



Abstract Booklet

Berlin,
Sept 18-20

#BernsteinConference

Welcome to the 15th Bernstein Conference!

The Bernstein Conference on Computational Neuroscience is a highly reputable international conference, attracting around 500 scientists from across the world. Having started out as the ‘Bernstein Symposium’ in 2005, gathering the members of the Bernstein Network, it turned into the largest annual computational neuroscience conference in Europe. This year, the Bernstein Conference takes place back-to-back with the Conference on Cognitive Computational Neuroscience (CCN), offering two excellent opportunities for international scientific exchange in the field of computational neuroscience.

With a total of eleven invited talks by internationally renowned experts in their fields, and seven contributed talks, which were selected in a double-blind review process based on submitted abstracts, the Main Conference covers a wide range of subdisciplines of neuroscience. Over 260 posters presented in two poster sessions, are an integral part of the conference.

This year’s special events will be the presentation of the Brains for Brains Young Researcher Award, as well as an evening lecture for the general public on Artificial Intelligence and Machine Learning (in German). Prior to the Main Conference, Satellite Workshops offer a platform for in-depth discussion of current research issues and the opportunity to develop novel scientific approaches. A Postdoc Meeting and a PhD Symposium are special platforms for young scientists to meet with their peers.

We wish you an inspiring stay at the 15th Bernstein Conference in Berlin!

Program

Satellite Workshops	September 17-18, 2019
Postdoc Meeting	September 17, 2019
Main Conference	September 18-20, 2019
PhD Symposium	September 20-21, 2019

Conference Chair and Host

Henning Sprekeler, Technische Universität Berlin

Program Chairs

Susanne Schreiber, Humboldt-Universität zu Berlin (Program Chair)
Elad Schneidman, Weizmann Institute of Science, Rehovot, Israel
(Program Vice Chair)

Satellite Workshop Chairs

Tatjana Tchumatchenko, Max Planck Institute for Brain Research,
Frankfurt a. M. (Workshop Chair)
Tim Vogels, University of Oxford, UK (Workshop Vice Chair)

Main Conference and Workshop Program Committee

Danielle Bassett, University of Pennsylvania, Philadelphia, USA
Alexander Borst, Max Planck Institute of Neurobiology, Munich
Alain Destexhe, Centre National de la Recherche Scientifique (CNRS),
Gif-sur-Yvette, France
Tim Gollisch, University of Goettingen
Máté Lengyel, University of Cambridge, UK
Stephanie Palmer, University of Chicago, USA
Terry Sejnowski, Salk Institute for Biological Studies, La Jolla, USA
Sara Solla, Northwestern University, Evanston, USA
Henning Sprekeler, Technische Universität Berlin
Gina Turrigiano, Brandeis University, Waltham, USA

Technical Organization

Bernstein Coordination Site (BCOS), Branch Office of the Forschungszentrum
Jülich at the University of Freiburg:

Anja Dorrn
Claudia Duppé
Silke Müller
Janina Radny
Nikola Schwarzer
Alexandra Stein

Abstract Handling

G-Node – Bernstein Facility for Data Technology:

Achilleas Koutsou

Michael Sonntag

Thomas Wachtler

Postdoc Meeting

Katharina Wilmes, Imperial College London, UK

PhD Symposium

Laura Bella Naumann, Technische Universität Berlin

Andrej Warkentin, Bernstein Center for Computational Neuroscience Berlin

Maryna Kapitonova, University of Freiburg

Simon Renner, LMU Munich

Registration Handling

Intercongress GmbH

Friedrichstr. 6

65185 Wiesbaden

Funding

The conference is financially supported by the Forschungszentrum Jülich GmbH, the German Research Foundation (DFG), and the Bernstein Network Computational Neuroscience.



Exhibitors



Human Brain Project



Sponsor



General Conference Information

Conference Venues

Main Conference:
Technische Universität Berlin, main building
Straße des 17. Juni 135
10623 Berlin

Satellite Workshops, Postdoc Meeting:
Technische Universität Berlin
Marchstr. 23
10623 Berlin

Conference Dinner:
Pier 13
Tempelhofer Damm 227
12099 Berlin

PhD Symposium:
Campus Nord of Humboldt-Universität zu Berlin
Bernstein Center Berlin
Philippstr. 13, House 6
10115 Berlin

Opening Hours Registration and Information Desk

Marchstr. 23, venue of the Satellite Workshops

Tuesday, Sept 17	12:00 - 18:30
Wednesday, Sept 18	08:00 - 11:00

Straße des 17. Juni 135, venue of the Main Conference

Wednesday, Sept 18	12:30 - 19:30
Thursday, Sept 19	08:30 - 18:30
Friday, Sept 20	08:30 - 13:30

Opening Hours Exhibition

Wednesday, Sept 18	13:30 - 19:00
Thursday, Sept 19	09:00 - 18:30
Friday, Sept 20	09:00 - 13:30

Poster Sessions

Session I, Wednesday, Sept 18	16:00 - 19:00
Session II, Thursday, Sept 19	12:30 - 15:30

Mounting and Dismounting Posters

Poster boards are numbered according to the abstract numbers in the poster booklet (W indicates the poster session I on Wednesday and T the poster session II on Thursday). Posterstrips for putting up posters will be provided. Posters can be mounted starting at noon on Wednesday and at 8:30 on Thursday. Please take your poster down after your session otherwise the conference staff will remove it. Removed posters that are not picked up at the information desk by Friday, September 20, 13:00 will be disposed of.

Abstracts

Conference abstracts including high-resolution versions of figures are published online: <https://doi.org/10.12751/nncn.bc2019>

Name Badges

Official name badges will be required for admission to all scientific conference events. Participants who lose their name badge will have to pay a fee of 10.00 EUR to retain a replacement badge.

Wardrobe

Storage space for wardrobe and luggage will be provided near the registration desk. The organizer assumes no liability for lost valuables of the wardrobe at the venue.

Silent Room/Working Space

You are welcome to use room 2035 on the 2nd floor of the TU Berlin main building.

Internet

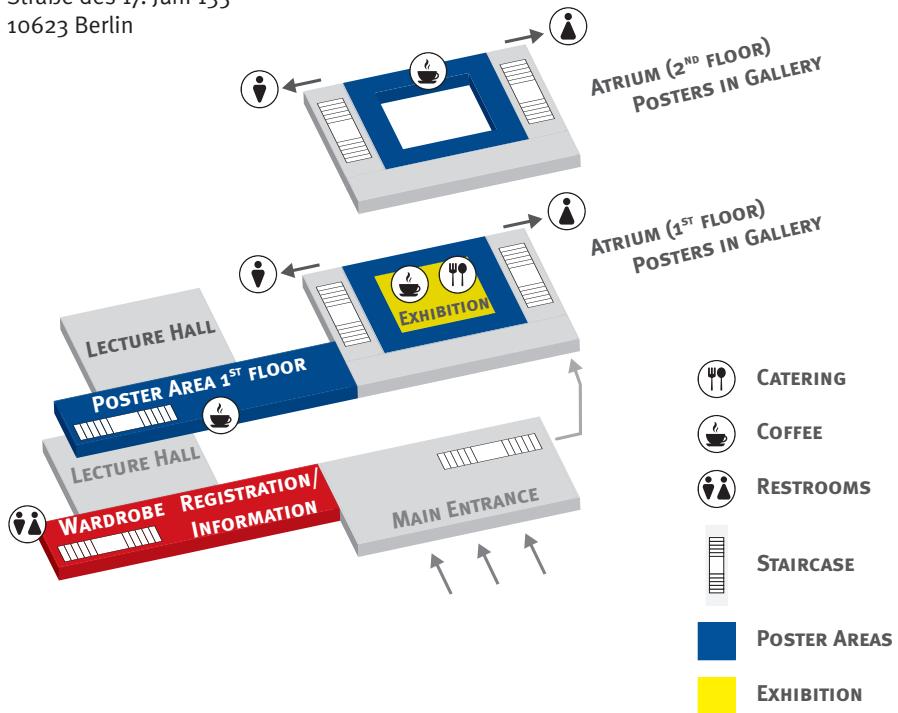
Wireless web access is provided free of charge. Logins are available on request at the registration desk. Furthermore, eduroam is available.

Access instructions for the wireless web access:

Please connect your device with the network (SSID) "TUB-Guest" and open a web browser. Your browser will be redirected to the login page of the guest network. Please enter your guest account name in the field user name and your corresponding password. After confirming the terms of use, you are online.

Floor Plan

Technische Universität Berlin, main building
Straße des 17. Juni 135
10623 Berlin



How to get to

Main Conference, Satellite Workshops, Postdoc Meeting and Public Lecture

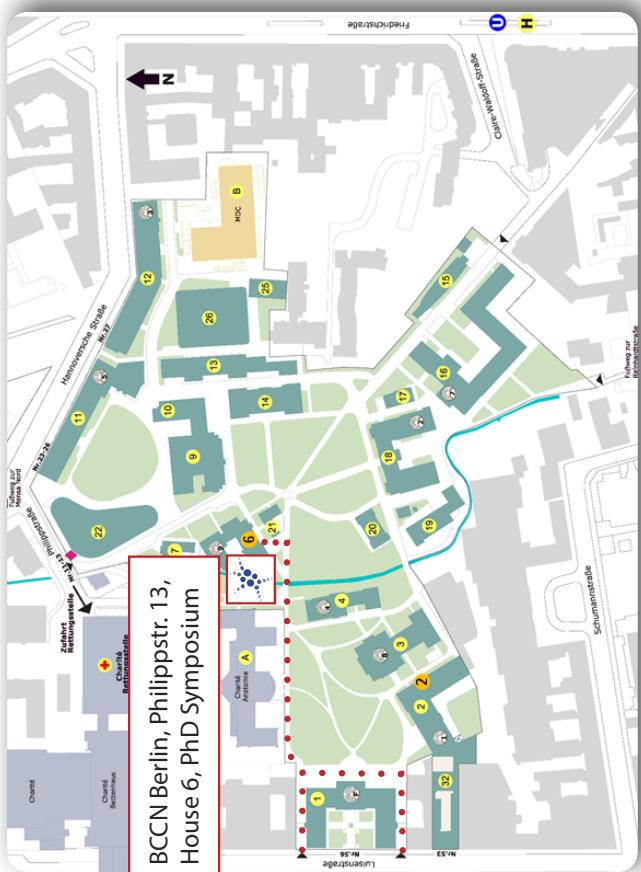
The Bernstein Conference will take place at Technische Universität Berlin, Marchstr. 23 (Satellite Workshops, Postdoc Meeting) and the main building, Straße des 17. Juni 135 (Main Conference, Public Lecture). From the central train station take an S-Bahn (any line in direction of Charlottenburg, Westkreuz, Potsdam or Spandau) to Tiergarten. The main campus is only a ten-minute walk from Tiergarten S-Bahn station.

The U-Bahn station Ernst-Reuter-Platz (Line 2) is close by.



PhD Symposium

The PhD Symposium will take place at the Bernstein Center for Computational Neuroscience Berlin, Philippstr. 13, House 6. From the central train station, you can take bus 147 (direction Unter-den-Linden/Glinkastr. or Puschkinallee/Elsenstr.) to Charité-Campus-Mitte. Gate D is located at Luisenstr. 56 close to the bus stop. Inside the campus turn left and walk along the paved walkway passing the backside of the Humboldt Graduate School building, then turn right and follow the pathway until you reach a small bridge. After the bridge the BCCN building (Haus 6) is the first building on your left hand side.

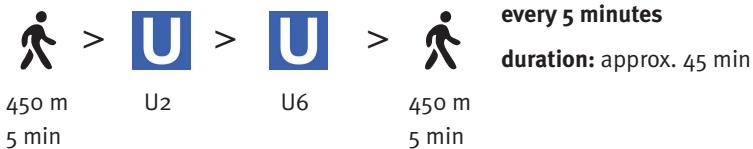


Bernstein Conference Dinner

The Bernstein Conference Dinner will take place at Pier 13, Tempelhofer Damm 227, 12099 Berlin. From the Bernstein Conference venue, you can take the following connections:



From S-Bahn station Tiergarten, take S5 (direction Strausberg Nord) or S3 (direction S Erkner Bhf) to Friedrichstraße. Change train to U6 (direction Alt-Mariendorf) to Ullsteinstraße. Walk approx. 450 m to Tempelhofer Damm 227.



From U-Bahn station Ernst-Reuter-Platz, take U2 (direction S+U Pankow) to Stadtmitte. Change train to U6 (direction Alt-Mariendorf) to Ullsteinstraße. Walk approx. 450 m to Tempelhofer Damm 227.



Conference Schedule

Satellite Workshops

The Bernstein Conference features a series of Satellite Workshops on September 17-18, which offer a platform for in-depth discussions of current research issues and novel scientific approaches in smaller groups. Details of the individual workshops are available on the conference webpage (www.bernstein-conference.de) and in the workshop booklet.

Full day workshops,

Tuesday, September 17, 14:00 - 18:30 and

Wednesday, September 18, 08:30 - 12:30

- Cortical computations via metastable activity
Room o.003
- Circuit mechanisms of adaptive learning and choice under uncertainty
Room o.007
- Cortical representations and processing of visual motion, slow eye movements, and self-motion
Room o.009
- Origins and functional implications of dendritic synaptic clustering
Room o.010
- Neurons vs. networks, dynamical and functional implications of neuronal diversity
Room o.011
- Integrating neuroscience and biomechanics: the neuromechanics of motor coordination in humans and other animals
Room o.017
- Brain against the machine
(♪ and now you do what they told ya! ♪)
Room 4.063
- Brain circuit insight: from brain circuit models to brain circuit insights
Room 4.064

**Half day workshops,
Tuesday, September 17, 14:00 - 18:30**

- Deep Learning in computational neuroscience
Room 0.001
- Dynamical richness of cortical networks: role and modulation across brain states
Room 0.015
- Neural computation through recurrent dynamics: from theory to experiment and back
Room 0.016

**Half day workshops,
Wednesday, September 18, 08:30 - 12:30**

- Spikes in a haystack: dimensionality reduction for neural data and unsupervised detection of (spiking) patterns and sequences
Room 0.001
- Neuronal processing of social cues
Room 0.015
- Neural oscillations in memory and navigation
Room 0.016

Main Conference

Wednesday, September 18

- 14:00 Welcome by **Christian Thomsen**
President of the Technische Universität Berlin
- 14:05 Welcome by **Henning Sprekeler**, Conference Chair, and
Susanne Schreiber, Chairwoman of the Bernstein Network
Computational Neuroscience (both Bernstein Center
Computational Neuroscience Berlin)
- 14:15 Opening Lecture
Eve Marder
(Brandeis University, Waltham, USA)
*Multiple cellular mechanisms allow the nervous system to
tile time*

Session 1

- 15:00 **Naoki Hiramatsu**
(University College London, UK)
*Developmental and evolutionary principles of olfactory
circuit designs*
- 15:15 Invited Lecture by **Nicolas Brunel**
(Duke University, Durham, USA)
How strongly coupled are cortical circuits?
- 16:00 - Poster session I
- 19:00
- 19:30 Public Lecture by **Florian Röhrbein**
(Alfred Kärcher SE & Co. KG, Intelligent Systems,
Winnenden, Germany)
Künstliche Intelligenz - Kopie oder Karikatur?

Thursday, September 19

Session 2

- 09:00 Invited Lecture by **Claudia Clopath**
(Imperial College London, UK)
Modelling hippocampal learning
- 09:45 Invited Lecture by **Matthias Bethge**
(University of Tübingen, Germany)
Neural decision making from pixels to percepts
- 10:30 Coffee break

Session 3

- 11:00 Invited Lecture by **Nachum Ulanovsky**
(Weizmann Institute of Science, Rehovot, Israel)
Neural codes for natural navigation in the hippocampal formation of bats
- 11:45 Invited Lecture by **Dora Angelaki**
(Baylor College of Medicine, Houston, USA)
A gravity-based three-dimensional compass in the mouse brain
- 12:30 - Poster session II
- 15:30

Session 4

- 15:30 Invited Lecture by **Haim Sompolinsky**
(The Hebrew University of Jerusalem, Israel and
Harvard University, Cambridge, USA)
Neural representations: geometry and computation
- 16:15 **Guillaume Bellec**
(Graz University of Technology, Austria)
*Biologically inspired alternatives to backpropagation through time
for learning in recurrent neural nets*
- 16:30 Coffee break

Session 5

- 17:00 **Katharina Wilmes**
(Imperial College London, UK)
Gating synaptic plasticity in cortical networks
- 17:15 **Malcolm MacIver**
(Northwestern University, Evanston, USA)
The shift from life in water to life on land advantaged planning in visually-guided behaviour
- 17:30 Invited Lecture by **Hopi Hoekstra**
(Harvard University, Cambridge, USA)
From mice to molecules: the genetics of behavioral evolution
- 18:15 End
- 19:30 Conference Dinner
at Pier 13
Tempelhofer Damm 227
12099 Berlin

Friday, September 20

Session 6

- 09:00 Invited Lecture by **Gašper Tkačik**
(Institute of Science and Technology Austria, Klosterneuburg, Austria)
Planning the arc between optimality theories and data
- 09:45 **Ho Ling Li**
(University of Nottingham, UK)
Energy efficient synaptic plasticity
- 10:00 Presentation of the Brains for Brains Young Researcher Award to **Tuan Pham** (University of Chicago, USA), followed by a talk by the awardee: *Electrical synapses and transient signals in feedforward canonical circuits*
- 10:30 Coffee break

Session 7

- 11:00 Invited Lecture by **Matthew Botvinick**
(DeepMind and University College London, UK)
A distributional code for value in dopamine-based reinforcement learning
- 11:45 **Vivek Sridhar**
(Max Planck Institute of Animal Behaviour, Radolfzell, and University of Konstanz, Germany)
The geometry of decision-making
- 12:00 **Sarah Goethals**
(Sorbonne University, INSERM, Paris, France)
The electrical impact of axon initial segment plasticity
- 12:15 Invited Lecture by **Gilles Laurent**
(Max Planck Institute for Brain Research, Frankfurt a. M., Germany)
A reptilian model for sleep control and evolution
- 13:00 Closing remarks
- 13:15 End

PhD Symposium

Venue: Bernstein Center for Computational Neuroscience (BCCN) Berlin,
Philipstr. 13 House 6, 10115 Berlin

Tuesday, September 17, 2019

- 19:00 PhD Social Event
Location: Café A, Straße des 17. Juni 150, 10623 Berlin, room Ao13

Friday, September 20, 2019

- 14:00 Meet & Greet
Venue: BCCN Berlin
- 14:30 Collection of topics for unconference sessions
- 15:30 Keynote Lecture 1 by **Benjamin Staude**
Academia vs. industry
- 16:30 Coffee break
- 17:00 Unconference session 1
Participant-driven discussions, workshops and projects
in smaller groups
- 18:30 Barbecue dinner
Venue: BCCN backyard/ Alte Schmiede

Saturday, September 21, 2019

- 9:00 Coffee Start
- 9:15 Keynote Lecture 2 by **Ashley Juavinett**
(University of California, San Diego, USA)
*How to make the most of your PhD when you're not sure what
comes next*
- 10:15 Panel discussion
- 11:00 Coffee break
- 11:30 Unconference session 2
- 12:30 Wrap-up and farewell
- 13:00 Optional: lunch & Berlin outing

Special Events

Postdoc Meeting

This event is an informal get-together for postdocs. It is an opportunity to get to know each other, foster collaborations, exchange experiences and ideas. No preparation required, but if you have an idea or a particular topic you want to discuss with your peers, bring it along. Drinks and snacks will be provided.

Date: Tuesday, September 17, 19:00, registration required

Venue: Marchstr. 23, room 0.002

Public Lecture: KI - Kopie oder Karikatur? (German)

by **Florian Röhrbein**

(Alfred Kärcher SE & Co. KG, Intelligent Systems, Winnenden, Germany)

Künstliche Intelligenz – ein Begriff in aller Munde und im Zentrum zahlreicher aktueller Debatten, doch bei der Frage nach seiner Bedeutung gehen die Meinungen weit auseinander. Was unterscheidet künstliche von natürlicher Intelligenz? Braucht Intelligenz einen Körper? Lässt sie sich kopieren? Und ist eine Kopie überhaupt wünschenswert? Als Forschungsgebiet an der Schnittstelle zwischen Neurowissenschaften, Informatik und weiteren Disziplinen wirft Künstliche Intelligenz viele Fragen auf. Ein Blick auf aktuelle Forschungsergebnisse sowie auf die über 60-jährige Geschichte der KI hilft, den aktuellen Hype um diesen Begriff besser zu verstehen und einzuordnen.

Date: Wednesday, September 18, 19:30

Venue: TU Berlin main building, lecture hall H0104

Conference Events

Brains for Brains Young Researcher Award

Tuan Pham (University of Chicago, USA) will be awarded the Brains for Brains Young Researcher Award 2019 of the Bernstein Network Computational Neuroscience. As an undergraduate, Pham simulated small networks of neurons to study electrical synapses. In his doctoral research, he seeks to combine computational approaches and experiments to investigate the computational properties of networks of biophysical neurons.

Since 2010, the Bernstein Network Computational Neuroscience grants the Brains for Brains Award, which recognizes the special achievements of young scientists who have shown their outstanding potential already at a very early career stage – even before starting their doctoral studies. The award is endowed with € 2000 and enables young scientists to visit the Bernstein Conference as well as exclusive laboratories in the Bernstein Network in Germany. This year, the award will be conferred for the 9th time. Past winners came from Australia, USA, Israel, France, Italy, Canada, the UK, and Cuba.

The Bernstein Network Information Booth

The Bernstein Network is a research network in the field of computational neuroscience. It unites different scientific disciplines, such as physics, biology, mathematics, medical science, psychology, computer science, engineering and philosophy in the endeavor to understand how the brain functions. The close combination of neurobiological experiments with theoretical models and computer simulations allows scientists of the Bernstein Network to pursue innovative approaches with regard to one of the most complex structures nature has created in the course of evolution: the human brain.

The network started in 2004 with a funding initiative of the Federal Ministry of Education and Research (BMBF) to develop and interconnect research structures in computational neuroscience throughout Germany and to promote the transfer of theoretical insight into clinical and technical applications. The Bernstein Network provides three central facilities. More information about the network and its facilities can be found throughout the conference at the Bernstein Network Information Booth in the Atrium (Lichthof) on the 1st floor.

Bernstein Coordination Site (BCOS)

BCOS is the connecting link to partners in science, industry, politics and the general public. It oversees a large information pool and can provide valuable networking resources. The activities of the Bernstein Coordination Site are aimed at facilitating scientific encounter, supporting young researchers and public outreach. The **SMARTSTART** Joint Training Program in Computational Neuroscience, which is coordinated by BCOS, prepares young researchers for a career in computational neuroscience. Meet the BCOS Team at the Bernstein Network Information Booth for further inquiries.

Bernstein Facility for Data Technology: G-Node

During the conference, the G-Node will present tools and services for research data management, including the odML format for metadata collection (g-node.org/odml), the NIX format for data integration and organization (g-node.org/nix), and the GIN service for versioning, collaboration and publication (g-node.org/gin). Conference participants are invited to visit the G-Node booth: Try out the tools, discuss research data management needs, hear about upcoming features. Demos will be given during poster sessions and coffee breaks. Walk-ins are welcome any time during the conference.

Bernstein Facility for High Performance Simulation and Data Analytics: SimLab Neuroscience

SimLab Neuroscience at the Jülich Supercomputing Centre supports the neuroscience community in solving problems with high scientific impact through the use of High-Performance Computing (HPC) resources. It provides advanced support in the fields of data analysis, modeling, simulation, HPC methods and visualization. SimLab Neuroscience also offers tutorials, workshops, and courses to help you make the transition to HPC.

Events at the Bernstein Network Information Booth

Travel Grant Award Ceremony

Date: Wednesday, September 18, 16:30

General Assembly 2019 of the Bernstein Network Computational Neuroscience

Date: Wednesday, September 18, 12:50 - 13:30

Venue: TU Berlin main building, room 2036, members only

Please Note: Photos will be taken during the event, which may be used for public relation and/or documentary purposes, in online and print media of the Bernstein Network Computational Neuroscience or related publications. By participating in the Conference, you declare that your picture may be used in respective publications.

If you do not want to be photographed, please see the information desk.



Invited Talks

[I 1] Multiple Cellular Mechanisms Allow the Nervous System to Tile Time

Eve Marder¹

1. Volen Center and Biology Department, Brandeis University, Waltham, USA

All neurons have many different kinds of ion channels that differ in their voltage and time dependence. Similarly, the nervous system uses many different neurotransmitters whose action is mediated by different receptor types and different time courses of action. At the same time, we understand that similar circuit dynamics can result from many different sets of ionic conductances. Models of neurons and networks loosely motivated by recordings from the crustacean stomotagastric nervous system show that, in response to perturbations such as temperature, neurons and networks maintain stable function by smoothly transitioning between different cellular and synaptic mechanisms. This suggests that the function of overlapping sets of molecular mechanisms is to allow neuronal and circuit stability over a wide dynamic range in response to a variety of perturbations.

