To do so, a noise-diffusion model was developed which tunes structural effective connectivity in order to reproduce empirically observed (with fMRI) functional connectivity profiles.

The results of these investigations were published in Human Brain Mapping:

Senden, M., Reuter, N., van den Heuvel, M. P., Goebel, R., Deco, G., & Gilson, M. (2018). Task-related effective connectivity reveals that the cortical rich club gates cortex-wide communication. Human Brain Mapping, 39(3), 1246–1262. https://doi.org/10.1002/hbm.23913

These modelling and neuroimaging results are important, because they are instructive when integrating each component of the visuo-motor architecture into a single whole; especially as we aim to increase the biological realism of our architecture. For instance, while salience forms a single functional component, it is distributed over a network involving the frontal eye fields, posterior parietal cortex, and the superior colliculus. Taking into consideration how interactions between these regions may result from direct as well as indirect communication pathways (via other regions and components) to a certain extent guards against the risk of developing an overly simplified architecture.

2.3.1 Achieved Impact

We achieved an improved understanding of the dynamic interactions between a large set of brain regions cooperatively executing cognitive tasks which will guide us in the integration of models of individual functional components into a unified large-scale architecture of visuo-motor integration. As mentioned before, the work has recently been published in an academic journal. Furthermore, it was presented as invited talk at the bi-annual Whistler workshop 'Brain Functional Organization, Connectivity, and Behavior' in Whistler, Canada, March 5, 2018. Finally, it resulted in a collaboration between three HBP partners (Maastricht University, Forschungszentrum Jülich, and Universitat Pompeu Fabra Barcelona) and an external institute (Brain Rudolf Magnus Center Utrecht).

2.3.2 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
1070	Collective behaviour of mean-field and neural population models: A comparative study	No	Model relied on neural mass models

2.4 Saccade generator

During the last 12 months, the saccade generation model originally proposed by Gancarz and Grossberg (1998) was key to drive the development of new neuron models for the NEST simulator. The successful implementation of this model in NEST showcases the extended capabilities of the NEST framework; it was published in the journal ReScience: Senden, M., Schuecker, J., Hahne, J., Diesmann, M., and Goebel, R. (2018). [Re] A neural model of the saccade generator in the reticular formation.

A final version of the model was implemented in the NEST simulator; it uses NEST's new rate neuron capabilities.

This model is important as it constitutes another critical component of the eye movement architecture that forms the link between target selection and actuators controlling the eyes/camera of a robotic system. Saccade generation and its interaction with other components have important implications for perceived visual stability in light of visual displacement. As such, they constitute a potential starting point for developing hypotheses on how the brain achieves visual stability.

2.4.1 Achieved Impact

Implementation of this model drove the integration of rate neuron models into NEST v2.16.0, it was successfully integrated into the Neurorobotics Platform. Moreover, it has resulted in a publication in an academic journal.