©(2019) Marder E

Cite as: Marder E (2019) Multiple Cellular Mechanisms Allow the Nervous System to Tile Time. Bernstein Conference 2019

Abstract. doi: [10.12751/nncn.bc2019.0001](https://doi.org/10.12751/nncn.bc2019.0001)

[I 2] How strongly coupled are cortical circuits?

Nicolas Brunel^{1,2}

1. Department of Neurobiology, Duke University, Durham, USA

2. Department of Physics, Duke University, Durham, USA

One of the major features of cortical circuits are their extensive recurrent connectivity. This recurrent connectivity has been postulated to play a major role in processing sensory inputs, in the maintenance of information in memory, and in various types of computations. Theoretical models of cortical circuits make very different assumptions about the strength of such recurrent connectivity. In the 'balanced network' model, coupling is assumed to be very large, such that average excitatory and inhibitory inputs are individually very large, but approximately cancel. A consequence of this strong coupling limit is that the network responds linearly to inputs. In the supralinear stabilized network model, coupling is only moderately large, which allows networks to respond non-linearly to inputs. In this talk, I will first describe experiments whose goal is to measure coupling strength in cortical networks, through a combination of optogenetic, electrophysiological and pharmacological approaches. I will then describe how coupling strength affects the response of the network to inputs, using a model of randomly connected networks of excitatory and inhibitory leaky integrate-and-fire neurons. In such networks, I will show that it is possible to classify the types of non-linearities that appear at finite coupling strength.

©(2019) Brunel N

Cite as: Brunel N (2019) How strongly coupled are cortical circuits?. Bernstein Conference 2019 Abstract.

doi: [10.12751/nncn.bc2019.0002](https://doi.org/10.12751/nncn.bc2019.0002)

[I 3] Modelling hippocampal learning

Claudia Clopath¹

1. Bioengineering Department, Imperial College London, UK

The hippocampus is able to rapidly learn incoming information, even if that information is only observed once. Furthermore, this information can be replayed in a compressed format in either forward or reverse modes during sharp wave–ripples (SPW–Rs). We leveraged state-of-the-art techniques in training recurrent spiking networks to demonstrate how primarily interneuron networks can achieve the following: (1) generate internal theta sequences to bind externally elicited spikes in the presence of inhibition from the medial septum; (2) compress learned spike sequences in the form of a SPW–R when septal inhibition is removed; (3) generate and refine high-frequency assemblies during SPW–R mediated compression; and (4) regulate the inter-SPW interval timing between SPW–Rs in ripple clusters. From the fast timescale of neurons to the slow timescale of behaviors, interneuron networks serve as the scaffolding for one-shot learning by replaying, reversing, refining, and regulating spike sequences.

©(2019) Clopath C

Cite as: Clopath C (2019) Modelling hippocampal learning. *Bernstein Conference 2019 Abstract.*

doi: [10.12751/nncn.bc2019.0003](https://doi.org/10.12751/nncn.bc2019.0003)

[I 4] Neural decision making from pixels to percepts

Matthias Bethge^{1,2}

1. Tübingen AI Center & Centre for Integrative Neuroscience, Eberhard Karls Universität Tübingen, Tübingen, Germany

2. Bernstein Center für Computational Neuroscience Tübingen, Tübingen, Germany

Biological vision is strikingly powerful. The visual brain manages to transform photo receptor signals into a huge range of useful predictions about the environment used for navigation, grasping, visual search and scene analysis under highly variable conditions. Recent progress in deep learning facilitated the possibility to build neural network models that outperform humans on specific tasks after extensive supervised training. However, we still lack fundamental principles of neural computation facilitating the robustness and data efficiency of biological vision. In this talk, I will give an overview on recent progress towards understanding the differences in human and machine decision making and promising findings that can help to overcome the lack of robustness in machine vision.

©(2019) Bethge M

Cite as: Bethge M (2019) Neural decision making from pixels to percepts. *Bernstein Conference 2019 Abstract.*

doi: [10.12751/nncn.bc2019.0004](https://doi.org/10.12751/nncn.bc2019.0004)

[I 5] Neural codes for natural navigation in the hippocampal formation of bats

Nachum Ulanovsky¹

1. Department of Neurobiology, Weizmann Institute of Science, Rehovot, Isreal

The work in our lab focuses on understanding the neural basis of spatial memory and spatial cognition – using bats as our animal model. To this end, we have developed wireless neurophysiology devices (neural loggers), which allow us to record single neurons from freely flying, behaving bats. In my talk I will present some of our recent studies, which explored the following questions: (i) How does the brain represent positions and directions in 3D? A set of studies revealed 3D place cells, 3D head-direction cells, and 3D grid cells in the bat hippocampal formation. (ii) How are navigational goals represented in the brain? We discovered a new kind of vectorial representation of spatial goals – whereby hippocampal neurons encode the direction and distance to a spatial goal. (iii) I will describe our recent discoveries of “social place-cells” in the bat hippocampus – neurons that represent the position of other bats (conspecifics), as well as “episodic cells” – neurons that encode spacetime (elapsed-time x location) for the bat itself as well as for conspecifics. (iv) Finally, I will describe ongoing work towards elucidating hippocampal neural codes in realistic, kilometer-scale environments – where we discovered an unexpected multi-scale coding of space. Our long-term vision is to develop a “Natural Neuroscience” approach for studying the neural basis of behavior – tapping into the animal’s natural behaviors in complex, large-scale, naturalistic settings.

©(2019) Ulanovsky N

Cite as: Ulanovsky N (2019) Neural codes for natural navigation in the hippocampal formation of bats. *Bernstein Conference 2019 Abstract.* doi: [10.12751/nncn.bc2019.0005](https://doi.org/10.12751/nncn.bc2019.0005)

[I 6] A gravity-based three-dimensional compass in the mouse brain

Dora E Angelaki¹

1. Department of Neuroscience, Baylor College of Medicine, Houston, Texas, USA

Head direction cells in the mammalian limbic system are thought to function as an allocentric neuronal compass. Although traditional views hold that the compass of ground-dwelling species is planar, we show that head-direction cells in the rodent thalamus, retrosplenial cortex and cingulum fiber bundle are tuned to conjunctive combinations of azimuth, pitch or roll, similarly to presubicular cells in flying bats. Pitch and roll orientation tuning is ubiquitous, anchored to gravity, and independent of visual landmarks. When head tilts, azimuth tuning is affixed to the head-horizontal plane, but also uses gravity to remain anchored to the terrestrial allocentric world. These findings suggest that gravity defines all three degrees of freedom of the allocentric orientation compass, and only the azimuth component can flexibly remap to local cues in different environments. Collectively, these results demonstrate that a three-dimensional, gravity-based, neural compass is likely a ubiquitous property of mammalian species, including ground-dwelling animals.

©(2019) Angelaki DE

Cite as: Angelaki DE (2019) A gravity-based three-dimensional compass in the mouse brain. *Bernstein Conference 2019 Abstract.* doi: [10.12751/nncn.bc2019.0006](https://doi.org/10.12751/nncn.bc2019.0006)

[I 7] Neural Representations: Geometry and Computation

Haim Sompolinsky^{1,2}

1. Edmond and Lily Safra Center for Brain Sciences, Hebrew University of Jerusalem, Jerusalem, Israel

2. Center for Brain Science, Harvard University, Cambridge, USA

Recent advances in systems neuroscience and AI have generated considerable interest and rich research on high dimensional neural representations. An overriding challenge is to identify interesting statistical measures of the underlying ensembles of neural population responses which go beyond traditional linear methods. In my talk, I will discuss recent work, with Dan Lee, SueYeon Chung, and Uri Cohen in which we introduced new geometric characterizations of perceptual manifolds. These manifolds stand for the collections of the population responses of sensory neurons, induced by the physical variability of stimuli corresponding to the same perceptual entity, such as visual objects. Manifold Dimensions and Radii are shown to predict the object classification capacity, a quantitative measure of the ability to support object classification. We apply our theory to illuminate the principles underlying changes in object representations across layers of Deep Convolutional Neural Networks. Recordings from cortical neurons responding to object and face stimuli have been similarly analyzed, allowing us to test the correspondence between DCNNs and the visual hierarchy in primate cortex. I will also discuss the role of manifold geometry in the generalization ability of neural representations.

©(2019) Sompolinsky H

Cite as: Sompolinsky H (2019) Neural Representations: Geometry and Computation. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0007](https://doi.org/10.12751/nncn.bc2019.0007)

[I 8] From mice to molecules: the genetics of behavioural evolution

Hopi E. Hoekstra^{1,2}

1. Howard Hughes Medical Institute

2. Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, MA, USA

This is an exciting time for the study of behaviour, when we can combine sophisticated experimental approaches from neuroscience and genetics to study the mechanistic basis of behavioural variation in wild populations. In this talk, I will introduce you to deer mice (genus *Peromyscus*) that have naturally-evolved differences in several heritable and ecologically-relevant behaviors. Using a combination of behavioural experiments, genetics, and neurobiology, I will characterize the genetic architecture of these behavioural differences. I will end by sharing the lessons we are learning about how behaviours may evolve – through changes in the genome and neural circuits.

©(2019) Hoekstra HE

Cite as: Hoekstra HE (2019) From mice to molecules: the genetics of behavioural evolution. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0008](https://doi.org/10.12751/nncn.bc2019.0008)

[I 9] Spanning the arc between optimality theories and data

Gašper Tkacik¹

1. Institute of Science and Technology Austria, Klosterneuburg, Austria

Ideas about optimization are at the core of how we approach biological complexity. Quantitative predictions about biological systems have been successfully derived from first principles in the context of efficient coding, metabolic and transport networks, evolution, reinforcement learning, and decision making, by postulating that a system has evolved to optimize some utility function under biophysical constraints. Yet as normative theories become increasingly high-dimensional and optimal solutions stop being unique, it gets progressively hard to judge whether theoretical predictions are consistent with, or "close to", data. I will illustrate these issues using efficient coding applied to simple neuronal models as well as to a complex and realistic biochemical reaction network. As a solution, we developed a statistical framework which smoothly interpolates between ab initio optimality predictions and Bayesian parameter inference from data, while also permitting statistically rigorous tests of optimality hypotheses.

©(2019) Tkacik G

Cite as: Tkacik G (2019) Spanning the arc between optimality theories and data. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0009](https://doi.org/10.12751/nncn.bc2019.0009)

[I 10] A distributional code for value in dopamine-based reinforcement learning

Matthew Botvinick^{1,2}

1. DeepMind Technologies

2. University College London, London, UK

Twenty years ago, a link was discovered between the neurotransmitter dopamine and the computational framework of reinforcement learning. Since then, it has become well established that dopamine release reflects a reward prediction error, a surprise signal that drives learning of reward predictions and shapes future behavior. According to the now canonical theory, reward predictions are represented as a single scalar quantity, which supports learning about the expectation, or mean, of stochastic outcomes. I'll present recent work in which we have proposed a novel account of dopamine-based reinforcement learning, and adduced experimental results which point to a significant modification of the standard reward prediction error theory. Inspired by recent artificial intelligence research on distributional reinforcement learning, we hypothesized that the brain represents possible future rewards not as a single mean, but instead as a probability distribution, effectively representing multiple future outcomes simultaneously and in parallel. This idea leads immediately to a set of empirical predictions, which we tested using single-unit recordings from mouse ventral tegmental area. Our findings provide strong evidence for a neural realization of distributional reinforcement learning.

©(2019) Botvinick M

Cite as: Botvinick M (2019) A distributional code for value in dopamine-based reinforcement learning. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0010](https://doi.org/10.12751/nncn.bc2019.0010)

[I 11] **A reptilian model for sleep control and evolution**

Gilles Laurent¹

1. Max Planck Institute for Brain Research, Frankfurt a.M., Germany

This talk will summarize recent results of this lab focused on understanding the mechanisms underlying brain dynamics during sleep and their coordination. Our work exploits the relative simplicity of the reptilian brain to address general functional questions, in the context of vertebrate evolution.

©(2019) Laurent G

Cite as: Laurent G (2019) A reptilian model for sleep control and evolution. *Bernstein Conference 2019 Abstract*.

doi: [10.12751/nncn.bc2019.0011](https://doi.org/10.12751/nncn.bc2019.0011)

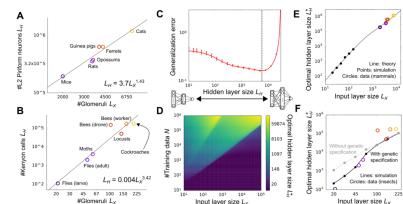
Contributed Talks

[C 1] Developmental and evolutionary principles of olfactory circuit designs

Naoki Hiratani¹, Peter E Latham¹

1. Gatsby Computational Neuroscience Unit, UCL, London, United Kingdom

A fundamental goal of neuroscience is to understand the design principle of neural circuits. That is hard to do in complete generality, so here we ask a slightly simpler question: can we predict the number of cells in various layers of a neural circuit by optimizing performance? We address this question in the context of olfaction, which shows clear scaling laws: in mammals, the number of layer 2 neurons in piriform cortex is proportional to the number of glomeruli to the 3/2 power (A; data from [1]), while in insects, the number of Kenyon cells is roughly cubic in the number of glomeruli according to our literature survey (B). We model the olfactory system as a three-layered nonlinear neural network, and analytically derive the scaling laws by estimating the network size that optimizes, over the lifetime of the animal, the ability to identify odors. Although having more neurons increases the information capacity, having too many neurons makes developmental tuning of synaptic weights difficult due to outfitting (C and D; here, non-monotonic phases arise partly due to nonlinearity in the activation function). Applying this tradeoff, commonly known as the bias-variance tradeoff, the optimal population sizes robustly follow the scaling law observed in mammals (E). This scaling is robust: it holds in full batch optimization and stochastic gradient learning, and under various choices of nonlinearity. We extend the framework to the case when a fraction of the olfactory circuit can be genetically specified, not developmentally learned, and numerically demonstrate that when there are a small number of glomeruli, this makes the scaling steeper, as is observed among insects (F). This study suggests that it may be possible to understand neural circuit from an optimality point of view, with optimization that occurs over evolutionary timescales.



A,B) The scaling laws among mammals (A; data is taken from [1]), and insects (B; data from literature survey). C, D) Analytical estimation of the optimal hidden layer size (C), and its training data size dependence (D). E,F) Fitting of the scalings among the mammals (E) and the insects (F).

Acknowledgements

This work is supported by the Gatsby Charitable Foundation and the Wellcome Trust.

References

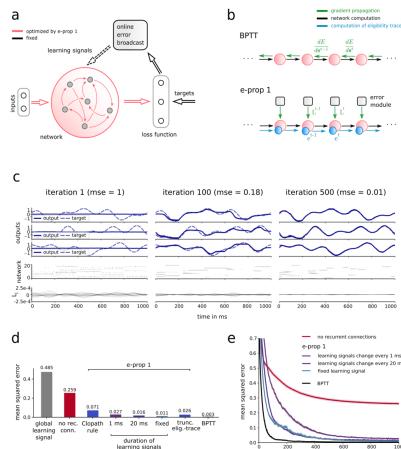
- 1 Srinivasan, Shyam, and Charles Stevens. "Scaling principles of distributed circuits." bioRxiv (2018): 449447. [10.1101/449447](https://doi.org/10.1101/449447)

[C 2] Biologically inspired alternatives to backpropagation through time for learning in recurrent neural nets

Guillaume Bellec¹, Franz Scherr¹, Elias Hajek¹, Darjan Salaj¹, Robert Legenstein¹, Wolfgang Maass¹

1. Institute for theoretical computer science, TU Graz, Infeldgasse 16b, Graz, Austria

The way how recurrently connected networks of spiking neurons in the brain acquire powerful information processing capabilities through learning has remained a mystery. This lack of understanding is linked to a lack of learning algorithms for recurrent networks of spiking neurons (RSNNs) that are both functionally powerful and can be implemented by known biological mechanisms. Since RSNNs are simultaneously a primary target for implementations of brain-inspired circuits in neuromorphic hardware, this lack of algorithmic insight also hinders technological progress in that area. The gold standard for learning in recurrent neural networks in machine learning is back-propagation through time (BPTT), which implements stochastic gradient descent with regard to a given loss function. But BPTT is unrealistic from a biological perspective, since it requires a transmission of error signals backwards in time and in space, i.e., from post- to presynaptic neurons. We show that an online merging of locally available information during a computation with suitable top-down learning signals in real-time provides highly capable approximations to BPTT. For tasks where information on errors arises only late during a network computation, we enrich locally available information through feedforward eligibility traces of synapses that can easily be computed in an online manner. The resulting new generation of learning algorithms for recurrent neural networks provides a new understanding of network learning in the brain that can be tested experimentally. In addition, these algorithms provide efficient methods for on-chip training of RSNNs in neuromorphic hardware.



- a) Learning architecture for e-prop 1. b) Temporal dynamics of information flows in BPTT and e-prop algorithms. The propagation of error signals backwards in time is replaced by a computation in real time of eligibility trace and learning signals. c-f) show performance comparisons.

Acknowledgements

This research was supported by the Human Brain Project of the European Union, Grant agreement No. 785907.

©(2019) Bellec G, Scherr F, Hajek E, Salaj D, Legenstein R, Maass W

Cite as: Bellec G, Scherr F, Hajek E, Salaj D, Legenstein R, Maass W (2019) Biologically inspired alternatives to backpropagation through time for learning in recurrent neural nets. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0013](https://doi.org/10.12751/nncn.bc2019.0013)

[C 3] Gating synaptic plasticity in cortical networks

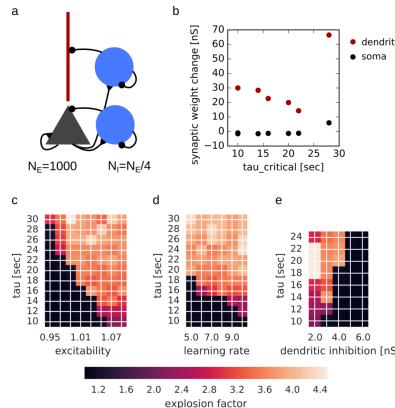
Katharina Anna Wilmes¹, Claudia Clopath¹

1. Bioengineering, Imperial College London, South Kensington Campus, United Kingdom

With Hebbian learning 'who fires together wires together', a well-known problem of plasticity-stability arises. On the one hand, plasticity can lead to unstable network dynamics, manifesting as run-away activity or silence. On the other hand, plasticity can erase or overwrite stored memories. These issues can partly be addressed with homeostatic plasticity mechanisms. Unfortunately, the time constants of homeostatic mechanisms required in network models are much shorter than what has been measured experimentally (Zenke et al. 2017).

Models requiring homeostatic plasticity with unrealistic time constants, however, assume that plasticity is continuously happening (e.g. Litwin-Kumar and Doiron 2014, Zenke et al. 2013). In contrast in the brain, plasticity is highly regulated by different neuromodulators (Pawlak et al. 2010), astrocytes (Valtcheva and Venance, 2016), and inhibitory interneurons (Artinian and Lacaille 2018). These different regulators of plasticity can slow down, speed up, gate, or flip plasticity. They differ in their temporal and spatial precision and hence enable rigorous plasticity control.

Here, we investigate how regulators with diverse properties influence the stability of network activity and stored memories. We use plastic balanced spiking neural networks consisting of excitatory neurons with a somatic and a dendritic compartment (which resemble cortical pyramidal cells in their firing properties), and inhibitory neurons targeting those compartments (Fig. 1a). We measure how different factors like excitability, learning rate, inhibition, and flipping the sign of plasticity affect the critical time constant for homeostatic plasticity (Fig. 1c-e). We compare different regulators in how much they permit synaptic weight changes and how spatially extended their influence can be without risking network instability. We specifically investigate how gating of dendritic versus somatic plasticity affects weight changes and stability in different ways. We suggest that the striking compartmentalisation of pyramidal cells and their inhibitory inputs enable large synaptic changes while maintaining network stability.



a. A balanced spiking network of 1000 two-compartment excitatory cells is interconnected with 250 inhibitory cells, which target soma and dendrites. Recurrent excitatory connections undergo triplet-based spike-timing-dependent plasticity with homeostasis. b. The total weight change of somatic versus dendritic synapses in stable network configurations with different excitability of the pyramidal cell model as a function of the critical time constant for homeostatic plasticity. The network tolerates more dendritic in comparison to somatic synaptic changes. c-e: Explosion factor (maximum population firing rate/mean population firing rate in the balanced regime without plasticity) as a function of the homeostatic time constant for plasticity tau and a plasticity regulating-factor (c: excitability, d: learning rate, e: dendritic inhibition). An explosion factor close to 1 hence means that the network is stable. Different plasticity-regulating factors influence and can hence loosen the constraint for the required homeostatic time constant for plasticity.

Gating synaptic plasticity in a balanced spiking neural network model

Acknowledgements

This work was supported by the German Research Foundation (DFG, Projektnummer 398005926) and by Wellcome Trust.

References

- 1 Zenke F, Gerstner W, and Ganguli S. (2017). The temporal paradox of Hebbian learning and homeostatic plasticity. *Current Opinion in Neurobiology*. 43:166-176. [10.1016/j.conb.2017.03.015](https://doi.org/10.1016/j.conb.2017.03.015)
- 2 Litwin-Kumar A and Doiron B. (2014) Formation and maintenance of neuronal assemblies through synaptic plasticity. *Nature Communications*. 5:5319. [10.1038/ncomms6319](https://doi.org/10.1038/ncomms6319)
- 3 Zenke F, Hennequin G, and Gerstner W (2013) Synaptic Plasticity in Neural Networks Needs Homeostasis with a Fast Rate Detector. *PLOS Computational Biology* 9(11): e1003330. [10.1371/journal.pcbi.1003330](https://doi.org/10.1371/journal.pcbi.1003330)
- 4 Pawlak V, Wickens JR, Kirkwood A, and Kerr JN. (2010) Timing is not Everything: Neuromodulation Opens the STDP Gate. *Front Synaptic Neurosci*. 2:146. [10.3389/fnsyn.2010.00146](https://doi.org/10.3389/fnsyn.2010.00146)
- 5 Valtcheva S and Venanc L. (2016). Astrocytes gate Hebbian synaptic plasticity in the striatum. *Nature communications*, 7, 13845. [10.1038/ncomms13845](https://doi.org/10.1038/ncomms13845)
- 6 Artinian J and Lacaille J-C. (2018) Disinhibition in learning and memory circuits: New vistas for somatostatin interneurons and long-term synaptic plasticity, *Brain Research Bulletin*. 141:20-26. [10.1016/j.brainresbull.2017.11.012](https://doi.org/10.1016/j.brainresbull.2017.11.012).

©(2019) Wilmes KA, Clopath C

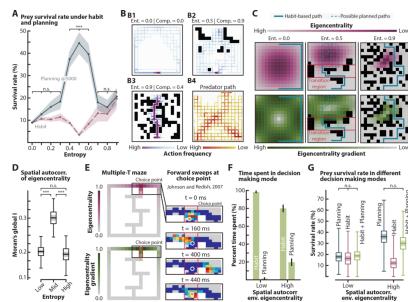
Cite as: Wilmes KA, Clopath C (2019) Gating synaptic plasticity in cortical networks. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0014](https://doi.org/10.12751/nncn.bc2019.0014)

[C 4] The shift from life in water to life on land advantaged planning in visually-guided behaviour

Malcolm A MacIver¹, Ugurcan Mugan¹

1. Neuroscience and Robotics Laboratory, Northwestern University, 2145 Sheridan Rd, Tech B224, United States

Other than formerly land-based mammals such as whales and dolphins that have returned to an aquatic existence, it is uncontroversial that land animals have developed more elaborated cognitive abilities than aquatic animals. Yet there is no apparent a-priori reason for this to be the case. A key cognitive faculty is the ability to plan. We modeled plan-based and habit-based action selection in a dynamic visually-guided behavior of crucialevolutionary importance, prey evading a predator while trying to reach a distant refuge. Simulations in environments with controlled levels of clutter from low to high show that planning provides a significant advantage, quantified by survival rate, over habit-based action selection, but only in environments with levels of clutter similar to that of terrestrial habitats. Analysis of the connectivity of these habitats shows that they feature clusters of open and closed spaces. Prior work on the neural basis of planning in rodents has shown that vicarious trial and error, which coincides with pronounced theta and gamma rhythms, occur at high cost choice points. Moreover, the theta coherence between the hippocampus and the prefrontal cortex (PFC)—hypothesized to be important for the PFC to sort through options—increases as rodents transition from a closed to open spaces. Such findings suggests that animals continuously switch between habit- and plan-based action selection. Inspired by these findings, we designed a prey that evaluates transitions in spatial connectivity to toggle between these decision making modes. We show that even when a majority of the simulated prey's time is spent under habit-based control, such a strategy results in indistinguishable performance when compared to continuous planning. Together, these results suggest that the evolution of planning is dependent on the massive increase in visual range and spatial complexity that greeted the first vertebrates to view the world above the waterline 380 million years ago. Our results have implications for understanding the evolutionary basis of the limited ability of animals, including humans, to plan ahead to meet slowly looming and distant threats, toward a neuroscience of sustainability.