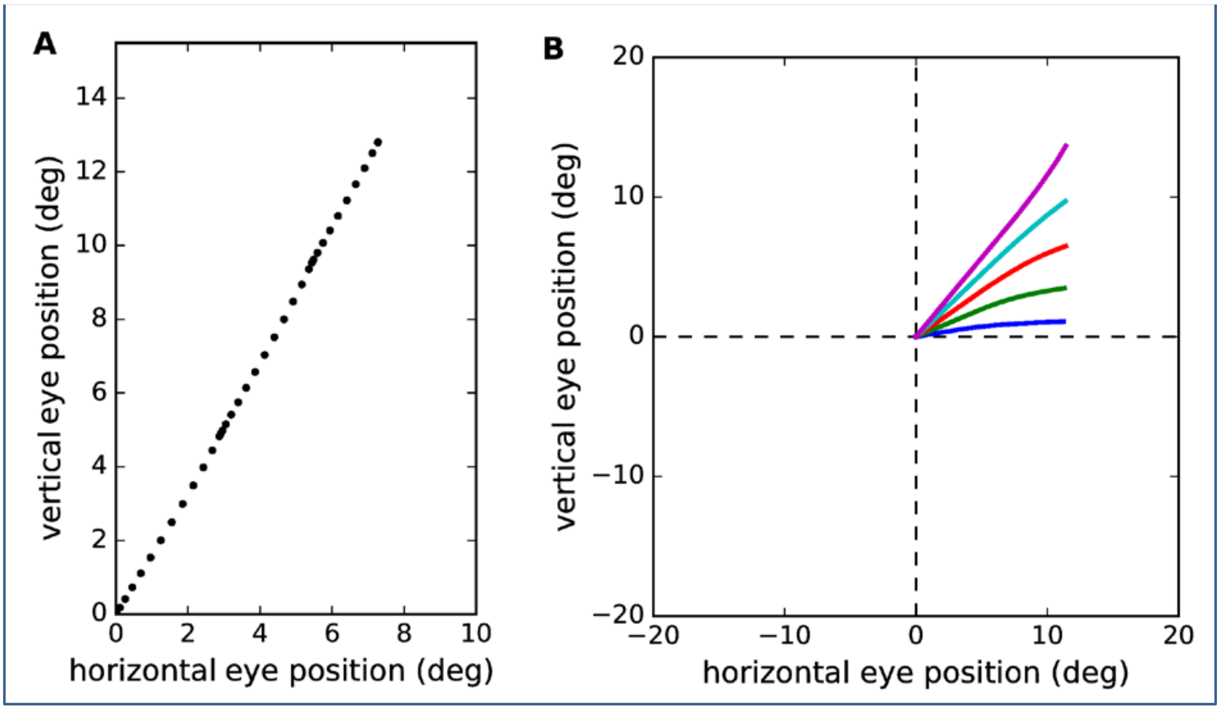

Figure 3: Saccadic eye movements

Panel A shows eye-simulated eye positions as the model generates eye movements towards the upper right corner. Dense collections of points indicate that the eye landed near that spot and remained there for a short while (fixation) before proceeding quickly to the next fixation in ballistic jumps (saccades). Panel B shows the typical shape of simulated trajectories of the eye for a range of different desired targets.

2.4.2 Component Dependencies

Component ID	Component Name	HBP Internal	Comment
209	NEST - The Neural Simulation Tool	No	Model is implemented in NEST simulator
510	Continuous dynamics code in NEST	No	Individual components of the large-scale architecture are implemented using spiking neurons at different rates. It is thus necessary to ensure that communication between components remains functional.

809	Measurements from Cognitive Experiments Performed In Silico on the Neurorobotics Platform	No	The saccade generation model is one component of a large-scale visuo-motor architecture and forms the basis for cognitive experiments performed *in silico* (as well as *in vivo*).

3. Component Details

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

3.1 Target selection model

Field Name	Field Content	Additional Information
ID	14331	
Component Type	model	
Contact	SENDEN, Mario	
Component Description	This model selects targets for eye movements based on salience distribution.	
Latest Release	1.0.0-beta 01-2018	
TRL	NA	
Location	Data hosted by task providing dataset	
Format	NEST framework using Python 2.7 interface	
Curation Status	PLA registered	
Validation - QC	Unchecked	
Validation - User	No	
Validation - Publications	No	
Privacy Constraints	No Privacy Constraint	
Sharing	Consortium	
License	GPLv2/GPLv3	
Component Access URL	https://collab.humanbrainproject.eu/#/collab/8809/nav/66615	
Technical Documentation URL	None	
Usage documentation URL	None	
Component Dissemination Material URL	None	

3.2 Image distortion

Field Name	Field Content	Additional Information
ID	14332	
Component Type	model	
Contact	DA COSTA, Danny	
Component Description	Distorts images according to retinal ganglion cell density.	
Latest Release	1.0.0-beta 01-2018	
TRL	NA	
Location	Data hosted by task providing dataset	
Format	Python 2.7	
Curation Status	PLA registered	
Validation - QC	Unchecked	
Validation - User	No	
Validation - Publications	No	
Privacy Constraints	No Privacy Constraint	
Sharing	Consortium	
License	GPLv2/GPLv3	
Component Access URL	https://collab.humanbrainproject.eu/#/collab/8809/nav/66615	
Technical Documentation URL	None	
Usage documentation URL	None	
Component Dissemination URL	None	