(Note: some statistics removed to stay within word limit) (A) Mean +/- s.e.m ($n=20$) of survival rate as a function of clutter level with 5000 states forward simulated (teal solid line), and with habit-based action selection (pink dashed line). (B1–B3) Heatmaps of all action sequences taken by the

Acknowledgements

This work was funded by NSF Brain Initiative ECCS-1835389.

©(2019) Maclver MA, Mugan U

Cite as: Maclver MA, Mugan U (2019) The shift from life in water to life on land advantaged planning in visually-guided behaviour. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0015](https://doi.org/10.12751/nncn.bc2019.0015)

[C 5] Energy efficient synaptic plasticity

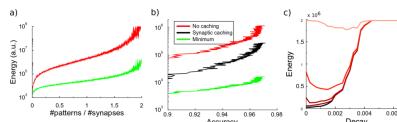
Ho Ling Li¹, Mark CW van Rossum²

1. School of Psychology, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

2. School of Psychology and School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

Many aspects of the brain's design can be understood as the result of evolutionary drive towards efficient use of metabolic energy. In addition to the energetic costs of neural computation and transmission [1, 2], experimental evidence has indicated that synaptic plasticity is metabolically demanding as well [2-5]. For example, Plaçais et al. found that fruit flies doubled their sucrose consumption during the formation of aversive long-term memory [4], while forcing starving fruit flies to form such memories reduced lifespan by 30% [5]. Yet, how energy cost might have shaped learning in the brain is not known.

To examine the metabolic energy cost associated to plasticity, we train both the perceptron and multi-layer networks with back-propagation to perform pattern classification. We find that the energy cost of synaptic plasticity rises rapidly with the number of patterns needed to be stored (fig. a), or required accuracy (fig. b). This indicates trade-offs between energy consumption, and network capacity and performance. The standard synaptic plasticity rules (red curves on fig. a and b) are found to be highly energy inefficient as they expend significantly more energy compared to the minimum (green curves on fig. a and b), but this can be avoided by precisely balancing transient forms of synaptic plasticity with more stable forms (black curve on fig. b). This algorithm, termed synaptic caching, can boost energy efficiency considerably. Depending on the decay and the maintenance cost of the transient plasticity, the energy required for training can range from as little as the minimum to as much as the energy required without caching (fig. c). Our results yield a novel interpretation of the multiple forms of neural synaptic plasticity observed experimentally, including synaptic tagging and capture phenomena, and are relevant for energy efficient neuromorphic designs.



(a) and (b): see abstract. (c) The amount of energy required for learning as a function of the decay of transient plasticity for various values of the maintenance cost (from bottom to top, low to high maintenance cost).

Acknowledgements

This project is supported by the Leverhulme Trust with grant number RPG-2017-404. MvR is supported by Engineering and Physical Sciences Research Council (EPSRC) grant EP/R030952/1. We would like to thank Joao Sacramento and Simon Laughlin for discussion and inputs.

References

- 1 Harris JJ, Jolivet R, Attwell D (2012) Synaptic energy use and supply. *Neuron* 75(5):762–777 [10.1016/j.neuron.2012.08.019](https://doi.org/10.1016/j.neuron.2012.08.019)
- 2 Attwell D, Laughlin SB (2001) An energy budget for signaling in the grey matter of the brain. *J Cereb Blood Flow Metab* 21(10):1133–1145 [10.1097/00004647-200110000-00001](https://doi.org/10.1097/00004647-200110000-00001)
- 3 Jaumann S, Scudelari R, Naug D (2013) Energetic cost of learning and memory can cause cognitive impairment in honeybees. *Biology Letters* 9(4):20130149 [10.1098/rsbl.2013.0149](https://doi.org/10.1098/rsbl.2013.0149)
- 4 Plaçais PY, et al. (2017) Upregulated energy metabolism in the drosophila mushroom body is the trigger for long-term memory. *Nature Communications* 8(15510) [10.1038/ncomms15510](https://doi.org/10.1038/ncomms15510)
- 5 Plaçais PY, Préat T (2013) To favor survival under food shortage, the brain disables costly memory. *Science* 339(6118):440–442 [10.1126/science.1226018](https://doi.org/10.1126/science.1226018)

©(2019) Li HL, van Rossum MC

Cite as: Li HL, van Rossum MC (2019) Energy efficient synaptic plasticity. Bernstein Conference 2019 Abstract.

doi: [10.12751/nncn.bc2019.0016](https://doi.org/10.12751/nncn.bc2019.0016)

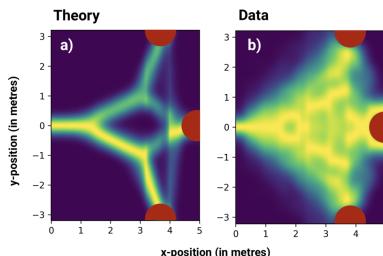
[C 6] The geometry of decision-making

Vivek H. Sridhar^{1,2,3}, Renaud Bastien^{1,2,3}, Paul Szyszka⁴, Nir S. Gov⁵, Iain D. Couzin^{1,2,3}

1. Centre for the Advanced Study of Collective Behaviour, Universität Konstanz, Universitätstraße 10, Germany
2. Department of Collective Behaviour, Max Planck Institute of Animal Behaviour, AG Couzin, Universitätstraße 10, Germany
3. Department of Biology, Universität Konstanz, Universitätstraße 10, Germany
4. Department of Zoology, University of Otago, Dunedin 9054, New Zealand
5. Department of Chemical Physics, Weizmann Institute of Science, Rehovot, Israel

Animals constantly make decisions regarding where to feed, whom to court, where to sleep etc. in a way that maximises their survival and reproductive success. In such scenarios, the spatial location of the available options can be represented in the animal's brain vectorially—an ensemble of neurons in the hippocampus encode distance and direction to goals [1]. If different neurons fire for different options, then decision-making can be viewed as a consensus paradigm among neurons within the goal-direction ensemble. Using a Hopfield neural network model, we reveal a simple algorithm based on vector superposition that explains decision-making in Euclidean space. In the two-choice scenario, the model predicts that individuals should switch from moving in the average of the two target directions to randomly selecting one of the two options when the angular disagreement exceeds 120°. Notably, this is the angle at which the summation of two equal-length vectors becomes shorter than each individual vector. When faced with more than two options, the model predicts that the individual reduces multi-choice decisions to a series of binary decisions where the locations of the decision points themselves are determined based on the geometry of the options from an egocentric standpoint. We validated these predictions by exposing sixty *Drosophila melanogaster* to visual decision-making tasks in a 2-D virtual reality environment. To do this, we exploited their natural tendency to fly to high-contrast vertical stripes [2]. By exposing individuals to multiple high-contrast pillars, we get a behavioural readout—and potentially a neural readout by proxy—of the decision-making process. As predicted by the model, bifurcations are observed in the trajectories and multi-choice decisions are reduced to a series of binary decisions. Finally, by reproducing these results using an established model of consensus decision-making in animal groups, and comparing this with existing work on fish schools and baboon troops [3,4], we show

that this algorithm is scale independent and applies to both individual and collective decision-making.



Choice is reduced in the brain by breaking multi-choice decisions to a series of binary decisions. a) shows results from the model while b) is trajectories from flies in a 2D virtual reality environment. In both cases, the three options available to the focal individual are presented as red circles.

References

- 1 Sarel, A., Finkelstein, A., Las, L., & Ulanovsky, N. (2017). Vectorial representation of spatial goals in the hippocampus of bats. *Science*, 355(6321), 176-180.
- 2 Heisenberg, M., & Wolf, R. (1979). On the fine structure of yaw torque in visual flight orientation of *Drosophila melanogaster*. *Journal of comparative physiology*, 130(2), 113-130.
- 3 Couzin, I. D., Krause, J., Franks, N. R., & Levin, S. A. (2005). Effective leadership and decision-making in animal groups on the move. *Nature*, 433(7025), 513.
- 4 Strandburg-Peshkin, A., Farine, D. R., Couzin, I. D., & Crofoot, M. C. (2015). Shared decision-making drives collective movement in wild baboons. *Science*, 348(6241), 1358-1361.

©(2019) Sridhar VH, Bastien R, Szyszka P, Gov NS, Couzin ID

Cite as: Sridhar VH, Bastien R, Szyszka P, Gov NS, Couzin ID (2019) The geometry of decision-making. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0017](https://doi.org/10.12751/nncn.bc2019.0017)

[C 7] The electrical impact of axon initial segment plasticity

Sarah Goethals¹, Romain Brette¹

¹ Sorbonne Université, INSERM, CNRS, Institut de la Vision, 17 Rue Moreau, 75012 Paris, France

In most vertebrate neurons, action potentials are triggered at the distal end of the axon initial segment (AIS). They are then transmitted to the soma where they are regenerated and further propagated in the dendritic tree. The AIS position and length are highly variable across and within neuron types. Moreover, recent studies have reported that the AIS undergoes structural plasticity. Changes in electrical activity can trigger a relocation or elongation/shortening of the AIS. In view of the crucial role of the AIS in spike initiation, these observations raise the question of the function of AIS geometry. What is the specific effect of AIS plasticity on electrical function? Experimentally, that effect is not straightforward to understand because AIS plasticity goes along with other intrinsic changes such as channel expression and phosphorylation. Simulations have also shown a variety of effects, with no clear understanding of the conditions for each of them. So we used a principled theoretical approach to understand the effect of changes in position, length and sodium channel density on electrical function. We start by studying analytically the impact of AIS geometry on excitability in a simple axon model by solving the cable equation in the AIS with appropriate boundary conditions. First, we look at the

impact of changes in AIS geometry on the somatic voltage threshold. Considering only Na channels in the AIS, our theoretical results suggest that the threshold depends mainly on the middle position of the AIS and on the total number of Na channels. In particular, shifting the AIS away from the soma decreases the threshold and in consequence increases excitability. Second, we show that if we add a hyperpolarizing current at the AIS (e.g. Kv channels), the effect of shifting the AIS is reversed. Third, we examine the impact of AIS geometry on the current that backpropagates to the soma. We find that this impact is determined mainly by the AIS start position, and by the Na channel density in the AIS. These theoretical results agree with simulations of an action potential model. Although previous studies have focused on changes in intrinsic excitability, we point out that the electrical effect of AIS plasticity is multidimensional. In particular, different geometrical factors affect the spike threshold and the backpropagation to the soma.

©(2019) Goethals S, Brette R

Cite as: Goethals S, Brette R (2019) The electrical impact of axon initial segment plasticity. *Bernstein Conference 2019*
Abstract. doi: [10.12751/nncn.bc2019.0018](https://doi.org/10.12751/nncn.bc2019.0018)

Posters Wednesday

Learning, plasticity and memory

[W 1] Information capacity of a network of spiking neurons.

Antonio de Candia¹, Silvia Scarpetta²

1. Dipartimento di Fisica "E. Pancini", Università di Napoli Federico II, Complesso Universitario di Monte S. Angelo, Napoli, Italy

2. Dipartimento di Fisica "E.R. Caianiello", Università di Salerno, Via Giovanni Paolo II, 132 - 84084 Fisciano (SA), Italy

We study a model of spiking neurons, with recurrent connections that result from learning a set of spatio-temporal patterns with a spike-timing dependent plasticity rule. We investigate the ability of the network to store and selectively replay multiple patterns of spikes, with a combination of spatial population and phase-of-spike code. Each neuron in a pattern is characterized by a binary variable determining if the neuron is active in the pattern, and a phase-lag variable representing the spike-timing order among the active units. After the learning stage, we study the dynamics of the network induced by a brief cue stimulation, and verify that the network is able to selectively replay the pattern correctly and persistently. We calculate the information capacity of the network, defined as the maximum number of patterns that can be encoded in the network times the number of bits carried by each pattern, normalized by the number of synapses, and find that it reaches a value $\alpha_{max} \simeq 0.27$, similar to the one of sequence processing neural networks, and almost double of the capacity of the static Hopfield model. We study the dependence of the capacity on the global inhibition, connection strength (or neuron threshold) and fraction of neurons participating to the patterns. The results show that a dual population and temporal coding can be optimal for the capacity of an associative memory.

©(2019) de Candia A, Scarpetta S

Cite as: de Candia A, Scarpetta S (2019) Information capacity of a network of spiking neurons.. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0019](https://doi.org/10.12751/nncn.bc2019.0019)

[W 2] Inhibitory plasticity can generate cortical novelty responses

Auguste Schulz^{1,2}, Jan Homann³, Michael Berry II³, Julijana Gjorgjieva^{1,4}

1. Computation in Neural Circuits, Max Planck Institute for Brain Research, Frankfurt, Germany

2. Electrical and Computer Engineering, Technical University Munich, Munich, Germany

3. Princeton Neuroscience Institute, Princeton University, Princeton, USA

4. School of Life Sciences Weihenstephan, Technical University Munich, Munich, Germany

The ability to predict the near and far future is crucial for the survival of an animal. In fact, the brain is known to perform predictive computations upon incoming sensory stimuli. How these predictive computations are implemented mechanistically, however, remains unknown. One way to test for predictive computations is to create violations of periodic and, therefore, predictable stimulus sequences. Interleaving a repeated image sequence with novel unpredictable images has been shown to elicit excess activity in a population of excitatory neurons in the mouse primary visual cortex [1]. This study further revealed that a small subset of the population shows sustained sequence-specific activity patterns during repeated sequence presentation. As of yet the mechanisms that generate these observed response types have not been identified. Here we investigate

inhibitory plasticity as a biologically plausible mechanism for generating the observed novelty responses in cortex. By implementing the corresponding experimental paradigm in a computational network model of spiking neurons [2], we show that plasticity between inhibitory and excitatory neurons is sufficient to capture the population novelty response. Specifically, we consider inhibitory spike time dependent plasticity [3]. Image presentations are implemented by modulating the rate of the feed-forward input to fixed, randomly selected subsets of neurons. The interaction of several plasticity mechanisms leads to the formation of stable Hebbian assemblies that correspond to the presented images [2]. Adaptation in our proposed network occurs due to increased inhibitory weights and, therefore, increased inhibition onto highly active neurons. Fast inhibitory learning allows to capture the adaptation to repeated stimuli on timescales that are consistent with the experimental observations. The model further predicts that neurons in primary visual cortex do not learn the exact temporal structure of a sequence, but rather adapt to the distribution of stimuli. Intriguingly, a large range of experimental data concerned with novelty detection in the cortex could be captured with this recurrent network that solely receives feed-forward input but no feedback from higher cortical areas.

Acknowledgements

AS and JG thank the Max Planck Society for funding and MJB and JH thank the NEI and the Princeton Accelerator Fund for funding.

References

- 1 Homann et al., Predictive Coding of Novel versus Familiar Stimuli in the Primary Visual Cortex, bioRxiv, 2017
- 2 Litwin-Kumar and Doiron, Formation and maintenance of neuronal assemblies through synaptic plasticity, Nature Communications, 2014
- 3 Vogels et al., Inhibitory Plasticity Balances Excitation and Inhibition in Sensory Pathways and Memory Networks, Science, 2011

©(2019) Schulz A, Homann J, Berry II M, Gjorgjieva J

Cite as: Schulz A, Homann J, Berry II M, Gjorgjieva J (2019) Inhibitory plasticity can generate cortical novelty responses. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0020](https://doi.org/10.12751/nncn.bc2019.0020)

[W 3] Innate behavior modulated by experience in zebrafish larvae

Hanna Zwaka¹, Kristian Herrera¹, Armin Bahl¹, Florian Engert¹

1. Molecular and Cellular Biology, Harvard University, 16 Divinity Avenue, United States

How does experience change behavior? Innate behaviors are not learned, but they can, however, change with experience: bumble bees have an innate color preference but can overcome that preference when they learn another color (Gumbert, 2000). Similarly, innate behaviors can be influenced by the animal's state; Drosophila only court vigorously when they have a food source nearby to sustain the progeny (Su and Wang, 2014). A well-studied innate behavior is the optomotor response (OMR). It is common to all fish and insects. This behavior stabilizes their course during locomotion when they are involuntarily displaced. In zebrafish larvae, intermediate stress measured as cortical level can influence innate behavior following an inverted u-shape curve (Ryu and Marco, 2017). Moreover, arousal can change the sensory threshold of zebrafish larvae: animals that were exposed to a water flow for a period of time were more likely to turn towards a slow-moving OMR stimulus than before. However, this change only persisted on the time scale of minutes. The larvae were not more responsive to other sensory stimuli than

those related to flow (Yokogawa et al., 2012). Here we study how experience, in our case stress paired with an OMR stimulus, can affect an innate behavior. We study stress in a free-swimming paradigm using sodium chloride as a stressor. To zebrafish, salt is an aversive stimulus that they avoid in a concentration dependent manner. We show that in larval zebrafish the sensitivity to moving stimuli is dependent on contrast and spatial frequency, a phenomenon known for many animals including humans. We can influence this sensitivity by a stressful experience caused by sodium chloride exposure. This experience can enhance the innate behavior optomotor response over several hours. More specifically, the experience modulates turning behavior in zebrafish larvae such that the animals show more correct turns and less incorrect turns. The larval zebrafish provides a vertebrate system that is genetically amenable, an optically accessible for whole-brain imaging at single cell resolution, and a brain that shares basic structures with humans. Using calcium imaging makes it possible to identify brain regions affected by the stress. Imaging these brain regions in an adapted head-fixed preparation, we plan to investigate circuit mechanisms underlying the changes in innate behavior caused by experience using two-photon imaging.

References

- 1 Gumbert, A. (2000). Color choices by bumble bees (*Bombus terrestris*): innate preferences and generalization after learning. *Behav. Ecol. Sociobiol.* 48, 36–43.
- 2 Su, C.-Y., and Wang, J.W. (2014). Modulation of neural circuits: how stimulus context shapes innate behavior in *Drosophila*. *Curr. Opin. Neurobiol.* 29, 9–16.
- 3 Ryu, S., and Marco, R.J.D. (2017). Performance on innate behaviour during early development as a function of stress level. *Sci. Rep.* 7, 7840. [10.1038/s41598-017-08400-4](https://doi.org/10.1038/s41598-017-08400-4)
- 4 Yokogawa, T., Hannan, M.C., and Burgess, H.A. (2012). The Dorsal Raphe Modulates Sensory Responsiveness during Arousal in Zebrafish. *J. Neurosci.* 32, 15205–15215. [10.1523/JNEUROSCI.1019-12.2012](https://doi.org/10.1523/JNEUROSCI.1019-12.2012)

©(2019) Zwaka H, Herrera K, Bahl A, Engert F

Cite as: Zwaka H, Herrera K, Bahl A, Engert F (2019) Innate behavior modulated by experience in zebrafish larvae. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0021](https://doi.org/10.12751/nncn.bc2019.0021)

[W 4] Interneuron-mediated homeostatic plasticity enables development of Pyr-PV cell assemblies in mouse V1

Owen Mackwood^{1,2}, Henning Sprekeler^{1,2}

1. *Modelling of Cognitive Processes, Technische Universität Berlin, Marchstr. 23, 10587 Berlin, Germany*
2. *Bernstein Center for Computational Neuroscience, Philippstraße 12, 10115 Berlin, Germany*

While inhibitory interneurons have long been recognized as crucial for controlling network excitability, their precise role in cortical computation is still debated [1]. In mouse primary visual cortex (V1), there is dense anatomical connectivity between pyramidal (Pyr) neurons and parvalbumin-expressing (PV) interneurons. Additionally, neighboring Pyr neurons often prefer different stimuli. Unless synaptic strengths are carefully tuned, those properties together would limit stimulus selectivity of the total excitatory current onto each PV neuron. In such a scenario, it has been hypothesised that PV neurons cannot provide stimulus-specific inhibitory feedback, but rather a "blanket of inhibition" [2].

Recent experiments by Znamenskiy et al. [3] revealed carefully tuned synapses between Pyr-PV cell pairs in mouse V1, indicating the presence of Pyr-PV cell assemblies, within which neurons prefer similar stimulus features. This suggests PV cells could exhibit stimulus selectivity, and thus provide stimulus-specific feedback inhibition rather than

offering a “blanket of inhibition”. The question we address here is, what synaptic plasticity mechanisms could produce such cell assemblies?

To answer that question, we begin with an assumption: The firing rate of Pyr neurons is homeostatically regulated by PV neuron-mediated inhibition. We derive a single mathematical expression that can be simplified to a pair of complementary plasticity rules, one of which modifies inhibitory PV-to-Pyr synapses (similarly to [4]) and the other modifies excitatory Pyr-to-PV synapses. In a computational model, we find that together these plasticity rules can account for key findings from Znamenskiy et al.: 1) Strong correlations that exist between the response similarity of a Pyr-PV cell pair and the synapses linking them. 2) For reciprocally connected pairs, the strength of the inhibitory synapse is highly correlated with the excitatory synapse strength. Notably, both rules are required to reproduce these experimental findings.

Our approach provides a mechanism that reproduces recent experimental data, by assuming that PV neuron-mediated inhibition regulates Pyr neuron firing rates. This work offers an explanation for the emergence of Pyr-PV cell assemblies in mouse V1, where the interplay of Pyr-to-PV and PV-to-Pyr synaptic plasticity is essential.

Acknowledgements

This work was funded by the German Federal Ministry for Education and Research (FKZ 01GQ1201).

References

- 1 Isaacson JS & Scanziani M (2011) How Inhibition Shapes Cortical Activity. *Neuron*, 72(2), 231-243. [10.1016/j.neuron.2011.09.027](https://doi.org/10.1016/j.neuron.2011.09.027)
- 2 Harris, K. D. and Mrsic-Flogel, T. D. (2013). Cortical connectivity and sensory coding. *Nature*, 503(7474):51. [10.1038/nature12654](https://doi.org/10.1038/nature12654)
- 3 Znamenskiy, P., Kim, M. H., Muir, D. R., Iacaruso, M. F., Hofer, S. B., and Mrsic-Flogel, T. D. (2018). Functional selectivity and specific connectivity of inhibitory neurons in primary visual cortex. *bioRxiv*, page 294835. [10.1101/294835](https://doi.org/10.1101/294835)
- 4 Vogels, T. P., Sprekeler, H., Zenke, F., Clopath, C., and Gerstner, W. (2011). Inhibitory plasticity balances excitation and inhibition in sensory pathways and memory networks. *Science* (New York, N.Y.), 334(6062):1569–73. [10.1126/science.1211095](https://doi.org/10.1126/science.1211095)

©(2019) Mackwood O, Sprekeler H

Cite as: Mackwood O, Sprekeler H (2019) Interneuron-mediated homeostatic plasticity enables development of Pyr-PV cell assemblies in mouse V1. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0022](https://doi.org/10.12751/nncn.bc2019.0022)

[W 5] Joint dynamics of synaptic weights and spike train correlations for nonlinear plasticity with higher-order correlations.

Gabriel Koch Ocker¹, Michael A. Buice^{1,2}

1. Allen Institute for Brain Science, Seattle, WA, USA

2. Department of Applied Mathematics, University of Washington, Seattle, WA, USA

The structure of neural networks shapes their activity by controlling the propagation of spikes. In turn, the strength of synaptic connections depends on the joint history of pre- and post-synaptic activity. This two-way interaction has posed a central challenge for understanding learning in neural circuits. Since the 1970s, theoretical methods for predicting spiking statistics from circuit structure have mainly focused on predicting firing rates and two-spike correlations by linearizing neural activity around a central operating point [1,2,3]. In recent years, generalizations of these methods have provided access to three-spike and higher-order correlations and to nonlinear corrections reflecting multi-spike synergy [4,5]. Self-consistent theories for the joint evolution of spiking statistics and connection strengths rely on a separation of timescales between spike time correlations (on the order of 10s up to 100s of milliseconds) and changes in synaptic weights (on the order of seconds to minutes or longer) [6]. Even within these self-consistent approaches, theoretical predictions have relied on assuming weak spike train correlations and have been restricted to plasticity driven by spike pairs [7-9].

Here, we present a general expansion for the joint dynamics of synaptic weights and activity statistics that accounts for nonlinear plasticity dynamics and higher-order correlations in spike trains. Using methods from statistical field theory, we directly treat the joint probability density functional of the activity and synaptic weights. We use the separation of timescales between activity and plasticity to average over the activity, obtaining an effective density for the synaptic weight evolution. We demonstrate the utility of our approach by analyzing the dynamics of spike triplet-dependent plasticity [10]. We demonstrate self-consistent predictions of the evolution of synaptic weights and triplet spike train correlations in recurrent circuits, and then study the fixed points of a homeostatically regulated triplet STDP model.

Acknowledgements

We wish to thank the Allen Institute founder, Paul G. Allen, for his vision, encouragement and support.