3.3 Saccade generation model

Field Name	Field Content	Additional Information
ID	14333	
Component Type	model	
Contact	SENDEN, Mario	
Component Description	This model selects targets for eye movements based on salience distribution.	
Latest Release	1.0.0 01-2018	
TRL	NA	
Location	Data hosted by task providing dataset	
Format	NEST framework using Python 2.7 interface	
Curation Status	PLA registered	
Validation - QC	Unchecked	
Validation - User	Yes	
Validation - Publications	Yes	
Privacy Constraints	No Privacy Constraint	
Sharing	Consortium	
License	GPLv2/GPLv3	
Component Access URL	https://collab.humanbrainproject.eu/#/collab/8809/nav/66615	
Technical Documentation URL	None	
Usage documentation URL	None	
Component Dissemination URL	None	

3.4 NEST

Field Name	Field Content	Additional Information
ID	209	
Component Type	software	
Contact	DIESMANN, Markus	
Component Description	NEST - The Neural Simulation Tool - is a highly scalable simulator for networks of point or few-compartment spiking neuron models. It includes multiple synaptic plasticity models, gap junctions, and rate-based models. NEST also provides techniques to define complex network structure.	
Latest Release	2017-10-20	
TRL	TRL 7 - Operational Integration	
Location	data hosted by other non-HBP 3rd party	
Format	NA	
Curation Status	NA	
Validation - QC	Pass	Continuous Integration and Code Review Process QC owner: NEST Initiative (Hans E. Plesser, President)
Validation - User	Yes	See D11.3.3, Sec 6.3
Validation - Publications	Yes	Over 40 publications based on NEST simulations in 2016 and 2017, see http://www.nest-simulator.org/publications
Privacy Constraints	No Privacy Constraint	
Sharing	anonymous - share with anonymous non-consortium members	
License	GPLv2 or later	
Component Access URL	http://github.com/nest/nest-simulator	
Technical Documentation URL	http://nest.github.io/nest-simulator/	
Usage documentation URL	http://www.nest-simulator.org/documentation/	
Component Dissemination URL	http://www.nest-simulator.org	

3.5 Continuous dynamics code in NEST

Field Name	Field Content	Additional Information
ID	510	
Component Type	software	
Contact	FROMMER, Andreas	
Component Description	The continuous dynamics code in NEST enables simulations of rate-based model neurons in the event-based simulation scheme of the spiking simulator NEST. The technology was included and released with NEST 2.14.0. Furthermore, additional rate-based models for the Co-Design Project "Visuo-Motor Integration" (CDP4) have been implemented and scheduled for the next release NEST 2.16.0.	
Latest Release	2017-10-20	
TRL	TRL 7 - Operational Integration	
Location	data hosted by other non-HBP 3rd party	
Format	NA	
Curation Status	NA	
Validation - QC	Pass	Formal NEST Initiative review
Validation - User	Yes	CDP4, used in preprints
Validation - Publications	Yes	Hahne et al. (2017) Front. Neuroinform. 11,34. doi:10.3389/fninf.2017.00034 https://arxiv.org/pdf/1709.05650.pdf https://arxiv.org/pdf/1801.06046.pdf
Privacy Constraints	No Privacy Constraint	
Sharing	anonymous - share with anonymous non-consortium members	
License	GPLv2/GPLv3	
Component Access URL	https://github.com/nest/nest-simulator/releases/tag/v2.14.0	
Technical Documentation URL	https://www.frontiersin.org/articles/10.3389/fninf.2017.00034/full	
Usage documentation URL	https://github.com/nest/nest-simulator/tree/master/pynest/examples	

Component Dissemination URL	https://www.frontiersin.org/articles/10.3389/fninf.2017.00034/full https://github.com/nest/nest-simulator	

3.6 Measurements from Cognitive Experiments Performed In Silico on the Neurorobotics Platform

Field Name	Field Content	Additional Information
ID	809	
Component Type	data	
Contact	KAISER, Jacques	
Component Description	The models of sensorimotor integration developed in CDP4 will be evaluated *in silico* on the Neurorobotics Platform. Each execution of an experiment will yield measurement data that can be stored, shared and validated.	
Latest Release		
TRL	TRL 6 - Prototype-to-Real-world Integration	
Location	data hosted by other non-HBP 3rd party	
Format	python; xml	
Curation Status	PLA registered	
Validation - QC	Pass	
Validation - User	Yes	Video release: Modelling the complete visual system in the NRP
Validation - Publications	CDP4 publication to be submitted	
Privacy Constraints	No Privacy Constraint	
Sharing	public authenticated - share with authenticated non-consortium members e.g. public collab	
License	GPLv2/GPLv3	
Component Access URL	https://github.com/HBPNeurorobotics/CDP4_experiment	
Technical Documentation URL	https://github.com/HBPNeurorobotics/CDP4_experiment	