References

- 1 Hawkes AG. Spectra of some self-exciting and mutually exciting point processes. *Biometrika*. 1971; 58(1):83–90. [10.1093/biomet/58.1.83](https://doi.org/10.1093/biomet/58.1.83)
- 2 Sejnowski TJ. Storing covariance with nonlinearly interacting neurons. *Journal of Mathematical Biology*. 1977; 4(4):303–321. [10.1007/BF00275079](https://doi.org/10.1007/BF00275079) PMID: 925522
- 3 Herfurth T, Tchumatchenko T. How linear response shaped models of neural circuits and the quest for alternatives. *Current Opinion in Neurobiology*. 2017; 46:234–240. [10.1016/j.conb.2017.09.001](https://doi.org/10.1016/j.conb.2017.09.001)
- 4 Jovanović S, Hertz J, Rotter S. Cumulants of Hawkes point processes. *Phys. Rev. E* 91, 042802. [10.1103/PhysRevE.91.042802](https://doi.org/10.1103/PhysRevE.91.042802)
- 5 Ocker GK, Josić K, Shea-Brown E, Buice MA (2017) Linking structure and activity in nonlinear spiking networks. *PLoS Comput Biol* 13(6): e1005583. [10.1371/journal.pcbi.1005583](https://doi.org/10.1371/journal.pcbi.1005583)
- 6 Kempter R, Gerstner W, Van Hemmen JL (1999) Hebbian learning and spiking neurons. *Physical Review E* 59: 4498. [10.1103/PhysRevE.59.4498](https://doi.org/10.1103/PhysRevE.59.4498)
- 7 Gilson M, Burkitt AN, van Hemmen JL (2010). STDP in recurrent neuronal networks. *Front Comput Neurosci* 4: 23. [10.3389/fncom.2010.00023](https://doi.org/10.3389/fncom.2010.00023)
- 8 Ocker GK, Litwin-Kumar A, Doiron B (2015) Self-Organization of Microcircuits in Networks of Spiking Neurons with Plastic Synapses. *PLoS Comput Biol* 11(8): e1004458. [10.1371/journal.pcbi.1004458](https://doi.org/10.1371/journal.pcbi.1004458)
- 9 avid Tannenbaum N, Burak Y (2016) Shaping Neural Circuits by High Order Synaptic Interactions. *PLoS Comput Biol* 12(8): e1005056. [10.1371/journal.pcbi.1005056](https://doi.org/10.1371/journal.pcbi.1005056)

- 10 Triplets of Spikes in a Model of Spike Timing-Dependent Plasticity. Jean-Pascal Pfister and Wulfram Gerstner. *Journal of Neuroscience* 20 September 2006, 26 (38) 9673-9682 [10.1523/JNEUROSCI.1425-06.2006](https://doi.org/10.1523/JNEUROSCI.1425-06.2006)

©(2019) Ocker GK, Buice MA

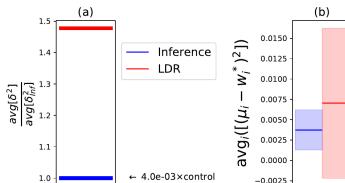
Cite as: Ocker GK, Buice MA (2019) Joint dynamics of synaptic weights and spike train correlations for nonlinear plasticity with higher-order correlations.. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0023](https://doi.org/10.12751/nncn.bc2019.0023)

[W 6] Learning as inference: dealing with correlated noise

Alexander D. Antrobus¹, Peter E. Latham¹

¹. *Gatsby Unit, University College London, 25 Howland St, Fitzrovia, London W1T 4JG, United Kingdom*

Learning synaptic weights is difficult. Connections receive global error signals, which are low dimensional and noisy, and local signals which lack information about relative contributions to the error. In this setting, it makes sense for connections to learn not just a ‘best guess’ of their weight, but also how confident they should be in this guess: i.e. to infer a *distribution* over their target weight. This idea was developed in [MacKay1992] and [Aitchison2017]. Similar concepts appear in [Hiratani2018]. In the aforementioned works the update equations are discrete in time and the likelihoods used in inference are Markov. This is not how things are in biology, where signals are continuous in time and temporally correlated. In this work we consider a non-Markov setting, deriving coupled ODEs which describe how the parameters of the posterior over the target weight evolve as more data is observed. We use a local temporal-smoothing method to deal with the fact that feedback is continuous and pre-synaptic spike events are discrete. We show that the window of smoothing can be chosen in a principled way: maximising the per-spike decrease in posterior uncertainty. We find our algorithm works better than the leaky delta rule with optimised learning rate. More importantly, for the simple model described, the method accurately predicts posterior variance. This is important because it provides a normative understanding for the variance in synaptic efficacy: the efficacy of the synapse at each spike can be seen as a *sample* drawn from this posterior distribution.



Mean squared-errors. (a) The mean squared-error in the output for the two algorithms, normalised by the inference scale. (b) Mean squared distance between the posterior mean and the target (shading is 1-sigma) across 100 neurons.

References

- 1 [MacKay1992] [10.1162/neco.1992.4.3.448](https://doi.org/10.1162/neco.1992.4.3.448)
- 2 [Aitchison2017]
- 3 [Hiratani2018] [10.1073/PNAS.1803274115](https://doi.org/10.1073/PNAS.1803274115)

©(2019) Antrobus AD, Latham PE

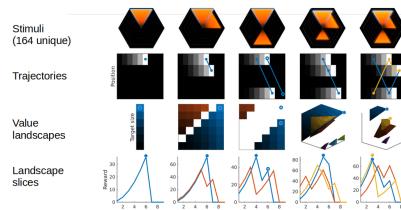
Cite as: Antrobus AD, Latham PE (2019) Learning as inference: dealing with correlated noise. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0024](https://doi.org/10.12751/nncn.bc2019.0024)

[W 7] Learning Complex Skills: Psychophysics in high dimensions

Gautam Agarwal¹, Tiago Quendera¹, Mattia Bergomi¹, Zachary Mainen¹

1. Systems Neuroscience Lab, Champalimaud Foundation, Av. Brasilia, Lisbon, Portugal

Learning a complex skill requires traversing a potentially enormous search space. While reinforcement learning (RL) algorithms can approach human levels of performance in complex tasks, they require much more training to do so. This may be because humans constrain search problems with prior knowledge, allowing them to more rapidly discover solutions. Importantly, the statistics that underlie this learning process are both poorly understood and hard to investigate in the large state spaces found in most complex tasks. To address this, we have designed a parametric variation of the traveling salesman problem, a standard NP-hard search problem. We find that subjects rapidly learn to solve the task by arriving at a strategy that exploits task invariances and generalizes to previously unencountered stimuli. However, as task dimensionality increases, this strategy becomes increasingly suboptimal, and is discarded only after extensive failure. In contrast, model-free RL agents initially learn the task slowly, unable to generalize, but subsequently avoid getting stuck with suboptimal solutions. Thus, human and RL agents improve in complementary ways, respectively showing flexibility in either the application or modification of their policy. Releasing this task as a mobile app, we now aim to model variability and learning in humans' plan construction in high-resolution.



Value landscapes grow in complexity as task dimensionality increases. For agents, the difficulty lies in escaping local maxima to achieve mildly higher scores.

©(2019) Agarwal G, Quendera T, Bergomi M, Mainen Z

Cite as: Agarwal G, Quendera T, Bergomi M, Mainen Z (2019) Learning Complex Skills: Psychophysics in high dimensions. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0025](https://doi.org/10.12751/nncn.bc2019.0025)

[W 8] Learning spatiotemporal signals using a recurrent spiking network that discretizes time

Amadeus Maes¹, Mauricio Barahona², Claudia Clopath¹

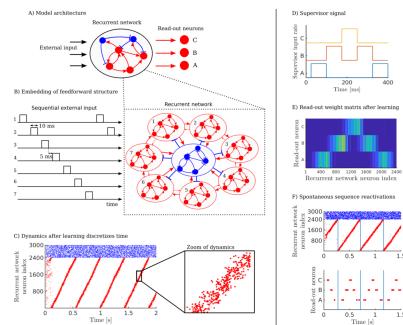
¹. Department of Bioengineering, Imperial College London, London, UK

². Department of Mathematics, Imperial College London, London, UK

Learning to produce spatiotemporal sequences is a common task the brain has to solve. The same neural substrate may be used by the brain to produce different sequential behaviours. The way the brain learns and encodes such tasks remains unknown as current computational models do not typically use realistic biologically-plausible learning [1]. Here, we propose a model where a spiking recurrent network of excitatory and inhibitory biophysical neurons drives a read-out layer (figure 1A): the dynamics of the recurrent network is constrained to encode time while the read-out neurons encode space. Space is then linked with time through plastic synapses that follow common Hebbian learning rules [2].

Time is discretized in the recurrent spiking network by C clusters of excitatory neurons, $t = [t_0, t_1, \dots, t_C]$. Previous studies have shown how a random switching dynamics on a behavioural time scale emerges from a clustered connectivity [3,4]. Here, the clusters are trained to be sequentially active by embedding a feedforward structure in the connectivity (figure 1B and 1C). Importantly, this structure and dynamics is stable under the set of plasticity rules present in the recurrent network. At each point in time, only a subset of neurons spike, i.d. the neurons belonging to the same cluster. This discretization enables Hebbian plasticity to bind read-out neurons to the recurrent neurons active in the relevant time-bin to learn a function of time: $t \rightarrow \phi(t)$. The neurons in the read-out layer encode 'space', meaning the D different dimensions of the signal: $\phi(t) = [\phi_1(t), \phi_2(t), \dots, \phi_D(t)]$ ($D = 3$ in figure 1D). The learned mapping is stored in the read-out weights (figure 1E).

In summary, we demonstrate that the proposed model is able to learn spatiotemporal dynamics on a timescale that is behaviourally relevant. Learned sequences are robustly replayed during a regime of spontaneous activity (figure 1F).



A) A recurrent network drives read-out neurons. B) Repeated sequential input creates a feedforward structure. C) The sequential dynamics discretizes time. D) Example target signal: ABCBA. E) The target signal is stored in the read-out weights after learning. F) Spontaneous sequence replays.

Acknowledgements

This work was supported by the Centre for Neurotechnology at Imperial College London.

References

- 1 Nicola and Clopath, 2017 [10.1038/s41467-017-01827-3](https://doi.org/10.1038/s41467-017-01827-3)
- 2 Clopath et al., 2010 [10.1038/nn.2479](https://doi.org/10.1038/nn.2479)
- 3 Litwin-Kumar and Doiron, 2014 [10.1038/ncomms6319](https://doi.org/10.1038/ncomms6319)
- 4 Schaub et al., 2015 [10.1371/journal.pcbi.1004196](https://doi.org/10.1371/journal.pcbi.1004196)

©(2019) Maes A, Barahona M, Clopath C

Cite as: Maes A, Barahona M, Clopath C (2019) Learning spatiotemporal signals using a recurrent spiking network that discretizes time. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0026](https://doi.org/10.12751/nncn.bc2019.0026)

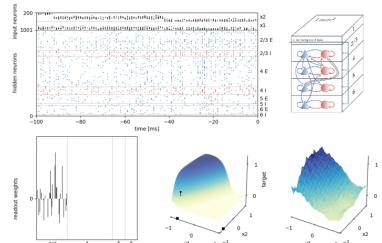
[W 9] Learning-to-Learn in Data-Based Columnar Models of Visual Cortex

Agnes Korcsak-Gorzo^{1,2}, Alexander van Meegen^{1,2}, Franz Scherr³, Anand Subramoney³, Wolfgang Maass³, Sacha J. van Albada¹

1. Institute of Neuroscience and Medicine (INM-6), Computational and Systems Neuroscience & Institute for Advanced Simulation (IAS-6), Theoretical Neuroscience & JARA-Institut Brain Structure-Function Relationships (INM-10), Forschungszentrum Jülich, Wilhelm-Johnen Straße, Jülich, Germany
2. Department of Physics, RWTH Aachen University, Otto-Blumenthal-Straße, Aachen, Germany
3. Institute of Theoretical Computer Science, TU Graz, Inffeldgasse 16b/1, Graz, Austria

In [1, 2] a full-density spiking neuronal network model of macaque vision-related cortex is realized that incorporates 32 areas including their laminar structure. While this large-scale columnar model mimics resting-state activity, it does not have any (visual) function yet. Since biological neural network connectivity can be seen as the result of optimization via evolution and development, the question arises if the biological constraints on the architecture in the multi-area model hold the potential to solve visual tasks. In this work, a short-cut toward understanding biological learning is taken by training cortical columns with machine learning techniques. This approach promises better comprehension of the interplay between architecture, computation, and the emergent function of cortical networks. Generalization of learning becomes increasingly important in state-of-the-art algorithms as it reduces the required labeled training data and thereby the amount of supervision. One approach that mimics the human ability to learn from few examples is “learning-to-learn”. We here apply this framework to tasks involving dynamic visual prediction, another ability humans excel at. We train the microcircuits with backpropagation-through-time (BPTT) using TensorFlow [3]. The training schedule consists of an outer loop optimizing recurrent weights to represent a family of tasks, and an inner loop optimizing the readout weights in a couple of shots on an unseen task from the family. After a proof-of-concept task on learning non-linear functions, we turn to prediction tasks with dynamic visual inputs under self-supervision. We probe the network trained on complex prediction tasks using simpler subtasks to investigate the order in which visual competencies such as figure-ground segmentation, object tracking, and recognizing occlusion are acquired. This is compared with the order in which the same competencies are learned during development. Further, we study the detailed connectivity resulting from the learning process and the roles played by the cortical layers and populations, also relating these to anatomical and physiological data. Finally, the presence of not only feedforward but also feedback connections in the model enables placing the results in the context of the predictive coding hypothesis [5]. These

comparisons between biological data and the optimized network serve to yield insights into biological vision and to convey these back to algorithm design.



Top: Spike outputs (left) of the microcircuit (right) after training in the outer loop during presentation of examples corresponding to one unseen function. Bottom: Readout weights (left), target function with instantaneous prediction by the network (middle) and the overall prediction (right).

Acknowledgements

Supported by the European Union's Horizon 2020 research and innovation program under Specific Grant Agreement No. 785907 (Human Brain Project SGA2), by Priority Program 2041 (SPP 2041) "Computational Connectomics" of the German Research Foundation (DFG), GCS/NIC Compute Time Grant hhd34 for JUWELS.

References

- Schmidt M, Bakker R, Hilgetag CC, Diesmann M, van Albada SJ (2018) Multi-scale account of the network structure of macaque visual cortex. *Brain Struct Funct* 223:1409–1435. [10.1007/s00429-017-1554-4](https://doi.org/10.1007/s00429-017-1554-4)
- Schmidt M, Bakker R, Shen K, Bezgin G, Diesmann M, van Albada SJ (2018) A multi-scale layer-resolved spiking network model of resting-state dynamics in macaque visual cortical areas. *PLoS Comput Biol* 14(10): e1006359. [10.1371/journal.pcbi.1006359](https://doi.org/10.1371/journal.pcbi.1006359)
- Bellec, G., Salaj, D., Subramoney, A., Legenstein, R., & Maass, W. (2018). Long short-term memory and learning-to-learn in networks of spiking neurons. In Advances in Neural Information Processing Systems (pp. 787–797).
- Bellec, G., Kappel, D., Maass, W., & Legenstein, R. (2017). Deep rewiring: Training very sparse deep networks. arXiv preprint arXiv:1711.05136.
- Bastos, A. M., Usrey, W. M., Adams, R. A., Mangun, G. R., Fries, P., & Friston, K. J. (2012). Canonical microcircuits for predictive coding. *Neuron*, 76(4), 695–711. [10.1016/j.neuron.2012.10.038](https://doi.org/10.1016/j.neuron.2012.10.038)

©(2019) Korcsak-Gorzo A, van Meegen A, Scherr F, Subramoney A, Maass W, van Albada SJ

Cite as: Korcsak-Gorzo A, van Meegen A, Scherr F, Subramoney A, Maass W, van Albada SJ (2019) Learning-to-Learn in Data-Based Columnar Models of Visual Cortex. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0027](https://doi.org/10.12751/nncn.bc2019.0027)

[W 10] Liquid state machine acquisition of paired associations with reward modulated Hebbian learning

Ganesh M Kumar^{1,2}, Cheston Tan³, Shih-Cheng Yen^{1,2}, Andrew Tan⁴

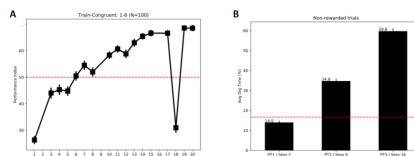
1. NUS Graduate School for Integrative Sciences and Engineering, National University of Singapore, 21 Lower Kent Ridge, 119077, Singapore

2. Department of Electrical and Computer Engineering, National University of Singapore, 4 Engineering Drive 3, 117583, Singapore

3. A*STAR Artificial Intelligence Initiative, Agency for Science, Technology and Research, 1 Fusionopolis Way, 138632, Singapore

4. Department of Physiology, YLLSOM, National University of Singapore, 2 Medical Drive, 117593, Singapore

Liquid state machines (LSMs) have been used to understand learning in the cortex and associated regions. As a starting point for understanding to what extent this architecture may support few-shot learning, we studied whether an LSM's output weights, trained by reward modulated Hebbian learning (RMHL) could learn paired associations (PA). RMHL optimizes the network by correlating the microcircuit dynamics with functional improvements attained while performing a task. The task was to associate sensory cues with respective targets to obtain reward. The LSM model with 1000 units was instantiated with 0.1 connection probability and output weights as zeros. The model's performance was evaluated during each session based on the number of errors made prior to predicting the correct target and cue-target preference was determined using non-rewarded probe trials. Our results show that six PAs could be gradually learned by the model over 20 sessions without catastrophic forgetting. Correct target preference was over 60% ($p < 0.0001$) while chance level performance was obtained on non-cued trials to demonstrate the learned cue-target association. We will discuss the model's potential use as a component for few-shot learning of a paired association task requiring spatial exploration and navigation.



LSM trained by RMHL (N=100) learns six paired associates A) Gradual increase in performance while non-cued session 18 shows chance level performance. b) Correct target preference increased from chance level in sessions 2 ($p > 0.001$) to 60% in session 16 ($p < 0.0001$) non-rewarded trials.

Acknowledgements

We would like to thank Camilo Libedinsky for valuable discussions.

References

- Hoerzer, G. M., Legenstein, R., & Maass, W. (2012). Emergence of complex computational structures from chaotic neural networks through reward-modulated hebbian learning. *Cerebral Cortex*, 24(3), 677–690. [10.1093/cercor/bhs348](https://doi.org/10.1093/cercor/bhs348)
- Tse, D., Langston, R. R. F., Kakeyama, M., Bethus, I., Spooner, P. a., Wood, E. R., ... Morris, R. G. M. (2007). Schemas and memory consolidation. *Science*, 316(5821), 76–82. [10.1126/science.1135935](https://doi.org/10.1126/science.1135935)
- Tse, D., Takeuchi, T., Kakeyama, M., Kajii, Y., Okuno, H., Tohyama, C., & Morris, R. G. M. (2011). Schema-Dependent Gene Activation. *Science*, 331(August), 891–896. [10.1126/science.1205274](https://doi.org/10.1126/science.1205274)
- McClelland, J. L. (2013). Incorporating rapid neocortical learning of new schema-consistent information into complementary learning systems theory. *Journal of Experimental Psychology: General*, 142(4), 1190–1210. [10.1037/a0033812](https://doi.org/10.1037/a0033812)

- 5 Wang, J. X., Kurth-Nelson, Z., Kumaran, D., Tirumala, D., Soyer, H., Leibo, J. Z., ... Botvinick, M. (2018). Prefrontal cortex as a meta-reinforcement learning system. *Nature Neuroscience*, 21(6), 860–868. [10.1038/s41593-018-0147-8](https://doi.org/10.1038/s41593-018-0147-8)

©(2019) Kumar GM, Tan C, Yen S, Tan A

Cite as: Kumar GM, Tan C, Yen S, Tan A (2019) Liquid state machine acquisition of paired associations with reward modulated Hebbian learning. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0028](https://doi.org/10.12751/nncn.bc2019.0028)

[W 11] Local Inhibitory Plasticity boosts the storage capacity and robustness of attractor networks

Emmanouil Giannakakis¹, Matthias Hennig¹

¹. Institute for Adaptive and Neural Computation, School of Informatics, University of Edinburgh, EH8 9AB, Edinburg, UK

Unlike excitatory plasticity which has been studied for decades, inhibitory plasticity has only recently become the subject of computational studies. Specifically, the role of inhibitory plasticity in the self-tuning of spiking neural networks as well as in memory consolidation and retrieval has been examined in several recent studies [1], [2], [3] which have shown that inhibitory plasticity can lead to the effective storage of memory patterns in neural networks by strengthening selected synaptic connections and the activation of these patterns when the appropriate stimulus is given. In order to further examine how plastic inhibition can affect the attractor dynamics of recurrent networks, we developed a high-level representation of a population of cell assemblies, which we modelled as a network of coupled Wilson-Cowan oscillators. Our model was able to display plausible attractor dynamics and the inclusion of local inhibitory plasticity - which has been previously shown to shape global activity in such networks [4] - had an observable effect on the performance of the network in terms of capacity and robustness. Our findings confirm with previous results about the importance of plastic inhibition in memory storage and retrieval. In addition, the simulation framework we have developed allows experimentation at the population level as well as the long-term simulation of memory formation and attractor dynamics at a high temporal resolution.

References

- 1 T. P. Vogels, H. Sprekeler, F. Zenke, C. Clopath, and W. Gerstner, "Inhibitory Plasticity Balances Excitation and Inhibition in Sensory Pathways and Memory Networks," *Science*, vol. 334, no. 6062, p. 1569, Dec. 2011. [
- 2 G. Hennequin, E. J. Agnes, and T. P. Vogels, "Inhibitory Plasticity: Balance, Control, and Codependence," *Annu. Rev. Neurosci.*, vol. 40, no. 1, pp. 557–579, Jul. 2017.
- 3 H. C. Barron, T. P. Vogels, T. E. Behrens, and M. Ramaswami, "Inhibitory engrams in perception and memory," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 114, no. 26, pp. 6666–6674, Jun. 2017.
- 4 P. J. Hellyer, B. Jachs, C. Clopath, and R. Leech, "Local inhibitory plasticity tunes macroscopic brain dynamics and allows the emergence of functional brain networks," *NeuroImage*, vol. 124, pp. 85–95, Jan. 2016.

©(2019) Giannakakis E, Hennig M

Cite as: Giannakakis E, Hennig M (2019) Local Inhibitory Plasticity boosts the storage capacity and robustness of attractor networks. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0029](https://doi.org/10.12751/nncn.bc2019.0029)

[W 12] Local Variance Optimization for the Autonomous Regulation of Echo State Networks

Fabian Schubert¹, Claudius Gros¹

1. Institute for Theoretical Physics, Goethe University Frankfurt am Main, Max-von-Laue-Str. 1, 60438 Frankfurt am Main, Germany

Echo state networks have proven to be a powerful tool in the field of time series prediction [1, 2]. Several approaches to the optimization of the dynamic reservoir have been investigated in the past, including global tuning for criticality [3], as well as local adaptation towards a given output distribution [4, 5]. The spectral radius $|\Lambda_{\max}|$ of the synaptic weight matrix provides a measure to regulate the network in an appropriate working regime [6]. We show that $|\Lambda_{\max}|$ can be regulated by local homeostasis of the variance σ_y^2 of neural activity. This variance control operates on the gain of the neural transfer function and its optimization target depends on the variance σ_{ext}^2 of external input. This optimization rule is biologically plausible since it only relies on locally available information. In contrast to previously proposed optimization rules via local intrinsic plasticity, our model relies on the assumption that external and recurrent input signals can be treated as two separate streams of information. The network can hence react autonomously to changes of the input statistics. We demonstrate the importance of this separation by means of network performance—quantified by a nonlinear memory recall task—under varying input statistics.

References

- 1 Jaeger, H. 2001. The "echo state" approach to analysing and training recurrent neural networks. GMD Report 148, GMD - German National Research Institute for Computer Science.
- 2 Lukoševičius, M. and Jaeger, H. 2009. Reservoir computing approaches to recurrent neural network training. Computer Science Review 3: 127 – 149.
- 3 Livi, L., Bianchi, F.M. and Alippi, C. 2016. Determination of the edge of cricritical in echo state networks through Fisher information maximization. arXiv:1603.03685v2 .
- 4 Schrauwen, B., Wardermann, M., Verstraeten, D., Steil, J.J. and Stroobandt, D. 2008. Improving reservoirs using intrinsic plasticity. Neurocomputing 71: 1159–1171.
- 5 Boedecker, J., Obst, O., Mayer, N.M. and Asada, M. 2009. Initialization and self-organized optimization of recurrent neural network connectivity. HFSP Journal 3: 340–349.
- 6 Caluwaerts, K., Wyffels, F., Dieleman, S. and Schrauwen, B. 2013. The spectral radius remains a valid indicator of the echo state property for large reservoirs. In IEEE International Joint Conference on Neural Networks (IJCNN). 6.

©(2019) Schubert F, Gros C

Cite as: Schubert F, Gros C (2019) Local Variance Optimization for the Autonomous Regulation of Echo State Networks. Bernstein Conference 2019 Abstract. doi: [10.12751/nncnbc2019.0030](https://doi.org/10.12751/nncnbc2019.0030)

[W 13] Modeling olfactory memory networks with co-tuned, balanced excitation and inhibition

Claire MEISSNER-BERNARD¹, Friedemann ZENKE¹, Rainer FRIEDRICH¹

1. Friedrich Miescher Institute for Biomedical Research, 4058 BASEL, Switzerland

The olfactory cortex plays a key role in the retrieval of olfactory memories [1] and is thought to function as an associative memory network. Furthermore, the zebrafish homolog of olfactory cortex (telencephalic nucleus Dp) enters a transient detailed balanced state during the presentation of an odor [2]: for each neuron, excitatory and inhibitory currents are correlated in odor space and in time, and the total synaptic conductance is larger than the resting conductance. We aim to investigate the consequences of a balanced state on memory retrieval in network models inspired by the olfactory cortex. We build a highly simplified, yet biologically plausible simulation of Dp using experimental observations to constrain a network of conductance-based neurons. Preliminary results indicate that co-tuning of excitatory and inhibitory currents can be obtained when Hopfield-like patterns are stored in a network with initially random connectivity. Retrieval of stored information is possible from partial or degraded sensory input. Unlike in classical attractor networks, but consistent with biological observations, memory states do not outlast the presentation of an input pattern. Further investigations will focus on the link between network connectivity, co-tuning of inputs and efficient memory storage and retrieval in order to better understand computations performed by the olfactory cortex and to explore effects of balanced state dynamics in memory networks.

Acknowledgements

We thank Novartis Research Foundation and Swiss National Science Foundation for funding.

References

- 1 Meissner-Bernard et al., 2019 [10.1016/j.cub.2018.12.003](https://doi.org/10.1016/j.cub.2018.12.003)
- 2 Rupprecht and Friedrich, 2018 [10.1016/j.neuron.2018.09.013](https://doi.org/10.1016/j.neuron.2018.09.013)

©(2019) MEISSNER-BERNARD C, ZENKE F, FRIEDRICH R

Cite as: MEISSNER-BERNARD C, ZENKE F, FRIEDRICH R (2019) Modeling olfactory memory networks with co-tuned, balanced excitation and inhibition. *Bernstein Conference 2019 Abstract.* doi: [10.12751/nncn.bc2019.0031](https://doi.org/10.12751/nncn.bc2019.0031)

[W 14] Neuronal memory for processing sequences with non-adjacent dependencies

Kristijan Armeni¹, Dick van den Broek², Hartmut Fitz^{1,2}

1. Centre for Cognitive Neuroimaging, Donders Institute for Brain, Cognition and Behaviour, Kapittelweg 29, 6525 EN Nijmegen, the Netherlands

2. Neurobiology of Language Department, Max Planck Institute for Psycholinguistics, Wundtlaan 1, 6525 XD Nijmegen, the Netherlands

In language processing, linguistic units are combined into a sentence-level interpretation and these units need not be contiguous (e.g., /pizza/ with mushrooms /is/ tasty). Neural networks for language therefore require processing memory to cope with such non-adjacent dependencies [1]. Despite the success of artificial neural networks ([2], [3]), it remains unknown how processing memory is achieved in biologically-plausible networks of spiking neurons. Here, we tested a recent proposal that intrinsic neuronal plasticity could provide memory of non-adjacent dependencies in sequence processing [4]. We simulated a recurrent network of spiking neurons on the 1-2-AX working memory task [5]. The input is a sequence of symbols drawn from $S = \{1, 2, A, B, C, X, Y, Z\}$. Symbols are presented one at a time and require a binary response (L for reject, R for accept). If the most recent digit was 1, the sequence A-X is accepted upon X, and similarly for 2... B-Y. The symbols C and Z are distractors. For example, the response to the sequence 1CYAX would be LLLLRL. To solve this task, the network must remember digit and letter cues across nested distractors which resembles non-adjacencies in language. The network consisted of 1,000 leaky integrate-and-fire neurons (80% excitatory, 20% inhibitory) with refractoriness and spike-rate adaptation (SRA). Both processes were modeled as spike-triggered conductances that decayed back to baseline exponentially with time constants ref and sra , respectively. We varied sra in the range between 50 ms and 1,500 ms to probe the role of neuronal adaptation for memory span. Recurrent connections (drawn randomly with 10% density) were modeled as current-based synapses with decay time constant $syn = 15$ ms. To assess the network's memory capacity, a logistic regression classifier was trained to map stimulus-averaged membrane states, recorded during processing, onto the response labels (L/R). We show that an increase of the SRA time constant across the network resulted in progressively higher cross-validated classification accuracy (min: 92%, max: 99%). The results suggest that membrane states can maintain information on behaviorally-relevant timescales when neurons are adaptive. This memory mechanism might play an important role in the temporal integration of non-adjacent dependencies in language [4]. It is supported by recent views on the role of intrinsic plasticity in memory formation and maintenance ([6], [7]).

References

1. U. Hasson, J. Chen, and C. J. Honey, "Hierarchical process memory: memory as an integral component of information processing," *Trends in Cognitive Sciences*, vol. 19, no. 6, pp. 304–313, Jun. 2015. [10.1016/j.tics.2015.04.006](https://doi.org/10.1016/j.tics.2015.04.006)
2. Z. C. Lipton, J. Berkowitz, and C. Elkan, "A critical review of recurrent neural networks for sequence learning," May 2015.
3. D. Yogatama et al., "Memory architectures in recurrent neural network language models," Feb. 2018.
4. H. Fitz, M. Uhlmann, D. van den Broek, R. Duarte, P. Hagoort, and K. M. Petersson, "Neuronal memory for language processing," *bioRxiv*. [10.1101/546325](https://doi.org/10.1101/546325)
5. R. C. O'Reilly and M. J. Frank, "Making working memory work: A computational model of learning in the prefrontal cortex and basal ganglia," *Neural Computation*, vol. 18, no. 2, pp. 283–328, Feb. 2006. [10.1162/089976606775093909](https://doi.org/10.1162/089976606775093909)
6. H. K. Titley, N. Brunel, and C. Hansel, "Toward a neurocentric view of learning," *Neuron*, vol. 95, no. 1, pp. 19–32, Jul. 2017. [10.1016/j.neuron.2017.05.021](https://doi.org/10.1016/j.neuron.2017.05.021)

- 7 D. Debanne, Y. Inglebert, and M. Russier, "Plasticity of intrinsic neuronal excitability," Current Opinion in Neurobiology, vol. 54, pp. 73–82, Feb. 2019. [10.1016/j.conb.2018.09.001](https://doi.org/10.1016/j.conb.2018.09.001)

©(2019) Armeni K, van den Broek D, Fitz H

Cite as: Armeni K, van den Broek D, Fitz H (2019) Neuronal memory for processing sequences with non-adjacent dependencies. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0032](https://doi.org/10.12751/nncn.bc2019.0032)

[W 15] Performance of biologically grounded models of the early visual system on standard object recognition tasks

Michael Teichmann¹, René Larisch¹, Fred Hamker¹

1. Computer Science, Technische Universität Chemnitz, Straße der Nationen 62, 09111 Chemnitz, Germany

Computational models, replicating neuro-physiological observations and phenomenons, aim to help understanding the functioning of the brain. One of the best studied areas is the visual cortex with a broad range of models, explaining very different phenomenons. Although a realistic model of the visual cortex must convince in object recognition, this aspect has been largely ignored. In the past years, few biological models have been tested on datasets for object recognition, as handwritten digits (MNIST). However, the interpretation of the obtained recognition accuracy is difficult and leads to comparison with other, non or loosely biological, approaches. It would be preferable to have a broader basis of biologically motivated models to compare with.

Here, we want to report the recognition accuracy for two models of the visual cortex on several object recognition datasets. Both models have been trained with unsupervised Hebbian learning rules on natural scene inputs and not on the datasets. An appropriate learning should lead to a general codebook of features of the early visual system, which should be applicable on any visual scene. The first model uses a rate-based learning rule and models the interplay between excitatory and inhibitory neurons in layer 4 and layer 2/3 of V1 and V2, including recurrent inter area connections (based on [1]). The second model is a spiking neural network of layer 4 (described in [2]), extended with a layer 2/3 of V1, which also aims to model the interplay of excitatory and inhibitory neurons. To measure the accuracy values, we recorded the neuronal responses evoked by the dataset images. Then, we fitted a linear support-vector-machine to the responses on the respective training set and use the responses on the test set to create the model predictions. The chosen datasets are different in their difficulties and range from the simple MNIST to the more complex CIFAR-10.

While we found that our models show good results on MNIST (97.6% rate-based; 98.04% spiking). The results on CIFAR-10 could not compete to state of the art deep neural networks. Despite this, we report the accuracy values to help other scientists to compare the performance values of their biologically motivated models to methodologically similar models. We also hope to encourage the community to go further in creating computational models, which aim to explain the fundamental abilities of the modeled brain areas, which is here visual recognition performance.

Acknowledgements

This work was supported by the European Social Fund (ESF) and the Freistaat Sachsen.

References

- 1 Teichmann, M. (2018). A plastic multilayer network of the early visual system inspired by the neocortical circuit. Dissertation. Universitätsverlag der Technischen Universität Chemnitz, Chemnitz. ISBN 978-3-96100-065-4

- 2 Larisch, R., Teichmann, M., Hamker, F. (2018) A Neural Spiking Approach Compared to Deep Feedforward Networks on Stepwise Pixel Erasement. In: Kúrková, Manolopoulos, Hammer, Iliadis, Maglogiannis (eds) Artificial Neural Networks and Machine Learning – ICANN 2018. LNCS, vol 11139. Springer Cham. [10.1007/978-3-030-01418-6_25](https://doi.org/10.1007/978-3-030-01418-6_25)

©(2019) Teichmann M, Larisch R, Hamker F

Cite as: Teichmann M, Larisch R, Hamker F (2019) Performance of biologically grounded models of the early visual system on standard object recognition tasks. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0033](https://doi.org/10.12751/nncn.bc2019.0033)

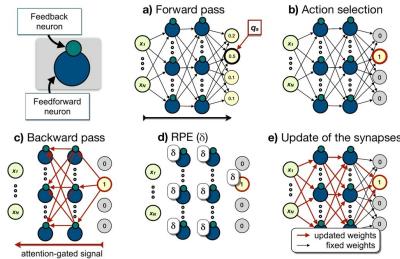
[W 16] Q-AGREL: Biologically Plausible Attention Gated Deep Reinforcement Learning

Isabella Pozzi¹, Sander M. Bohté¹, Pieter R. Roelfsema²

1. *Machine Learning, Centrum Wiskunde & Informatica, Amsterdam, Netherlands*

2. *Vision & Cognition, Netherlands Institute for Neuroscience, Amsterdam, Netherlands*

The success of deep learning in end-to-end learning on a wide range of complex tasks is now fuelling the search for similar deep learning principles in the brain [1-9]. While most work has focused on biologically plausible variants of error-backpropagation, learning in the brain seems to mostly adhere to a reinforcement learning paradigm, and while biologically plausible neural reinforcement learning has been proposed, these studies focused on shallow networks learning from compact and abstract sensory representations [4-5]. Such learning rules realized that in a reinforcement learning setting the synaptic error derivative can be split into two factors: a reward prediction error (RPE) which is positive if an action selected by the network is associated with more reward than expected or if the prospects of receiving reward increase while it is negative if the outcome of the selected action is disappointing. In the brain, the RPE is signaled by neuromodulatory systems that project diffusely to many synapses so that they can inform them about the RPE [10]; the second factor is an attentional feedback signal that is known to propagate from the motor cortex to earlier processing levels in the brain [11-12]. When a network chooses an action, this feedback signal is most pronounced for those neurons and synapses that can be held responsible for the selection of this action and hence for the resulting RPE. These two factors jointly determine synaptic plasticity. We demonstrate how these learning schemes generalize to deep networks with an arbitrary number of layers. The resulting reinforcement learning rule is equivalent to a particular form of error-backpropagation that trains one output unit at anytime (for more details, see Figure 1). We demonstrate the learning scheme on classical and hard image-classification benchmarks, namely MNIST, CIFAR10 and CIFAR100, cast as direct reward tasks, both for fully connected, convolutional and locally connected architectures. We show that our learning rule - Q-AGREL - performs comparably to supervised learning via error-backpropagation, requiring only 1.5-2.5 times more epochs, even when classifying 100 different classes as in CIFAR100. Our results provide new insights into how deep learning may be implemented in the brain.



Schematic depiction of Q-AGREL. At each node, a feedforward neuron (blue) and a feedback neuron (green) are present; separate feedforward and feedback weights connect the nodes in the network.

Acknowledgements

I.P. was supported by NWO NAI grant 656.000.002, P.R.R. by HBP FP7 grant 7202070 and ERC grant 339490.

References

- 1 Amit, Y. (2018). Biologically plausible deep learning. arXiv preprint arXiv:1812.07965.
- 2 Brosch, T., Neumann, H., & Roelfsema, P. R. (2015). Reinforcement learning of linking and tracing contours in recurrent neural networks. PLoS computational biology, 11(10).
- 3 Richards, B. A., & Lillicrap, T. P. (2019). Dendritic solutions to the credit assignment problem. Current opinion in neurobiology, 54.
- 4 Roelfsema, P. R., & Ooyen, A. v. (2005). Attention-gated reinforcement learning of internal representations for classification. Neural computation, 17(10).
- 5 Rombouts, J. O., Bohte, S. M., & Roelfsema, P. R. (2015). How attention can create synaptic tags for the learning of working memories in sequential tasks. PLoS computational biology, 11(3).
- 6 Sacramento, J., Costa, R. P., Bengio, Y., & Senn, W. (2018). Dendritic cortical microcircuits approximate the backpropagation algorithm. In Advances in neural information processing systems.
- 7 Scellier, B., & Bengio, Y. (2019). Equivalence of equilibrium propagation and recurrent backpropagation. Neural computation, 31(2).
- 8 Schiess, M., Urbanczik, R., & Senn, W. (2016). Somato-dendritic synaptic plasticity and error-backpropagation in active dendrites. PLoS computational biology, 12(2).
- 9 Urbanczik, R., & Senn, W. (2014). Learning by the dendritic prediction of somatic spiking. Neuron, 81(3).
- 10 Schultz, W. (2002). Getting formal with dopamine and reward. Neuron, 36(2).
- 11 Pooresmaili, A., Poort, J., & Roelfsema, P. R. (2014). Simultaneous selection by object-based attention in visual and frontal cortex. Proceedings of the National Academy of Sciences.
- 12 Roelfsema, P. R., & Holtmaat, A. (2018). Control of synaptic plasticity in deep cortical networks. Nature Reviews Neuroscience, 19(3).

©(2019) Pozzi I, Bohté SM, Roelfsema PR

Cite as: Pozzi I, Bohté SM, Roelfsema PR (2019) Q-AGREL: Biologically Plausible Attention Gated Deep Reinforcement Learning. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0034](https://doi.org/10.12751/nncn.bc2019.0034)

[W 17] Reinforcement-Mediated Plasticity in a Spiking Model of the Drosophila Larva Olfactory System

Anna-Maria Jürgensen¹, Michael Schleyer², Bertram Gerber², Martin Paul Nawrot¹

1. Computational Systems Neuroscience, University of Cologne, Zülpicher Str 47b, Köln, Germany

2. Genetics of Learning and Memory, Leibniz Institut für Neurobiologie, Brennekestraße 6, Magdeburg, Germany

The mushroom body is a center of integration of sensory input and reinforcement information in insects [1]. In Drosophila larva it consists of less than two hundred neurons [2], yet the animal is able to identify and learn about odors and their context to guide behavior [3]. This spiking model is based on a generic insect model [4] and takes advantage of the recently released full synaptic connectome of the mushroom body [2,5]. Leaky integrate-and-fire neurons with an emphasis on biologically realistic neuron parameters are modeled in network simulator Brian2. Sparse coding has been demonstrated a key feature of insect sensory systems. In our model, temporal sparseness is achieved through spike frequency adaptation at the cellular level, while population sparseness is caused by lateral inhibition [6] and feedback inhibition via the anterior paired lateral neuron [7]. Reinforcement-mediated plasticity between the intrinsic and the output neurons of the mushroom body is sufficient to account for fundamental features of memory formation. The model is compared to the behavior of larval Drosophila in a variety of conditioning experiments. It charms with its exact implementation of the network size and its connectivities [2], along with the biological plausibility of the neuron parameters and the naturalistic behavior of cells with spike frequency adaptation [8].

Acknowledgements

Funded by the German Research Foundation (grant 403329959) Research Unit 'Structure, Plasticity and Behavioral Function of the Drosophila mushroom body' (FOR 2705)

References

- 1 Mushroom body memoir: from maps to models. [10.1038/nrn1074](https://doi.org/10.1038/nrn1074)
- 2 The complete connectome of a learning and memory centre in an insect brain [10.1038/nature23455](https://doi.org/10.1038/nature23455)
- 3 Associative Learning of Stimuli Paired and Unpaired With Reinforcement: Evaluating Evidence From Maggots, Flies, Bees, and Rats [10.3389/fpsyg.2018.01494](https://doi.org/10.3389/fpsyg.2018.01494)
- 4 Circuit and cellular mechanisms facilitate the transformation from dense to sparse coding in the insect olfactory system [10.1101/240671](https://doi.org/10.1101/240671)
- 5 Multilevel feedback architecture for adaptive regulation of learning in the insect brain [10.1101/649731](https://doi.org/10.1101/649731)
- 6 Parallel representation of stimulus identity and intensity in a dual pathway model inspired by the olfactory system of the honeybee [10.3389/fneng.2011.00017](https://doi.org/10.3389/fneng.2011.00017)
- 7 Sparse, decorrelated odor coding in the mushroom body enhances learned odor discrimination [10.1038/nn.3660](https://doi.org/10.1038/nn.3660)
- 8 Intrinsic membrane properties and inhibitory synaptic input of kenyon cells as mechanisms for sparse coding? [10.1152/jn.00183.2009](https://doi.org/10.1152/jn.00183.2009)

©(2019) Jürgensen A, Schleyer M, Gerber B, Nawrot MP

Cite as: Jürgensen A, Schleyer M, Gerber B, Nawrot MP (2019) Reinforcement-Mediated Plasticity in a Spiking Model of the Drosophila Larva Olfactory System. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0035](https://doi.org/10.12751/nncn.bc2019.0035)

[W 18] **Reorganization of phase space structure during network learning**

Rainer Engelken^{1,2}, Laurence F. Abbott^{1,2}

1. Zuckerman Institute, Columbia University, New York, USA

2. Center for Theoretical Neuroscience, Columbia University, New York, USA

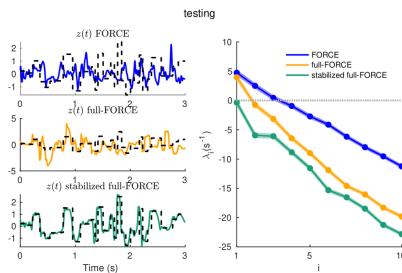
The coordinated activity of biological neural circuits gives rise to complex input-output functions that can be mimicked mathematically in recurrent network models. During learning, network dynamics are often reshaped to a low-dimensional manifold. The mechanism behind this reorganization of the phase space is not well understood. How do subtle changes in the network structure cause drastic changes in the dynamics? Which mathematical tools are suitable for understanding the emergence of low-dimensional neural manifolds during learning? How does learning reshape the dimensionality of network activity?

To answer these long-standing questions in recurrent firing-rate network models we present a spatiotemporally resolved analysis of dynamic stability during learning. Our approach is applicable to arbitrary network structures and firing-rate dynamics. Using concepts from dynamical systems theory, we calculate the attractor dimensionality and dynamic entropy rate of the network dynamics during learning based on the full Lyapunov spectrum. We calculate covariant Lyapunov vectors to map out stable and unstable manifolds.

We show that the dimensionality of the network activity after learning reflects the dimensionality of the task (fixed point, limit cycle, chaotic attractor). We analyze the learning dynamics and dynamic stability of different learning algorithms (FORCE, full-FORCE, backpropagation through time (BPTT)) and study when and how learning fails for excessively difficult tasks. A time-resolved analysis of instability reveals that failure of learning is often accompanied by an inability to stabilize the trajectory locally. We show that perturbations along the least-stable direction during training help to stabilize the trajectory and increase the basins of attraction.

Our study opens a novel avenue for characterizing the complex dynamics of rate networks and their reorganization during learning. This not only gives a deeper understanding of learning dynamics and dynamic stability after learning, it also helps harness computational capacities, e.g. for learning more stable trajectories.

Previous approaches to understanding trained recurrent network dynamics were limited to the analysis of fixed points (Rivkind, Barak 2017; Mastrogiovanni, 2018) or linearizations around 'slow points' (Sussillo, Barak 2012). We instead linearize along a trained trajectory, which map out the stable and unstable manifolds of the dynamics.



Improved stability by perturbing in unstable direction during training. Output of network trained with FORCE, full-FORCE and stabilized full-FORCE. Positive Lyapunov exponent during testing indicates chaos in the full-FORCE network, while stabilized full-FORCE network performs the task reliably.

Acknowledgements

NSF NeuroNex Award DBI-1707398 The Gatsby Charitable Foundation The Swartz Foundation

©(2019) Engelken R, Abbott LF

Cite as: Engelken R, Abbott LF (2019) Reorganization of phase space structure during network learning. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0036](https://doi.org/10.12751/nncn.bc2019.0036)

[W 19] Role of consistent temporal context in learning to recognize complex 3D shapes

Ehsan Kakaei^{1,2,3}, Stepan Aleshin^{2,3}, Jochen Braun^{2,3}

1. ESF graduate school ABINEP, Otto-von-Guericke University, Leipziger strasse 44, 39120 Magdeburg, Germany

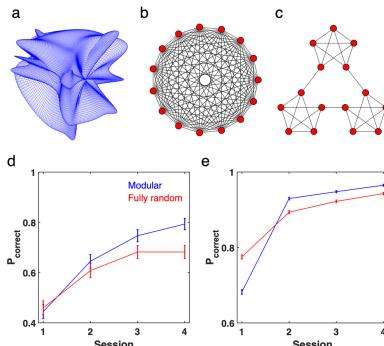
2. Institute of Biology, Otto-von-Guericke University

3. Center for Behavioral Brain Sciences, Otto-von-Guericke University

Consistent temporal context is thought to help learning. To study this beneficial effect, we asked observers to become familiar with and recognize 15 complex 3D objects (Fig. 1a), which were presented repeatedly in quasi-random order (180 object presentations per block), intermixed with 6% 'novel' objects (appearing exactly once in the experiment). The order of presentation was either 'fully random' (graph connected fully without repetitions) or 'modular' with distinct episodes of consistent temporal context (three modules of 5 objects each, graph connected fully only within modules, without repetitions), as shown in Fig. 1bc. Observers performed 4 sessions on successive days (24 blocks in total) for each condition (fully random and modular).

Detection of novel objects reached higher levels of performance under modular than under fully random conditions. Especially in the second and third sessions, detection performance was significantly better under modular than under fully random conditions (Fig. 1d). Detection of familiar objects also reached significantly higher levels of performance under modular conditions (Fig. 1e). Interestingly, initial performance (session 1) was significantly inferior under modular conditions. In modular sequences, one may further distinguish between objects marking the beginning and end of episodes ('terminal' objects) and objects occurring within episodes ('inner' objects). Our results additionally show interesting differences in the learning rates of these object types.

We conclude that consistent temporal context significantly benefits learning of complex 3D objects.



Example 3D object (a). Fully random (b) and modular graphs (c) of 15 objects, generating 'fully random' and 'modular' object sequences. Novel (d) and (e) familiar object detection performance over sessions, under modular and fully random conditions, mean \pm binomial SEM.

Acknowledgements

The project was funded by the federal state Saxony-Anhalt and the European Structural and Investment Funds (ESF, 2014–2020), project number ZS/2016/08/80645.