Usage documentation URL	https://collab.humanbrainproject.eu/#/collab/8809/nav/89946	
Component Dissemination URL		

3.7 Collective behaviour of mean-field and neural population models: A comparative study

Field Name	Field Content	Additional Information
ID	1070	
Component Type	report	
Contact	ZAMORA-LOPEZ, Gorka	
Component Description	There exist many population models to simulate the activity of one brain region. The goal of this component is to understand how those models behave, collectively, when simulating a network of interacting brain areas.	
Latest Release	As of yet not released. During SGA1, the research plan for the component has been designed. Preliminary proofs of concept were tested using simulations of networks of neurons, which showed the diverse collective behaviour depending on the specific model of choice. These observations confirmed the need to better understand, at a theoretical level, how such models behave at the network level depending on the particular choices taken to build them.	Achievement of the component was compromised because the dedicated postdoc left the HBP. The component will be continued during SGA2 and extended to population and mean-field models.
TRL	1	
Location	Data hosted by task providing dataset	
Format	Python 2.7	
Curation Status	N/A – see Latest Release	
Validation - QC	N/A – see Latest Release	
Validation - User	N/A – see Latest Release	
Validation - Publications	N/A – see Latest Release	
Privacy Constraints	Not specified – see Latest Release	
Sharing	N/A – see Latest Release	
License	Not specified – see Latest Release	

Component Access URL	N/A – see Latest Release	
Technical Documentation URL	N/A – see Latest Release	
Usage documentation URL	N/A – see Latest Release	
Component Dissemination URL	N/A – see Latest Release	

4. Conclusion and Outlook

During the past 12 months, all parties involved with CDP4 have made significant progress towards achieving the scientific as well as platform-related goals of this Co-Design Project. In particular: i) a retinotopically organised model able to select a target for an upcoming saccade based on salience was developed, ii) an image distortion algorithm mimicking sampling of visual space by retinal ganglion cells was implemented, iii) all functional components were embedded in a robotic system, iv) new insights into adaptive communication among a large set of brain regions were gained, v) a contribution to NEST v 2.16.0 was made, and vi) CDP4 inspired the addition of deep learning capabilities (TensorFlow) to the Neurorobotics Platform.

During the next 12 months, it will be critical to use the embedded architecture to address neuroscientific questions. Embedding our model in a robotic system is of special importance for developing and testing new theories of visual stability, since blur and visual displacement occur naturally in such a system and their implications can be studied in a straightforward manner. As such, the architecture can and should be used, among others, for the investigation of proposed mechanisms, such as attention remapping in response to corollary discharge. Since visual stability constitutes an active field of research, but currently lacks concrete mechanisms explaining observed effects, the neuroscientific community can strongly benefit from the further development of our architecture.

Furthermore, in the upcoming 12 months it will be pivotal to integrate all functional components into a working visuomotor architecture and to embed this within a simulated robot. Several components have already been successfully interlinked. For instance, the salience architecture, target selection model and saccade generator have already been linked. Similarly, the aforementioned components have been successfully embedded in simulated robots. However, integration of all functional component remains to be completed.

Finally, during the next 12 months it will be important to gradually increase the biological realism of the architecture. This goal has been slightly impeded by key personal related to component 1070 leaving the HBP. It was thus not possible to rely on new knowledge regarding the collective behaviour of interacting mean-field and population equations. In spite of this, work has already started with the saccade generator. Specifically, with the aim to replace rate neuron equations with population firing rate equations, the saccade generator has been analysed with respect to its biological shortcomings (for example, individual neuron types making both excitatory and inhibitory monosynaptic connections; rate neuron implementation conflates membrane potential dynamics and firing rates), solutions to these shortcomings have been identified and a full translation is underway