©(2019) Kakaei E, Aleshin S, Braun J

Cite as: Kakaei E, Aleshin S, Braun J (2019) Role of consistent temporal context in learning to recognize complex 3D shapes. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0037](https://doi.org/10.12751/nncn.bc2019.0037)

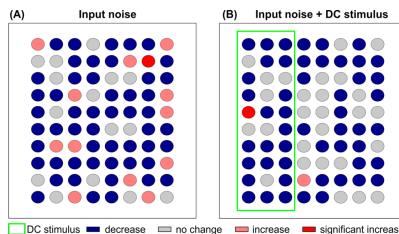
[W 20] Simulation of center-surround responses in the cerebellum Granular layer through structural plasticity

Alice Geminiani¹, Caterina Sbandati¹, Milena Tortora¹, Ceren Yavuz¹, Vasco Orza¹, Alessandra Pedrocchi¹

1. Department of Electronics, Information and Bioengineering, Politecnico di Milano, via Ponzio 34/5, Italy

The cerebellar granular layer (GL) performs a spatio-temporal filtering of sensory inputs, thanks to a center-surround organization: external stimulation of adjacent Granule cells (GrC) increases their firing rate in the center, while the surrounding GrC rate decreases. Experimentally, the center-surround pattern is supposed to emerge from GL recurrent loops between GrC –excitatory, and Golgi cells (GoC) –inhibitory [1]. To test this hypothesis, a small-scale model of the GL network was exploited, where connectivity was generated through structural plasticity (SP) model [2][3]. Different inputs to the GL model were applied to verify whether network connectivity resulting from SP could account for the center-surround pattern, confirming experimental hypotheses. The GL was modelled as a spiking network of integrate-and-fire units in PyNEST, including 80 GrC and 20 GoC. Network connections were created and/or deleted during simulations according to the SP rule, based on electrical activity homeostasis [2]. During two 200-s simulations, two types of stimuli were tested: (A) Poisson spike generator - random noise, to all neurons; (B) superimposed Direct Current (DC) generator of 100 pA - input

stimulus, exciting 30 GrC for the first 100 s. The overall change of firing rates in GoC and GrC was computed, identifying GrC with a significant increase and decrease of firing rate (center-surround pattern). In case (A), GoC increased (+76%) and GrC decreased (-7%) their firing rate on average, with one GrC significantly increasing. In case (B), the firing rate increased significantly for one GrC, i.e. center (+88%), in the stimulated cluster, and decreased for remaining stimulated GrC, i.e. surround (-5%), more than for external GrC (-2%) (Fig. 1). GoC firing rate increased on average (+60%). Thus, in the second case, three patterns of activity change were obtained: SP lead to a final configuration of connections causing the emergence of a center-surround in the GL network, which differentiated the response in the stimulated GrC with respect to the response in the background, due to a different generated pattern of connectivity. The results support the hypothesis that center-surround emerges from connectivity loops within the GL[1]. Future work includes associating a spatial position to neurons based on GrC and GoC morphology, and developing an ad hoc SP learning rule for the GL, considering also the filtering properties that derive from GL single neuron dynamics[4].



Firing rate changes in the 80 GrC for simulations (A)-(B). (A) 1 GrC significantly increases, others increase/decrease uniformly across network. (B) In stimulated GrC, 1(center) significantly increases, the others(surround) decrease, more than those receiving only noise (better signal-to-noise ratio).

Acknowledgements

This work has been developed within CerebNEST, Partnering Project of the Human Brain Project.

References

- 1 E. D'Angelo, S. Solinas, J. Mapelli, D. Gandolfi, L. Mapelli, and F. Prestori, "The cerebellar Golgi cell and spatiotemporal organization of granular layer activity," *Front. Neural Circuits*, vol. 7, no. May, pp. 1-21, 2013. [10.3389/fncir.2013.00093](https://doi.org/10.3389/fncir.2013.00093)
- 2 M. Butz and A. van Ooyen, "A Simple Rule for Dendritic Spine and Axonal Bouton Formation Can Account for Cortical Reorganization after Focal Retinal Lesions," *PLoS Comput. Biol.*, vol. 9, no. 10, Oct. 2013. [10.1371/journal.pcbi.1003259](https://doi.org/10.1371/journal.pcbi.1003259)
- 3 H.-J. Boele, S. K. E. Koekkoek, C. I. De Zeeuw, and T. J. H. Ruigrok, "Axonal Sprouting and Formation of Terminals in the Adult Cerebellum during Associative Motor Learning," *J. Neurosci.*, vol. 33, no. 45, pp. 17897-17907, 2013. [10.1523/JNEUROSCI.0511-13.2013](https://doi.org/10.1523/JNEUROSCI.0511-13.2013)
- 4 A. Geminiani, C. Casellato, F. Locatelli, F. Prestori, A. Pedrocchi, and E. D'Angelo, "Complex dynamics in simplified neuronal models: reproducing Golgi cell electroresponsiveness," *Front. Neuroinform.*, vol. 12, no. 88, pp. 1-19, 2018. [10.3389/fninf.2018.00088](https://doi.org/10.3389/fninf.2018.00088)

©(2019) Geminiani A, Sbandati C, Tortora M, Yavuz C, Orza V, Pedrocchi A

Cite as: Geminiani A, Sbandati C, Tortora M, Yavuz C, Orza V, Pedrocchi A (2019) Simulation of center-surround responses in the cerebellum Granular layer through structural plasticity. *Bernstein Conference 2019 Abstract*.

doi: [10.12751/nncn.bc2019.0038](https://doi.org/10.12751/nncn.bc2019.0038)

[W 21] Sleep-like slow oscillations induce hierarchical memory association and synaptic homeostasis in thalamo-cortical simulations

Cristiano Capone¹, Elena Pastorelli^{1,2}, Bruno Golosio^{3,4}, Pier Stanislao Paolucci¹

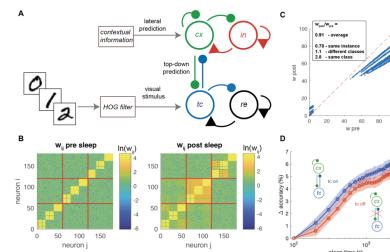
1. INFN Sezione di Roma, Italy

2. PhD Program in Behavioural Neuroscience, "Sapienza", University of Rome, Italy

3. INFN Sezione di Cagliari, Italy

4. Dipartimento di Fisica, Università di Cagliari, Italy

The occurrence of sleep passed through the evolutionary sieve and is widespread in animal species [1]. Sleep is known to be beneficial to cognitive and mnemonic tasks, while chronic sleep deprivation is detrimental. Despite the importance of the phenomenon [2], a theoretical and computational approach demonstrating the underlying mechanisms is still lacking. We implemented in NEST a minimal thalamo-cortical model (see Fig.1A, *cx* and *in* are respectively excitatory and inhibitory cortical populations of spiking neurons, while *tc* and *re* are excitatory and inhibitory thalamic neurons) and trained it with examples drawn from the MNIST set of handwritten digits. During a training phase, spike-timing-dependent-plasticity (STDP) sculpts a pre-sleep synaptic matrix which associates training examples with well separated groups of cortical neurons and creates top-down synapses toward the thalamus. Then, the network is induced to produce cortically generated deep-sleep-like slow oscillations (SO), while being disconnected from sensory and lateral stimuli and driven by its internal activity. During sleep up-states, thalamic cells are activated by top-down predictive stimuli produced by cortical neural groups and respond with a forward feedback, recruiting other cortical neurons. If spike-timing-dependent-plasticity (STDP) is active during slow oscillations, a differential homeostatic process is observed. It is characterized by both a specific enhancement of connections among groups of neurons associated to instances of the same class (digit) and a simultaneous down-regulation of stronger synapses created by the training (see Fig.1B and Fig.1C). This is reflected in a hierarchical organization of post-sleep internal representations. Such effects favor higher performance in retrieval and classification tasks (Fig.1D) and create hierarchies of categories in integrated representations. The model leverages on the coincidence of top-down contextual information with bottom-up sensory flow during the training phase and on the integration of top-down predictions and bottom-up thalamo-cortical pathways during deep-sleep-like slow oscillations. Also, such mechanism hints at possible applications to artificial learning systems.



A. Sketch of our thalamo-cortical model. B. Scatter-plot of the synaptic weights before and after the occurrence of sleep-like activity. C. Synaptic weights before (left) and after (right). D. Change in classification accuracy across over sleep with (blue) and without (red) thalamic feedback.

Acknowledgements

This work has been supported by the European Union Horizon 2020 Research and Innovation program under the FET Flagship Human Brain Project (SGA2 grant agreement SGA2 n. 785907), System and Cognitive Neuroscience subproject, WaveScalES experiment.

References

- 1 Tononi G. & Cirelli C., From synaptic and cellular homeostasis to memory consolidation and integration. *Neuron* 81, 12-34 (2014)
- 2 Network Homeostasis and State Dynamics of Neocortical Sleep" Watson et al., (2016), *Neuron* 90, 839–852

©(2019) Capone C, Pastorelli E, Golosio B, Paolucci PS

Cite as: Capone C, Pastorelli E, Golosio B, Paolucci PS (2019) Sleep-like slow oscillations induce hierarchical memory association and synaptic homeostasis in thalamo-cortical simulations. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0039](https://doi.org/10.12751/nncn.bc2019.0039)

[W 22] Spontaneous activity and multi-sensory integration in the developing higher-order cortex

Marina Wosniack^{1,2}, Julijana Gjorgjieva^{1,2}

1. Computation in Neural Circuits, Max Planck Institute for Brain Research, Germany

2. School of Life Sciences Weihenstephan, Technical University of Munich, Germany

Many sensory systems generate spontaneous activity during early brain development even before the onset of sensory experience. This activity contains important cues for the establishment of appropriate network connectivity and functional maps. Multiple studies have characterized spatiotemporal properties of correlated spontaneous activity in the primary visual (V1) and sensory (S1) cortex and their role in the maturation of thalamocortical connectivity. These studies also revealed that before eye opening the spontaneous events in S1 are sparser and more decorrelated than their counterparts in V1, implicating an earlier maturation of the somatosensory cortex (Golshani et al. 2009). However, how spontaneous activity assists the refinement of synapses between primary and higher cortical areas is still an open question. The rostralateral (RL) region is a higher cortical area that receives input from V1 and S1 and integrates multi-sensory information (visual and tactile). In adult mice, more than 60% of RL neurons are bimodal, and the visual and tactile maps are topographically aligned (Olcese et al. 2013). Combining theory and modeling, we investigated the role of correlated spontaneous activity in the co-refinement of V1 and S1 synaptic connections to RL and the emergence of bimodal RL neurons in a network model. Based on the statistics of spontaneous events, we derived the correlation matrices of events within V1 and S1, and explored possible cross-correlations across V1 and S1. We investigated two alternative hypotheses in our model: (1) spontaneous events in V1 and S1 have the same statistics and the immature cortices project simultaneously to RL, and (2) S1 to RL connectivity is mature and synapses from V1 to RL are still developing. For the two hypotheses we derived the conditions for the emergence of bimodal RL neurons and confirmed our predictions in numerical simulations. Thus, our proposed network model provides a framework for investigating the maturation of connectivity between primary and higher cortical areas when the primary cortices are at different developmental stages.

Acknowledgements

Thanks to the Max Planck Society (MW, JG), the Alexander von Humboldt Foundation (MW) and the ERC (JG).

References

- 1 Golshani et al. 2009 [10.1523/JNEUROSCI.2012-09.2009](https://doi.org/10.1523/JNEUROSCI.2012-09.2009)
- 2 Olcese et al. 2013 [10.1016/j.neuron.2013.06.010](https://doi.org/10.1016/j.neuron.2013.06.010)

©(2019) Wosniack M, Gjorgjieva J

Cite as: Wosniack M, Gjorgjieva J (2019) Spontaneous activity and multi-sensory integration in the developing higher-order cortex. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0040](https://doi.org/10.12751/nncn.bc2019.0040)

[W 23] The random dynamics of hippocampal place fields

Alexander Schmidt^{1,2,3}, Kotaro Mizuta^{2,4}, Yasunori Hayashi^{2,4}, Fred Wolf^{1,3}

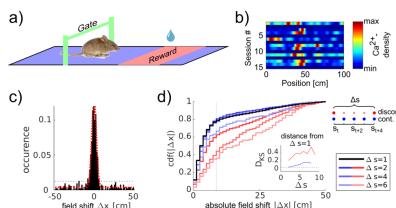
1. Max-Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany
2. Department of Pharmacology, Kyoto University, Graduate School of Medicine, Kyoto 606-8501 Japan, Japan
3. Campus Institute for Dynamics of Biological Networks, Georg August-University Göttingen, Hermann-Rein-Strasse 3, 37075 Göttingen, Germany
4. RIKEN Brain Science Institute, 2-1 Hirosawa, Wako, Saitama 351-0106, Japan, Japan

Place cells and their respective place fields are a core functional characteristic of the hippocampal coding of space. Technological and methodological advances now allow for large scale and longitudinal recordings of neuronal activity. Accumulating evidence suggests that various hippocampal regions display an overall turnover of place cell coding with timescales of the order of days and weeks [Ziv2013, Rubin2016, Bartos2018]. While the overall dynamics and its possible function has received substantial attention, so far the individual dynamics of the cells' place fields remain incompletely understood.

We analyzed two-photon activity imaging of neurons expressing G-CaMP7 in the hippocampal CA1-region of behaving, head-fixed mice navigating a virtual environment, twice daily over about 2 weeks. Within the VR-environment, the mice moved unidirectional through a linear, circular environment, in which they encountered visual stimuli of differing saliency as well as reward stimuli at a fixed location, which was not marked otherwise.

We tracked neurons over 15 sessions and determined sessions with and without place field activity. Many cells switched from place encoding to non-coding behavior (Fig.1b). Specifically we found that ... 1) place field activation / deactivation follows a Poissonian random process 2) continuously coding cells largely maintain their place field in a closely circumscribed region of space, but have a low probability of long-range relocation (Fig.1c) 3) periods of non-coding facilitate random relocation, with the relocation probability increasing with the duration of non-coding episodes (Fig.1d) 4) transition rates between coding and non-coding states, as well as relocation probabilities are modulated by visual salience of place-field-location, as well as whether they code for a rewarded location

In conclusion, we find that place field dynamics in CA1 consists of localized random motion, interrupted by long-range random relocation. Periods of non-coding activity are associated with place field turnover by promoting chances of place field relocation.



a) sketch of the VR environment; b) calcium activity map for 15 recorded sessions of a single neuron; c) distribution of place field shifts for consecutive sessions d) cdf of absolute place field shifts for continuous (blue) and interrupted (red) coding for different time-lags

References

- 1 Bartos2018 [10.1038/s41586-018-0191-2](https://doi.org/10.1038/s41586-018-0191-2)
- 2 Ziv2013 [10.1038/nn.3329](https://doi.org/10.1038/nn.3329)
- 3 Rubin2016 [10.7554/eLife.12247](https://doi.org/10.7554/eLife.12247)

©(2019) Schmidt A, Mizuta K, Hayashi Y, Wolf F

Cite as: Schmidt A, Mizuta K, Hayashi Y, Wolf F (2019) The random dynamics of hippocampal place fields. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0041](https://doi.org/10.12751/nncn.bc2019.0041)

[W 24] The role of slow PRG1 dynamics in synaptic working memory

Sophia Becker^{1,2}, Andreas Nold¹, Tatjana Tchumatchenko¹

1. Theory of neural dynamics group, Max-Planck-Institute for Brain Research, Max-von-Laue-Str. 4, 60438 Frankfurt/Main, Germany
2. Goethe University, Frankfurt/Main, Germany

Working memory plays a crucial role in the perception and processing of sensory stimuli in both animals and humans. This becomes particularly clear in psychiatric diseases such as schizophrenia and autism, which, among others, are characterized by deficits in working memory. Recently, a new synaptic mechanism has been discovered, whose failure is associated with working memory impairments and can be observed in several schizophrenia patients. Spikes transmitted through the synapse modulate the activity of the postsynaptically located molecule PRG1, which acts on the release probability of the presynaptic terminal through lysophosphatidic acid (LPA) concentrations in the synaptic cleft. In contrast to other known synaptic short-term plasticity mechanisms, this PRG1-LPA signalling mechanism takes place on longer timescales of several seconds. Despite our current understanding of the PRG1 mechanism on the synaptic level, its involvement in network-level phenomena, such as the limit cycle dynamics usually associated with working memory, is still unclear. Based on experimental data [1-4], we extended the Tsodyks-Markram model of short-term plasticity [5] towards a phenomenological model of the PRG1 synaptic mechanism. Using both analytical calculations and computer simulations, we analyzed how PRG1 signalling influences the long-term dynamics of both single synapses and spiking networks, aiming for a general understanding of PRG1 dynamics. Since experimental evidence indicates that PRG1 signalling is crucial for working memory function, we also studied the impact of slow PRG1 dynamics on activity patterns characteristic for working memory. Building upon the working memory model by Mongillo et al. [6,7], which represents sequential working memory activity in terms

of cyclic population spikes, we investigated the underlying analytical regimes as well as the functional role of slow PRG1 dynamics in working memory. In particular, we found that PRG1 impacts the duration and stability of the limit cycles that are associated with synaptic memory storage.

Acknowledgements

This work was supported by the Max Planck Society and the Cooperation Programme of the CRC 1080 'Molecular and Cellular Mechanisms of Neural Homoeostasis'. We thank Prof. Dr. Johannes Vogt, Heiko Endle and Pierre Ekelmans for fruitful discussions about the model design.

References

- 1 C. Thalman, G. Horta, L. Qiao et al. (2018) Synaptic phospholipids as a new target for cortical hyperexcitability and E/I balance in psychiatric disorders. *Nature Mol. Psych.* 23 (8): 1699-1710. [10.1038/s41380-018-0053-1](https://doi.org/10.1038/s41380-018-0053-1)
- 2 P. Unichenko, S. Kirischuk, J.-W. Yang et al. (2016) Plasticity-related gene 1 affects mouse barrel cortex function via strengthening of glutamatergic thalamocortical transmission. *Cereb. Cortex* 26 (7): 3260-3272. [10.1093/cercor/bhw066](https://doi.org/10.1093/cercor/bhw066)
- 3 J. Vogt, J.-W. Yang, A. Mobsacher et al. (2016) Molecular cause and functional impact of altered synaptic lipid signaling due to a prg-1 gene SNP. *EMBO Mol. Med.* 8 (1): 25-38. [10.15252/emmm.201505677](https://doi.org/10.15252/emmm.201505677)
- 4 T. Trimbuch, P. Beed, J. Vogt et al. (2009) Synaptic PRG-1 Modulates Excitatory Transmission via Lipid Phosphate-Mediated Signaling. *Cell* 138 (6): 1222-1235. [10.1016/j.cell.2009.06.050](https://doi.org/10.1016/j.cell.2009.06.050)
- 5 M. Tsodyks, K. Pawelzik, H. Markram (1998) Neural Networks with Dynamic Synapses. *Neural Comp.* 10 (4): 821-835. [10.1162/089976698300017502](https://doi.org/10.1162/089976698300017502)
- 6 G. Mongillo, O. Barak, M. Tsodyks (2008) Synaptic Theory of Working Memory. *Science* 319 (5869): 1543-1546. [10.1126/science.1150769](https://doi.org/10.1126/science.1150769)
- 7 Y. Mi, M. Katkov, M. Tsodyks (2017) Synaptic Correlates of Working Memory Capacity. *Neuron* 93 (2): 323-330. [10.1016/j.neuron.2016.12.004](https://doi.org/10.1016/j.neuron.2016.12.004)

©(2019) Becker S, Nold A, Tchumatchenko T

Cite as: Becker S, Nold A, Tchumatchenko T (2019) The role of slow PRG1 dynamics in synaptic working memory. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0042](https://doi.org/10.12751/nncn.bc2019.0042)

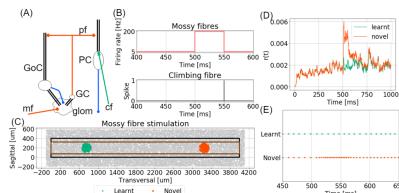
[W 25] Using cerebellar Purkinje cell models at different levels of abstraction as a read-out mechanism for pattern recognition in a biologically detailed granular layer model.

Ohki Katakura¹, Reinoud Maex¹, Neil Davey¹, Shabnam Kadir¹, Volker Steuber¹

1. Centre for Computer Science and Informatics Research, University of Hertfordshire, College Lane, Hatfield, Hertfordshire, AL10 9AB, United Kingdom

The cerebellum is thought to be essential for our adaptive control. Its anatomy, physiology, circuitry and functionality have been well-studied [1–3], and several biologically detailed models of cerebellar neurons [4–9] and microcircuits [10,11] have been proposed. However, most existing network models that include the input layer (granular layer) and the output cell (Purkinje cell, PC) are based on simplified neuronal models [12–15]. Here, hybrid network models of cerebellar cortex were constructed based on a realistic granular layer model [11] and one of two kinds of abridged PC models: an inner product of synaptic weights and parallel fibre (pf) inputs [16,17], and an integrate-and-fire unit [13,14]. The granular layer model consisted of detailed granule and Golgi cell (GC and GoC) models, mossy fibres (mfs) and glomeruli (glom) (panel A). The PC received synapses from pfs (GC axons) originating within a 4,000 μm transversal \times 250 μm sagittal \times 100 μm vertical volume of granular layer comprising about 192,000 GCs. The models were implemented and simulated with NEURON (version 7.4) and Python (version 3.7.0) and studied in the context of a pattern recognition tasks. During this task, mfs were spontaneously active at 5 Hz and, in addition, a mf patch of 100 μm radius was activated at 200 Hz for 50 ms (panels B,C). At the offset of the mf patch

stimulus, climbing fibre (cf) input induced long-term depression (LTD) of synapses from active pfs to the PC. After training, the two types of PC models showed distinct responses to learnt and novel patterns of stimulated mfs, both in their inner product and in their number of spikes during the stimulated 50 ms (red and green traces in panels D,E). The increase in inner product and firing rate in response to burst activity of mfs were absent in response to input to the learnt patch, but were still present in response to novel input, which implies that the transformation of stimuli in the granular layer does not prevent learning with pfs-PC LTD. As a next step, more realistic PC models [4,5,9] will be used as read-out neurons, and the effect of sparseness and clustering on pattern recognition will be studied.



(A) Model circuit. GC, GoC, PC: granule, Golgi and Purkinje cells. mf, pf, cf: mossy, parallel, and climbing fibres. glom: glomeruli. (B) Timing of mfs and cf stimulation. (C) Stimulated patches of mfs. (D) Dot products of synaptic weight and pfs. (E) Spike sequences of the integrate-and-fire unit.

Acknowledgements

The first author appreciates the help of Dr. Tadashi Yamazaki at University of Electro-Communications, Tokyo and fruitful discussions with Dr. Sergio Solinas at the Institute of Neuroinformatics, Zurich. This work made use of the University of Hertfordshire's high-performance computing facility.

References

- 1 Eccles, J.C., Ito, M. & Szentágothai, J. (1967) The cerebellum as a neuronal machine. New York: Springer-Verlag. [10.1007/978-3-662-13147-3](https://doi.org/10.1007/978-3-662-13147-3)
- 2 Palay, S.L. & Chan-Palay, V. (1974) Cerebellar cortex: Cytology and organization. New York: Springer-Verlag. [10.1007/978-3-642-65581-4](https://doi.org/10.1007/978-3-642-65581-4)
- 3 Ito, M. (2012) The cerebellum: Brain for an implicit self. Upper Saddle River: FT Press.
- 4 De Schutter, E. & Bower, J.M. (1994) An active membrane model of the cerebellar Purkinje cell. I. Simulation of current clamps in slice. *Journal of Neurophysiology*, 71(1):375–400. [10.1152/jn.1994.71.1.375](https://doi.org/10.1152/jn.1994.71.1.375)
- 5 De Schutter, E. & Bower, J.M. (1994) An active membrane model of the cerebellar Purkinje cell. II. Simulation of synaptic responses. *Journal of Neurophysiology*, 71(1):401–419. [10.1152/jn.1994.71.1.401](https://doi.org/10.1152/jn.1994.71.1.401)
- 6 Nieuw, T., Sola, E., Mapelli, J., Saftenku, E., Rossi, P. & D'Angelo, E. (2006) LTP regulates burst initiation and frequency at mossy fibre-granule cell synapses of rat cerebellum: Experimental observations and theoretical prediction. *Journal of Neurophysiology*, 95(2):686–699. [10.1152/jn.00696.2005](https://doi.org/10.1152/jn.00696.2005)
- 7 Solinas, S., Forti, L., Cesana, E., Mapelli, J., De Schutter, E. & D'Angelo, E. (2007) Computational reconstruction of pacemaking and intrinsic electrosensitivity in cerebellar Golgi cells. *Frontiers in Cellular Neuroscience*, 1:2. [10.3389/neuro.03.002.2007](https://doi.org/10.3389/neuro.03.002.2007)
- 8 Solinas, S., Forti, L., Cesana, E., Mapelli, J., De Schutter, E. & D'Angelo, E. (2007) Fast-reset of pacemaking and theta-frequency resonance patterns in cerebellar Golgi cells: Simulations of their impact in vivo. *Frontiers in Cellular Neuroscience*, 1:4. [10.3389/neuro.03.004.2007](https://doi.org/10.3389/neuro.03.004.2007)
- 9 Zang, Y., Dieudonné, S. & De Schutter, E. (2018) Voltage- and branch-specific climbing fiber responses in Purkinje cells. *Cell Reports*, 24(6):1536–1549. [10.1016/j.celrep.2018.07.011](https://doi.org/10.1016/j.celrep.2018.07.011)
- 10 Solinas, S., Nieuw, T. & D'Angelo, E. (2010) A realistic large-scale model of the cerebellum granular layer predicts circuit spatio-temporal filtering properties. *Frontiers in Cellular Neuroscience*, 4:12. [10.3389/fncel.2010.00012](https://doi.org/10.3389/fncel.2010.00012)
- 11 Sudhakar, S.K., Hong, S., Raikov, I., Publio, R., Lang, C., Close, T., Guo, D., Negrello, M. & De Schutter, E. (2017) Spatiotemporal network coding of physiological mossy fiber inputs by the cerebellar granular layer. *PLoS Computational Biology*, 13(9):e1005754. [10.1371/journal.pcbi.1005754](https://doi.org/10.1371/journal.pcbi.1005754)
- 12 Medina, J.F., Garcia, K.S., Nores, W.L., Taylor, N.M. & Mauk, M.D. (2000) Timing mechanisms in the cerebellum: Testing predictions of a large-scale computer simulation. *The Journal of Neuroscience*, 20(14):5516–5525. [10.1523/jneurosci.20-14-05516.2000](https://doi.org/10.1523/jneurosci.20-14-05516.2000)
- 13 Yamazaki, T. & Tanaka, S. (2007) A spiking network model for passage-of-time representation in the cerebellum. *European Journal of Neuroscience*, 26(8):2279–2292. [10.1111/j.1460-9568.2007.05837.x](https://doi.org/10.1111/j.1460-9568.2007.05837.x)
- 14 Yamazaki, T., Igarashi, J., Makino, J. & Ebisuzaki, T. (2017) Real-time simulation of a cat-scale

- artificial cerebellum on PEZY-SC processors. *The International Journal of High Performance Computing Applications*, 33(1):155-168. [10.1177/1094342017710705](https://doi.org/10.1177/1094342017710705)
- 15 Casali, S., Marenzi, E., Medini, C., Casellato, C. & D'Angelo, E. (2019) Reconstruction and simulation of a scaffold model of the cerebellar network. *Frontiers in Neuroinformatics*, 13:37. [10.3389/fninf.2019.00037](https://doi.org/10.3389/fninf.2019.00037)
- 16 Steuber, V., Mittmann, W., Hoebeek, F.E., Silver, R.A., De Zeeuw, C.I., Häusser, M. & De Schutter, E. (2007) Cerebellar LTD and pattern recognition by Purkinje cells. *Neuron*, 54(1):121-136. [10.1016/j.neuron.2007.03.015](https://doi.org/10.1016/j.neuron.2007.03.015)
- 17 Safaryan, K., Maex, R., Davey, N., Adams, R. & Steuber, V. (2017) Nonspecific synaptic plasticity improves the recognition of sparse patterns degraded by local noise. *Scientific Reports*, 7(1):46650. [10.1038/srep46550](https://doi.org/10.1038/srep46550)

©(2019) Katakura O, Maex R, Davey N, Kadir S, Steuber V

Cite as: Katakura O, Maex R, Davey N, Kadir S, Steuber V (2019) Using cerebellar Purkinje cell models at different levels of abstraction as a read-out mechanism for pattern recognition in a biologically detailed granular layer model.. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0043](https://doi.org/10.12751/nncn.bc2019.0043)

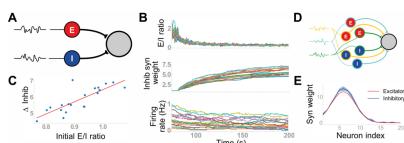
[W 26] Voltage-based inhibitory plasticity as a flexible model for network homeostasis

Victor Pedrosa^{1,2}, Claudia Clopath^{1,2}

1. Department of Bioengineering, Imperial College London, London, SW7 2AZ, UK

2. Capes Foundation, Ministry of Education of Brazil, Brasilia, 70040-020, Brazil

The balance between excitatory and inhibitory inputs (E/I balance) can ensure network stability [1-2]. Moreover, inhibitory neurons are directly involved in neural computations and can shape sensory representations [3-5]. Therefore, in face of excitatory synaptic plasticity, inhibitory connections are likely to adapt to maintain network stability. A widely used inhibitory synaptic plasticity rule [4] regulates network dynamics by imposing a target firing rate. This results in a network in which all neurons fire, on average, at the same firing rate. Here we propose a model of inhibitory plasticity in which synaptic updates depend on presynaptic spike arrival and postsynaptic membrane voltage. Our plasticity rule regulates the network activity by setting a target value for a low-pass-filtered version of the postsynaptic membrane potential. We then simulate a feedforward network composed of excitatory and inhibitory neurons receiving uncorrelated input (figure 1A). Similarly to what has been shown in a theoretical work using a co-dependent inhibitory and excitatory plasticity model [6], our inhibitory plasticity model regulates E/I ratio while allowing for a broad range of postsynaptic firing rates and thus network diversity (figure 1B). The change in inhibitory synaptic weight increases with the initial E/I ratio (figure 1C). In a feedforward network in which excitatory and inhibitory neurons receive correlated input (figure 1D), our plasticity rule allows for the development of co-tuned excitation and inhibition (figure 1E), in agreement with recordings in rat auditory cortex [2-3]. Therefore, our voltage-dependent inhibitory plasticity model accounts for network homeostasis while allowing for diverse neuronal dynamics observed *in vivo*.



Voltage-based inhibitory plasticity stabilises E/I ratio without a target firing rate. A) Network diagram. B) Evolution of E/I ratio, inhibitory synaptic weight, and firing rate. C) Change in synaptic weight as a function of initial E/I ratio. D) Correlated E-I input. E) Final synaptic weights.

Acknowledgements

V.P. is supported by CAPES Foundation, process n. 99999.001758/2015-02.

References

- 1 Vreeswijk, C. & Sompolinsky, H. Chaos in Neuronal Networks with Balanced Excitatory and Inhibitory Activity. *Science* 274, 1724-1726 (1996). [10.1126/science.274.5293.1724](https://doi.org/10.1126/science.274.5293.1724)
- 2 Wehr, M. & Zador, A. Balanced inhibition underlies tuning and sharpens spike timing in auditory cortex. *Nature* 426, 442-446 (2003). [10.1038/nature02116](https://doi.org/10.1038/nature02116)
- 3 Froemke, R., Merzenich, M. & Schreiner, C. A synaptic memory trace for cortical receptive field plasticity. *Nature* 450, 425-429 (2007). [10.1038/nature06289](https://doi.org/10.1038/nature06289)
- 4 Vogels, T., Sprekeler, H., Zenke, F., Clopath, C. & Gerstner, W. Inhibitory Plasticity Balances Excitation and Inhibition in Sensory Pathways and Memory Networks. *Science* 334, 1569-1573 (2011). [10.1126/science.1211095](https://doi.org/10.1126/science.1211095)
- 5 Clopath, C., Vogels, T., Froemke, R. & Sprekeler, H. Receptive field formation by interacting excitatory and inhibitory synaptic plasticity. (2016). [10.1101/066589](https://doi.org/10.1101/066589)
- 6 Agnes, E. J., Vogels, T. Learn, forget, relearn, amplify: codependent synaptic plasticity in spiking networks. *Cosyne Abstracts* (2018), Denver, United States.

©(2019) Pedrosa V, Clopath C

Cite as: Pedrosa V, Clopath C (2019) Voltage-based inhibitory plasticity as a flexible model for network homeostasis. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0044](https://doi.org/10.12751/nncn.bc2019.0044)

Attention, reward, decision making

[W 27] A Data Flow Analysis during a Rewarded Decision-Making Activity in Rats Based on Transfer Entropy

Elham Najafiani¹, Behnaz Rabiee², Mahdi Aliyari Shoorehdeli¹, Abbas Haghparast³

1. Dept. of Mechatronics Eng., K. N. Toosi University of Technology, Tehran, Iran

2. Dept. of Control Eng., K. N. Toosi University of Technology, Tehran, Iran

3. Neuroscience Research Center, School of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran

Functional connectivity between different parts of the brain during behavioral activities is one of the concerning issues neuroscientists are facing. The importance of this issue is clarified when it comes to the diagnosis of neurological disorders, mapping out a comprehensive brain's map and improving the design of brain and machine interfaces (BMI). Decision-making is a profound cognitive activity which contains other individual cognitive activities and engages a large part of the brain during the. Thus, causality assessment during this momentous activity which is common to human and mammals plays an active role in recognizing brain circuits. Our aim in this research is to figure out causality between two brain areas, ACC (Anterior Cingulate Cortex) and OFC (Orbitofrontal Cortex), as two active parts in value-based decision making cognitive activity, by analyzing the direction of data flow between them. This analysis is done

using real local field potential (LFP) data which has been recorded simultaneously from the two channels, ACC and OFC, in the process of an experiment in which, guided freely moving rats in a T-maze were rewarded for making the correct decision. The data consists of both correct and incorrect intervals for different rats. Causality analysis is performed by comparing the inner information of two channels for each interval, based on transfer entropy methods. In this study, we faced two different approaches; to use the whole signal or divide it into three parts (before the alarm, after the alarm-before turning and after turning) and use the most important one which we assumed was the second. Finally, the driven result of this study shows that i) Data transfer during value-based decision-making activity, for correct intervals, is from ACC to OFC which their connection is proven biologically [1], ii) the data of incorrect intervals do not give similar information for inferring causality, iii) It is better to use the whole signal to obtain more valuable results, and iv) Phase transfer entropy works more reasonably than magnitude transfer entropy in our approach.

Acknowledgements

Hereby we thank Dr. Zahra Fatahi at the Neuroscience research center, Shahid Beheshti University of Medical Sciences for providing the LFP data used in this study.

References

- 1 Fatahi, Z., Haghparast, A., Khani, A. and Kermani, M., 2018. Functional connectivity between anterior cingulate cortex and orbitofrontal cortex during value-based decision making. *Neurobiology of learning and memory*, 147, pp.74–78. [10.1016/j.nlm.2017.11.014](https://doi.org/10.1016/j.nlm.2017.11.014)

©(2019) Najafiani E, Rabiee B, Aliyari Shoorehdeli M, Haghparast A

Cite as: Najafiani E, Rabiee B, Aliyari Shoorehdeli M, Haghparast A (2019) A Data Flow Analysis during a Rewarded Decision-Making Activity in Rats Based on Transfer Entropy. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0045](https://doi.org/10.12751/nncn.bc2019.0045)

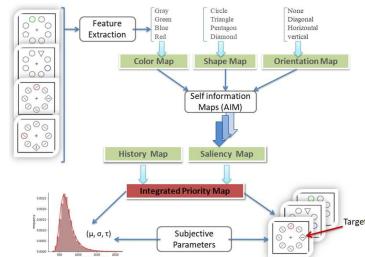
[W 28] A Model of Selection History in Visual Attention

Neda Meibodi¹, Sara Müller¹, Anna Schubö¹, Dominik Endres¹

1. Psychology Department, Philipps University, Marburg, Germany

We present a computational model of visual attention including the bias induced by previous learning experience. In this model, top-down guidance, bottom-up influences and visual selection history compete to guide the observers' attention toward a specific stimulus. Inspired by the proposition of an integrated priority map [1], saliency, history and task-relevant information are fused to guide attention, see figure 1. After extracting shape, orientation and color features from the visual input as proposed by [2], the model computes saliency for each of these feature dimensions via the self-information of the feature distribution, similiar to 'Attention based on Information Maximization' (AIM) [3]. A key difference to previously proposed models is the 'history map' biasing attention based on selection history [1]. It represents the cumulative effects of past experiences and resulting reward expectations in the model. These maps are fed into a two-layer neural network evaluating the integrated priority map, which is then used to predict the selected stimulus and the reaction time distribution parameters. The model is tested on a reaction-time data set from the experiments presented in [4]. Out of six different types of reaction time distributions tested on the data, the ex-Gaussian distribution [5] provides the best fit. We show that the model can predict the reaction time distribution

parameters for each participant and also across the experimental groups, effectively capturing selection history effects on visual attention.



Schematic of the model. Arrows represent direction of information flow. The model predicts both the selected stimulus and the reaction time for this selection.

Acknowledgements

N. Meibodi, A. Schubö and D. Endres were supported by the DFG SFB-TRR 135

References

- 1 Edward Awh, Artem V. Belepnolsky, and Jan Theeuwes. Top-down versus bottom-up attentional control: a failed theoretical dichotomy. *Trends in Cognitive Science*, 16(8):437–443, 2012. [10.1016/j.tics.2012.06.010](https://doi.org/10.1016/j.tics.2012.06.010)
- 2 Laurent Itti, Christof Koch, and Ernst Niebur. A model of saliency-based visual attention for rapid scene analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 20(11):1254 – 1259, 1998. [10.1109/34.730558](https://doi.org/10.1109/34.730558)
- 3 Neil D. B. Bruce and John K. Tsotsos. Saliency , attention , and visual search: An information theoretic approach. *Journal of Vision*, 9(3):1–24, 2009. [10.1167/9.3.5](https://doi.org/10.1167/9.3.5)
- 4 Tobias Feldmann-Wüstefeld, Metin Uengoer, and Anna Schubö. You see what you have learned. Evidence for an interrelation of associative learning and visual selective attention. *Psychophysiology*, 52(11):1483–1497, 2015. [10.1111/psyp.12514](https://doi.org/10.1111/psyp.12514)
- 5 Dora Matzke and Eric Jan Wagenmakers. Psychological interpretation of the ex-gaussian and shifted wald parameters: A diffusion model analysis. *Psychonomic Bulletin and Review*, 16(5):798–817, 2009. [10.3758/PBR.16.5.798](https://doi.org/10.3758/PBR.16.5.798)

©(2019) Meibodi N, Müller S, Schubö A, Endres D

Cite as: Meibodi N, Müller S, Schubö A, Endres D (2019) A Model of Selection History in Visual Attention. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0046](https://doi.org/10.12751/nncn.bc2019.0046)

[W 29] A structurally simple model explains MT transients under variable stimulus and behavioral conditions

Xiao Chen¹, Lisa Bohnenkamp¹, Detlef Wegener², Udo Ernst¹

1. Institute for Theoretical Physics, University of Bremen, 28334 Bremen, Germany

2. Brain Research Institute, University of Bremen, 28334 Bremen, Germany

Natural, cluttered visual scenes often contain rapidly changing information. For successful behavior, it is crucial to process and evaluate such changes as quickly as possible. In monkey area MT it was shown that motion-selective neurons represent sudden speed changes in fast transient responses [1]. Both spatial and non-spatial visual attention modulate the transient's latencies, which in turn closely correlate with reaction time [2, 3]. We investigate the underlying computational mechanisms by a structurally simple model providing divisive inhibition to MT neurons, to quantitatively reproduce the time course of transient responses under passive viewing conditions. Mathematical analysis of the circuit explains hallmark effects of transient activations, identifying the relevant parameters determining response latency, peak response, and sustained activation. Analysis of the model also predicts a consistent increase in the transient's rise time for a corresponding positive input change under conditions of attention, matching the experimental findings. Interestingly, the model predicts faster decay times for negative transients following attended speed decrements. We present new physiological data from monkey area MT confirming this prediction and showing that latency of speed change transients is subject to attentional modulation also in rapid reductions of firing rates. Thus, the model provides a unique framework for a mechanistic understanding of MT response dynamics under very different sensory and behavioral conditions.

Acknowledgements

Supported by Bernstein Award 01GQ1106 (UE) and DFG grant WE 5469/2-1 (DW)

References

- 1 Traschütz A, Kreiter AK, Wegener D (2015). "Transient activity in monkey area MT represents speed changes and is correlated with human behavioral performance", Journal of Neurophysiology 113: 890-903. [10.1152/jn.00335.2014](https://doi.org/10.1152/jn.00335.2014)
- 2 Galashan FO, Saßen HC, Kreiter AK, Wegener D (2013). "Monkey area MT latencies to speed changes depend on attention and correlate with behavioral reaction times", Neuron 78: 740-750 [10.1016/j.neuron.2013.03.014](https://doi.org/10.1016/j.neuron.2013.03.014)
- 3 Schledde B, Galashan FO, Przybyla M, Kreiter AK, Wegener D (2017). "Task-specific, dimension-based attentional shaping of motion processing in monkey area MT", Journal of Neurophysiology 118: 1542-1555 [10.1152/jn.00183.2017](https://doi.org/10.1152/jn.00183.2017)

©(2019) Chen X, Bohnenkamp L, Wegener D, Ernst U

Cite as: Chen X, Bohnenkamp L, Wegener D, Ernst U (2019) A structurally simple model explains MT transients under variable stimulus and behavioral conditions. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0047](https://doi.org/10.12751/nncn.bc2019.0047)

[W 30] Brain dynamics for adaptive learning

Florent Meyniel¹

1. NeuroSpin, CEA Paris-Saclay, Gif sur Yvette, France

Learning in a world that is both changing and uncertain is a difficult problem. An efficient solution, popular in artificial intelligence and neuroscience [1,2], is to pool past observations, which averages noise out, and to assign larger weights to more recent observations, which enables to cope with changes in the statistics of our environment. The balance between past and current observations sets the tradeoff between flexibility and stability of learned estimates. Adaptive learning is the capability to adjust this balance dynamically so as to promote stability when the environment is stable, and flexibility when the environment changes [3,4]. Optimal adaptive learning is achieved by Bayesian models, which not only estimate parameters but also the associated uncertainty, or conversely, confidence. Surprise arising from a discrepancy between new observations and the current estimate leads to update this estimate, but this update is all the smaller that the confidence associated with the estimate is higher. This confidence-weighting is a key feature of adaptive learning [5]. Here, 24 human subjects performed a probability learning task, in which the hidden statistics generating a sequence of auditory stimuli changed unpredictably and discontinuously. I used the optimal Bayesian model as reference and quantified confidence about an estimate as its posterior precision. Subjects occasionally reported their probability estimates and their confidence; both reports were close to the optimal Bayesian model as in previous studies [6-7]. Brain waves evoked by stimuli were recorded with magneto-encephalography. They were enhanced when the stimulus appeared unlikely to the optimal model, akin to surprise signals [8]. Some of those surprise signals (peaking at 200 ms) were reduced when confidence was higher, while later waves (400-700ms) reflected surprise unmodulated by confidence. Stronger beta-range (15-40 Hz) oscillations and smaller tonic pupil size were associated with higher confidence, and with reduced evoked surprise responses. Beta range power before questions also predicted subjective confidence. Together, those results support the following mechanism for adaptive learning. Confidence about current estimates would recruit neuromodulation and increase beta-range oscillations (which are often associated with top-down control [9-12]) so as to gate the incoming observation and reduce potential surprise signals, thereby regulating the updating process.

Acknowledgements

I thank Micha Heilbron and Maxime Maheu who collected the data. This work is funded by a grant from Collège de France, and a grant from French ANR (18-CE37-0010).

References

- 1 Rescorla R A, Wagner A R. A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In: AH., Black, &, W.F., Prokasy WF, Back AH, editors. Classical conditioning II: Current research and theory. New York Appleton-Century Crofts; 1972
- 2 Sutton RS, Barto AG. Introduction to Reinforcement Learning. 1st ed. Cambridge, MA, USA: MIT Press; 1998.
- 3 Nassar MR, Wilson RC, Heasly B, Gold JI. An Approximately Bayesian Delta-Rule Model Explains the Dynamics of Belief Updating in a Changing Environment. *J Neurosci*. 2010;30: 12366–12378. [10.1523/JNEUROSCI.0822-10.2010](https://doi.org/10.1523/JNEUROSCI.0822-10.2010)
- 4 Behrens TEJ, Woolrich MW, Walton ME, Rushworth MFS. Learning the value of information in an uncertain world. *Nat Neurosci*. 2007;10: 1214–1221. [10.1038/nn1954](https://doi.org/10.1038/nn1954)
- 5 Meyniel F, Dehaene S. Brain networks for confidence weighting and hierarchical inference during probabilistic learning. *Proc Natl Acad Sci*. 2017; 201615773 [10.1073/pnas.1615773114](https://doi.org/10.1073/pnas.1615773114)
- 6 Boldi A, Blundell C, De Martino B. Confidence modulates exploration and exploitation in value-based learning. *Neurosci Conscious*. 2019 [10.1093/nc/niz004](https://doi.org/10.1093/nc/niz004)
- 7 Meyniel F, Schluencker D, Dehaene S. The Sense of Confidence during Probabilistic Learning: A Normative Account. *PLoS Comput Biol*. 2015;11: e1004305 [10.1371/journal.pcbi.1004305](https://doi.org/10.1371/journal.pcbi.1004305)

- 8 Squires KC, Wickens C, Squires NK, Donchin E. The effect of stimulus sequence on the waveform of the cortical event-related potential. *Science*. 1976;193: 1142–1146 [10.1126/science.959831](https://doi.org/10.1126/science.959831)
- 9 Buschman TJ, Miller EK. Top-down versus bottom-up control of attention in the prefrontal and posterior parietal cortices. *Science*. 2007;315: 1860–1862 [10.1126/science.1138071](https://doi.org/10.1126/science.1138071)
- 10 Salazar RF, Dotson NM, Bressler SL, Gray CM. Content-Specific Fronto-Parietal Synchronization During Visual Working Memory. *Science*. 2012;338: 1097–1100 [10.1126/science.1224000](https://doi.org/10.1126/science.1224000)
- 11 Bastos AM, Vezoli J, Bosman CA, Schoffelen JM, Oostenveld R, Dowdall JR, et al. Visual Areas Exert Feedforward and Feedback Influences through Distinct Frequency Channels. *Neuron*. 2015;85: 390–401 [10.1016/j.neuron.2014.12.018](https://doi.org/10.1016/j.neuron.2014.12.018)
- 12 Siegel M, Donner TH, Engel AK. Spectral fingerprints of large-scale neuronal interactions. *Nat Rev Neurosci*. 2012;13: 121–134 [10.1038/nrn3137](https://doi.org/10.1038/nrn3137)

©(2019) Meyniel F

Cite as: Meyniel F (2019) Brain dynamics for adaptive learning. *Bernstein Conference 2019* Abstract.
doi: [10.12751/nncn.bc2019.0048](https://doi.org/10.12751/nncn.bc2019.0048)

[W 31] Closed-loop attention control of audio-visual speech

Alessandro Catania¹, Daniel D.E. Wong², Jonatan Märcher-Rørsted¹, Torsten Dau¹, Alain de Cheveigné², Jens Hjortkjær¹

1. Department of Health Technology, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark

2. Département d'Etudes Cognitives, Ecole Normale Supérieure/ CNRS, Paris, France

When attending to a speech source in acoustic environments with many talkers, low-frequency activity in auditory cortex is known to be selectively synchronized with slow amplitude fluctuation in the attended speech signal. In everyday communication, a listener can typically also see the face of the attended talker, but it remains unclear how attention-driven speech processing is influenced by visual information. Here, we investigated the impact of visual information on a closed-loop system that decodes the attended talker from scalp EEG and then amplifies the acoustic speech signal of that talker. To decode attention in real-time from scalp EEG, we used canonical correlation analysis (CCA) in order to relate multichannel EEG to a model of the audio-visual (AV) speech stimulus. First, we investigated a model of the temporal envelope of the acoustic speech signals passed through a modulation filtering stage mimicking the auditory midbrain. We found higher attention decoding accuracy and faster attention switching of the closed-loop system for listeners trained with audio-visual speech, compared to listeners presented with only audio. We also observed an earlier response to the acoustic envelope with audio-visual speech compared to audio-only speech. Next, we found that the attended talker could be decoded based on a CCA-model of visual features alone, using a measure of optical flow. Finally, combining audio and visual features in a CCA model improved accuracy further compared to models based on either auditory or visual features alone.

©(2019) Catania A, Wong DD, Märcher-Rørsted J, Dau T, de Cheveigné A, Hjortkjær J

Cite as: Catania A, Wong DD, Märcher-Rørsted J, Dau T, de Cheveigné A, Hjortkjær J (2019) Closed-loop attention control of audio-visual speech. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0049](https://doi.org/10.12751/nncn.bc2019.0049)

[W 32] Cognitive control of speed-accuracy trade-off in a neural model of two-stage decision making

Dominic Standage¹, Gunnar Blohm², Dietmar Heinke³

1. School of Psychology, University of Birmingham, UK

2. Centre for Neuroscience Studies, Queen's University, Canada

3. School of Psychology, University of Birmingham, UK

In decision making tasks, subjects are faster and less accurate when motivated to favour speed, and are slower and less accurate when motivated to favour accuracy. The speed-accuracy trade-off (SAT) is nearly ubiquitous across tasks and species, and provides a window on cognitive control. We investigated the neural basis of this control with a biophysically-based model of the frontal eye fields (FEF), simulating experiments in which single-neuron activity and local field potentials (LFP) were recorded from FEF in monkeys performing a visual search task, where a pre-trial cue indicated SAT condition and monkeys made their choices by foveating one of the stimuli [1,2]. Monkeys were faster and less accurate in the speed condition (vice versa for accuracy), where neurons responsive to stimuli (visual neurons) and neurons that increase their firing rates prior to eye movements (movement neurons) showed elevated rates during a pre-stimulus interval following the cue. We tested the hypothesis that this firing-rate modulation reveals a cognitive signal projected diffusely to FEF, controlling the dynamics of a two-stage decision process. Our model consists of simulated pyramidal neurons and inhibitory interneurons, connected by AMPA, NMDA and GABA conductance synapses. A network of visual neurons responds to stimuli and projects to a network of movement neurons. A diffuse (non-selective) signal controls SAT in the model, where a stronger signal produces higher response rates and earlier target selection in the visual network, and produces steeper ramping and higher peak rates in the movement network, as seen experimentally in the speed condition [1]. We simulated LFPs by summing synaptic currents onto stimulus-selective pyramidal populations, searching for biophysical parameters under which the model accounts for the relative timing of stimulus onset, discrimination of SAT condition, and discrimination of target selection from single-neuron and LFP activity [2]. Similarly, we tested the model's ability to account for increased spike-field coherence in the gamma and alpha bands under speed and accuracy conditions respectively [2]. The model makes testable predictions for the time-frequency response of LFPs in different task conditions, associating its predictions with sources of error during visual search.

References

- 1 Heitz RP, Schall JD: Neural mechanisms of speed-accuracy tradeoff. *Neuron*. 2012; 76: 616-628 [10.1016/j.neuron.2012.08.030](https://doi.org/10.1016/j.neuron.2012.08.030)
- 2 Heitz RP, Schall JD: Neural chronometry and coherency across speed-accuracy demands reveal lack of homomorphism between computational and neural mechanisms of evidence accumulation. *Phil Trans R Soc B*. 2013; 368: 1-11 [10.1098/rstb.2013.0071](https://doi.org/10.1098/rstb.2013.0071)

©(2019) Standage D, Blohm G, Heinke D

Cite as: Standage D, Blohm G, Heinke D (2019) Cognitive control of speed-accuracy trade-off in a neural model of two-stage decision making. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0050](https://doi.org/10.12751/nncn.bc2019.0050)

[W 33] Context dependent reinstatement of learning strategies

Armin Maddah^{1,2}, Luca F. Kaiser³, Lennart Luettgau², Gerhard Jocham²

1. Center for Behavioral Brain Sciences, Leipziger Str. 44, 39120, Magdeburg, Germany

2. Institute of Experimental Psychology, Heinrich Heine University Düsseldorf, Germany

3. SFB 779, Neurobiology of Motivated Behavior, Magdeburg, Germany

Research in instrumental learning has successfully employed reinforcement learning (RL) theory to explain the mechanisms of learning and memory in a wide range of neurobiological data. This line of research has established an important role for fronto-striatal brain systems with two key components: reward prediction error signals in the firing of dopaminergic cells and neural correlates of RL values in striatum [1,2]. In recent years, more detailed investigations lead to emergence of an idea about the contribution of multiple systems to learning and it seems that human instrumental learning is unlikely to solely rely only on incremental learning from prediction errors. A major observation relating to this account is the wide recruitment of brain regions that strongly implicate prefrontal cortex in instrumental learning paradigms. Indeed, recent data suggests working memory processes (presumably reliant on prefrontal cortex) interacting with RL system to guide behaviour [3]. In the first part of our project we aimed to replicate these findings by employing the same behavioral protocol [3] and following an extensive computational approach [4] to fit parameters, compare and validate a spectrum of models starting from heuristics up to pure RL and more sophisticated models which take into account the interaction between RL systems and more WM-like strategies. In the second part of our study, we aim to investigate whether these two dissociable learning strategies (WM based vs. RL-based value estimation) can be conditioned to certain contexts.

References

- 1 Lau, B., & Glimcher, P. W. (2007). Action and outcome encoding in the primate caudate nucleus. [10.1523/JNEUROSCI.3060-07.2007](https://doi.org/10.1523/JNEUROSCI.3060-07.2007)
- 2 Pessiglione, M., Seymour, B., Flandin, G., Dolan, R. J., & Frith, C. D. (2006). Dopamine-dependent prediction errors underpin reward-seeking behaviour in humans. [10.1038/nature05051](https://doi.org/10.1038/nature05051)
- 3 Collins, A. G., & Frank, M. J. (2012). How much of reinforcement learning is working memory, not reinforcement learning? A behavioral, computational, and neurogenetic analysis. [10.1111/j.1460-9568.2011.07980.x](https://doi.org/10.1111/j.1460-9568.2011.07980.x)
- 4 Wilson, R., & Collins, A. (2019). Ten simple rules for the computational modeling of behavioral data. [10.31234/osf.io/46mbn](https://doi.org/10.31234/osf.io/46mbn)

©(2019) Maddah A, Kaiser LF, Luettgau L, Jocham G

Cite as: Maddah A, Kaiser LF, Luettgau L, Jocham G (2019) Context dependent reinstatement of learning strategies.

Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0051](https://doi.org/10.12751/nncn.bc2019.0051)

[W 34] Exploration biased by former stimulus-response associations due to plasticity in the subthalamic nucleus – external globus pallidus loop in the basal ganglia

Oliver Maith¹, Javier Baladron¹, Fred Hamker¹

1. Department of Computer Science, Chemnitz University of Technology, Chemnitz, Germany

Imagine you want to turn on a computer. As usual you press the on button, but unexpectedly the computer doesn't start. You may look immediately at the power strip instead of opening the computer to see if all cables are properly seated. Testing well known alternative solutions before others is often effectively and time-saving. In a recent computational study, it was shown that the subthalamic nucleus (STN) – external globus pallidus (GPe) loop in the basal ganglia could play an important role for this cognitive ability [1]. Depending on how the connections in the STN-GPe loop were defined, the loop could bias exploratory decisions, which occur after the learned action isn't rewarded anymore. The authors hypothesized that these actions could be promising alternatives, such as former rewarded actions. Here we introduce a possible mechanism by which such connectivity patterns in the STN-GPe loop can be learned from former experiences. We took the computational spiking basal ganglia model from the above-mentioned study and implemented a plastic connection from the STN neurons to the GPe neurons. The implemented learning rule consists of a LTP part and a LTD part. The LTP part increases the weights when the postsynaptic neuron activity is below average, and the LTD part decreases the weights when the presynaptic activity is above average. This simple plasticity mechanism leads to a stronger facilitation of previously rewarded actions in future exploration periods. We let the model perform several stimulus-response tasks, in which the rewarded action changed for multiple times. The model learned repeatedly to choose the new rewarded action. In the different tasks we varied how often certain actions become the rewarded action and how long they remain the rewarded action. The results show a significant change in the exploration behavior over time for the model with the plastic STN-GPe connection compared to the model with a fixed STN-GPe connection. The more often actions have been rewarded in the past, the more likely they are to be explored after a rule change and a faster behavioral switch is achieved. Also, the response times of action selections during the exploration periods change due to the plastic STN-GPe connection. Response times decrease for exploration of former rewarded actions and increase for actions that rarely or never have been rewarded.

References

- 1 Baladron, J., Nambu, A., & Hamker, F. H. (2017). The subthalamic nucleus-external globus pallidus loop biases exploratory decisions towards known alternatives: a neuro-computational study. *The European Journal of Neuroscience*. [10.1111/ejn.13666](https://doi.org/10.1111/ejn.13666)

©(2019) Maith O, Baladron J, Hamker F

Cite as: Maith O, Baladron J, Hamker F (2019) Exploration biased by former stimulus-response associations due to plasticity in the subthalamic nucleus – external globus pallidus loop in the basal ganglia. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0052](https://doi.org/10.12751/nncn.bc2019.0052)

[W 35] History-related influences during mouse orientation discrimination

Shreya Khanal^{1,2}, Anna Vasilevskaya³, Gregory Born^{1,2}, Steffen Katzner¹, Thomas Wachtler^{1,4,5}, Laura Busse^{1,4,5}

1. Division of Neurobiology, Department Biology II, LMU Munich, 82151 Munich, Germany

2. Graduate School of Systemic Neuroscience (GSN), LMU Munich, 82151 Munich, Germany

3. ENB Elite Master of Science Program in Neuroengineering, Technical University of Munich, 80333 Munich, Germany

4. Bernstein Center for Computational Neuroscience, 82151 Munich, Germany

5. Senior authors

Finding regularities in the environment and utilising them is important in this complex, yet structured world. Hence, our decisions do not only depend on current sensory input, but are also influenced by previous experience. Many studies have documented that such influences include the history of stimuli [1, 2] and rewards [4].

To investigate history effects during visual perceptual decision making, we trained head-fixed mice to perform a lick-left / lick-right orientation discrimination task using a two-alternative forced choice paradigm (modified from [3]). Once animals achieved stable performance (4 consecutive days), we measured behaviour during baseline conditions and conditions, in which we systematically manipulated reward statistics by doubling the reward size for one of the correct choices. In addition, we modelled mouse decision-making behaviour with a logistic regression framework to investigate the relative influences of different factors, such as the current visual stimulus, but also past stimuli, choices and reward manipulation.

Mice learned the task and achieved stable performance after 8 weeks of training (accuracy of 66%). To understand which factors contributed to the improvement in task performance, we analysed the development of model weights during learning. We found that progress in learning was paralleled by increases in weight assigned to the current stimulus ($R^2 = 0.98$). Even after stable performance was reached, however, mice assigned almost equally strong weights to the previous choice (32%) as to the current stimulus (33%), indicating substantial history-related effects. History effects were 10% stronger after a previous success than a failure, and were consistent with a win-stay strategy.

To investigate how mice trade-off stimulus-related and contextual information, we also modelled performance in experiments where we introduced blocks of trials with stimulus-specific imbalances of reward. Here, mice showed a consistent bias towards the response side associated with the larger reward. Our model revealed that the weight assigned to the current stimulus decreased by 40% compared to blocks with balanced rewards. This shows that reward expectation can bias visually-driven choices.

We conclude that, even for simple visual stimuli well above threshold, perceptual decision-making in mice is substantially influenced not only by the current visual stimulus but also by the history of past trials and the context of reward.

Acknowledgements

We thank L. Petreanu, P. Goltstein and S. Reinert for help implementing the behavioral paradigm, and M. Sotgia for technical support. This research was funded by the DFG RTG 2175 ("Perception in Context and its Neural Basis").

References

- 1 A. Akrami, C. D. Kopec, M. E. Diamond, and C. D. Brody. Posterior parietal cortex represents sensory history and mediates its effects on behaviour. *Nature*, 554(7692):368–372, Feb. 2018. ISSN 1476-4687. doi: 10.1038/nature25510 [10.1038/nature25510](https://doi.org/10.1038/nature25510)
- 2 J. Fischer and D. Whitney. Serial dependence in visual perception. *Nature Neuroscience*, 17(5):738, May 2014. ISSN 1546-1726. doi: 10.1038/nn.3689. [10.1038/nn.3689](https://doi.org/10.1038/nn.3689)
- 3 T. Marques, M. T. Summers, G. Fioreze, M. Fridman, R. F. Dias, M. B. Feller, and L. Petreanu. A Role for Mouse Primary Visual Cortex in Motion Perception. *Current Biology*, 28(11):1703–1713.e6, June 2018. ISSN 0960-9822. doi: 10.1016/j.cub.2018.04.012 [10.1016/j.cub.2018.04.012](https://doi.org/10.1016/j.cub.2018.04.012)
- 4 A. E. Rorie, J. Gao, J. L. McClelland, and W. T. Newsome. Integration of sensory and reward information during perceptual decision-making in lateral intraparietal cortex (LIP) of the macaque monkey. *PLoS One*, 5(2):e9308, 2010. doi: 10.1371/journal.pone.0009308. [10.1371/journal.pone.0009308](https://doi.org/10.1371/journal.pone.0009308)

©(2019) Khanal S, Vasilevskaya A, Born G, Katzner S, Wachtler T, Busse L

Cite as: Khanal S, Vasilevskaya A, Born G, Katzner S, Wachtler T, Busse L (2019) History-related influences during mouse orientation discrimination. Bernstein Conference 2019 Abstract. doi: [10.12751/hnncn.bc2019.0053](https://doi.org/10.12751/hnncn.bc2019.0053)

[W 36] **Human local field potentials in visual cortex show increase in beta activity following eye blinks during a visual task**

Franz Aiple¹, Armin Brandt¹, Julie Blumberg², Peter Reinacher³, Markus Kern⁴, Andreas Schulze-Bonhage¹

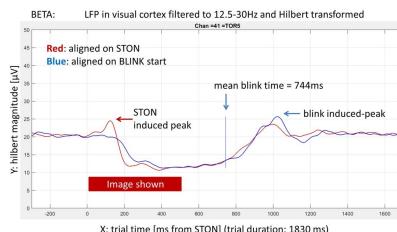
1. Epilepsy Center, Univ.Medical Center, Freiburg, Germany

2. Dept of Neuropediatrics, Univ.Medical Center, Freiburg, Germany

3. Dept of Stereotactic Neurosurgery, Univ.Medical Center, Freiburg, Germany

4. Dept of Neurosurgery, Univ.Medical Center, Freiburg, Germany

Epilepsy patients were implanted with depth electrodes in temporal and occipital brain regions for diagnostic purposes. Intracortical local field potentials (LFPs) were recorded continuously while participants performed a visual task. Mooney images (binary black and white, difficult to recognize) and corresponding greyscale images were presented for 500ms, followed by inter stimulus intervals of 1330ms. Subjects had to indicate whether they recognized something or not by pressing one of two keys. Eye blinks were detected on the basis of EOG signals. Two classes of trials - with or without eye blinks - and 2 classes of eye blinks - inside or outside of trials - were analysed separately. Eye blinks in trials were mostly time locked to stimulus onset (STON), occurring mainly between 700 and 1100ms after STON. LFPs were analysed with respect to stimulus onset and eye blink occurrence times, respectively, for different frequency bands in the delta to gamma range (0.5–256Hz). STON-aligned averaging revealed visual evoked potentials (VEPs), blink-aligned averaging revealed blink related potentials (BRPs) in many electrodes. Coupling of blinks to trial timing confounded the two contributions. This was resolved by analysing amplitude and sharpness of peaks. In occipital electrodes (areas V1, V2, FG) beta activity (11–32Hz) increased shortly after blinks in 4 of 5 patients, more strongly for blinks within than outside of trials. Otherwise STON was followed by a decrease in beta activity. Alignment on eye blinks revealed that activity comes back to pre stimulus levels faster than with STON alignment and the fast recovery is introduced by a transient overshoot. Alpha and gamma activities are modulated in a way similar to beta, but with less pronounced effects. In particular we do not see a gamma enhancement during the stimulus presentation. Modulation of alpha and beta activity during visual tasks was discussed in the literature in the context of attention, with less consideration given to the contribution of eye blinks. Here, we report that beta activity is decreased after the appearance of visual stimuli and reset to pre stimulus levels after eye blinks.



Red peak at 130 ms: induced by the onset of the image (STON). Blue peak at 1000 ms: mainly induced by the blink happening shortly before (blue vertical line)

Acknowledgements

This work was supported by Society for Neuroscience and BMBF Award for US-German collaboration in Computational Neuroscience 01GQ1010.

©(2019) Aiple F, Brandt A, Blumberg J, Reinacher P, Kern M, Schulze-Bonhage A

Cite as: Aiple F, Brandt A, Blumberg J, Reinacher P, Kern M, Schulze-Bonhage A (2019) Human local field potentials in visual cortex show increase in beta activity following eye blinks during a visual task. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0054](https://doi.org/10.12751/nncn.bc2019.0054)

[W 37] Modelling spatial attention as a spatiotopic decision process in a two dimensional field

Brad Wyble¹, Chloe Callahan-Flintoft², Aakash Sarker³, Toma Marinov¹

1. Psychology, Penn State University, 140 Moore Building, United States

2. Army Research Lab, Aberdeen Proving Grounds, United States

3. Psychology, Boston University, 64 Cummington Mall

Cognitive systems that process visual data benefit from attention, which establishes priority of processing from certain locations of the visual field according to a variety of factors such as physical salience, and task, goal, reward or other forms of top-down influence. Computational studies of visual attention focus primarily on understanding how attentional priority should be computed from a given visual input. This attentional priority can then be used to determine a specific location of attentional focus for e.g. predicting the x,y coordinates of eye-gaze, but this approach overlooks a more nuanced aspect of attention, which is the ability to focus attention on regions of the visual field, rather than single points. In humans, covert attention mechanisms are thought to be deployed across regions rather than single points (Erickson & St James 1986), and artificial systems also benefit from regionwide form of attention (Anderson et al. 2018). The challenge, then, is how to convert priority signals across the visual field into active attention. The simplest approach would apply attention in proportion to the priority at each location, but this permits information from locations with moderate priority to interfere with the processing of information at higher priority locations. Drawing inspiration from human experimental work (Gasparin, Luck & Leonard 2015), here is proposed a circuit that makes realtime decisions about how to deploy attention in a two-dimensional space based on a continuously changing priority value. The circuitry uses competitive inhibitory dynamics to mediate the competition between different locations and allows a broad variety of outcomes expressed as region-wide deployments of attention. The decision process allows attention at highly priority locations to

selectively suppress the deployment of attention at locations with lower priority values (Figure 1). However, the decision process is also flexible, having the ability also to focus on multiple regions simultaneously as well as large regions. This flexibility, is likely to be crucial for accommodating the wide variety of image processing scenarios that occur in natural vision contexts.

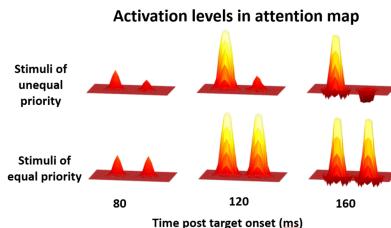


Figure 1: Simulations of attention deploying to a higher priority location while suppressing the other (top) and attending equally to two equal priority stimuli (bottom)

Acknowledgements

This work was supported by NSF Grant 173422 to B.W.

References

- Anderson, P., He, X., Buehler, C., Teney, D., Johnson, M., Gould, S., & Zhang, L. (2018). Bottom-up and top-down attention for image captioning and visual question answering. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (pp. 6077-6086). Eriksen, C. W., & James, J. [10.1109/CVPR.2018.00636](https://doi.org/10.1109/CVPR.2018.00636)
- Eriksen, C. W., & James, J. D. S. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & psychophysics*, 40(4), 225-240. [10.3758/bf03211502](https://doi.org/10.3758/bf03211502)
- Gaspelin, N., Leonard, C. J., & Luck, S. J. (2015). Direct evidence for active suppression of salient-but-irrelevant sensory inputs. *Psychological science*, 26(11), 1740-1750 [10.1177/0956797615597913](https://doi.org/10.1177/0956797615597913)

©(2019) Wyble B, Callahan-Flintoft C, Sarker A, Marinov T

Cite as: Wyble B, Callahan-Flintoft C, Sarker A, Marinov T (2019) Modelling spatial attention as a spatiotopic decision process in a two dimensional field. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0055](https://doi.org/10.12751/nncn.bc2019.0055)

[W 38] Persistent activity explained through resource constraints: A normative model of delay activity in prefrontal cortex

Severin Berger¹, Christian K. Machens¹

1. Champalimaud Research, Champalimaud Centre for the Unknown, Av. Brasília, 1400-038 Lisboa, Portugal

Higher-order brain areas, such as the prefrontal cortex (PFC), are thought to be crucial for executive functions, such as working memory and attentional control, in order to produce goal-directed behaviour. Up to now, though, no normative theory has been proposed that could account for the neural activities observed in PFC when animals are performing simple, psychophysical tasks. The currently probably most popular approach to understanding neural activities in PFC is to train recurrent neural networks (RNNs) to solve the same behavioural tasks that the animals were supposed to solve, and then compare experimentally recorded PFC activity to modelled RNN activity. Here we show, using an RNN implementation by Song et al (2016) that models the somatosensory working memory task by Romo et al (1999), that even if the resulting activity may resemble recorded activities well on a single neuron level, RNNs may fail to properly capture activity on a population level. To gain a deeper understanding of the nature of

the code in PFC, we then set out to explain key aspects of PFC delay activity using a normative approach. We introduce an approach based on a basis function representation of task-relevant variables, and show good agreement with data on the same task. Finally, we show that this representation can be understood as the result of an optimal trade off between working memory accuracy and capacity, therefore providing a principled explanation of the working memory component of higher-order brain activity.

Acknowledgements

Severin Berger thanks Fundação para a Ciência e a Tecnologia and Fundação Champalimaud for funding.

References

- 1 Song HF, Yang GR, Wang XJ (2016) Training Excitatory-Inhibitory Recurrent Neural Networks for Cognitive Tasks: A Simple and Flexible Framework. *PLOS Computational Biology* 12(2): e1004792. [10.1371/journal.pcbi.1004792](https://doi.org/10.1371/journal.pcbi.1004792)
- 2 Romo, R., Brody, C. D., Hernández, A., & Lemus, L. (1999). Neuronal correlates of parametric working memory in the prefrontal cortex. *Nature*, 399(6735), 470–473. [10.1038/20939](https://doi.org/10.1038/20939)

©(2019) Berger S, Machens CK

Cite as: Berger S, Machens CK (2019) Persistent activity explained through resource constraints: A normative model of delay activity in prefrontal cortex. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0056](https://doi.org/10.12751/nncn.bc2019.0056)

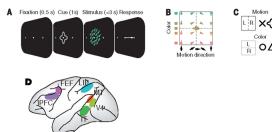
[W 39] Representations of Sensory Signals and Abstract Categories in Brain Networks

Dimitris Pinotsis^{1,2}, Markus Siegel³, Earl Miller²

1. Center for Mathematical Neuroscience and Psychology, City —University of London, Northampton Square, UK
2. Brain and Cognitive Sciences, MIT, 43 Vassar Street, USA
3. Center for Integrative Neuroscience and MEG Center, University of Tübingen, 72076 Tübingen, Germany

Many recent advances in AI are rooted in visual neuroscience. However, ideas from decision-making are less used. Achieving human-level performance in decision-making tasks is still a challenge. At the same time, these tasks are easy for humans. Thus, understanding brain dynamics during such tasks could improve AI performance. We reanalyzed data previously published in (1) using Representation Similarity Analysis (RSA; 2) and deep recurrent neural networks (RNNs). Monkeys performed a decision-making task. See Figure 1. They categorized motion direction and color. Before stimulus onset, a central cue indicated which feature to categorize. Monkeys indicated their choice with a leftward or rightward saccade. To understand neural representations in different brain areas, we computed 1) the similarity of neural representation in a brain area with the geometry of the sensory or category domain represented (which we call domain selectivity); 2) The similarity of neural computation performed by a brain area with predictions from 2 deep RNNs: one trained to distinguish categories and the other to process visual information (computation selectivity). We first considered domain selectivity. We followed (2) and computed the dissimilarity between brain Representation Dissimilarity Matrices (RDMs) and sensory/category DMs. Brain RDMs were obtained using LFP recordings from each brain area. We then turned to computation selectivity. This was defined based on the similarity of brain activity with predictions from RNNs. We considered 2 variants of the same RNN. One trained to perform sensory processing and the other abstract categorization. Then we compared the RNN predictions to brain activity, that is, brain and RNN RDMs. We found the same results for each brain area using both domain and computation selectivity. V4 showed preference towards sensory

processing in the color task and motion categorization in the motion task. MT was more selective for categorization during both the motion and color tasks. FEF and IT showed clear preference for sensory processing during both tasks. See (3) for more details. Interestingly, neural representations and computations changed depending on context. This is different from visual neuroscience tasks modeled with usual feedforward neural networks, like CNNs. Overall, our results shed light to the biological basis of categorization and differences in selectivity and computations in different brain areas.



(A) Monkeys categorized the motion direction, or color, of centrally presented, colored random dot stimuli. (B) Stimuli systematically covered motion, direction, and color space. (C) Schematic display of the recorded brain regions.

Acknowledgements

This work was supported by NIMH R37MH087027. DAP acknowledges illuminating discussions and useful comments by Dr Pouya Bashivan.

References

- 1 Siegel, M., Buschman, T.J. & Miller, E.K. (2015). Cortical information flow during flexible sensorimotor decisions. *Science* 348, 1352–1355. [10.1126/science.aab0551](https://doi.org/10.1126/science.aab0551)
- 2 Kriegeskorte, N., Mur, M. & Bandettini, P.A. (2008). Representational similarity analysis-connecting the branches of systems neuroscience. *Frontiers in Systems Neuroscience* 2, 4. [10.3389/neuro.06.004.2008](https://doi.org/10.3389/neuro.06.004.2008)
- 3 Pinotsis, D.A., Siegel, M., and Miller, E.K. (2019). Sensory Processing and Categorization in Cortical and Deep Neural Networks. *BioRxiv* 647222. [10.1101/647222](https://doi.org/10.1101/647222)

©(2019) Pinotsis D, Siegel M, Miller E

Cite as: Pinotsis D, Siegel M, Miller E (2019) Representations of Sensory Signals and Abstract Categories in Brain Networks. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0057](https://doi.org/10.12751/nncn.bc2019.0057)

[W 40] RNNs develop history biases in an expectation-guided two-alternative forced choice task

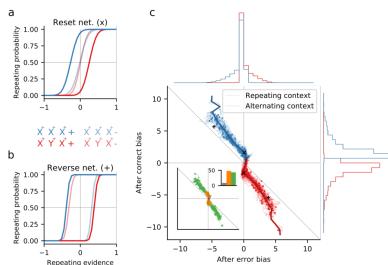
Manuel Molano-Mazon¹, Guangyu Robert Yang², Ainhoa Hermoso-Mendizabal¹, Jaime de la Rocha¹

1. IDIBAPS, Barcelona, Spain

2. Center for Theoretical Neuroscience, Columbia University, New York, USA

Understanding how expectations bias perceptual decisions constitutes an unavoidable step towards deciphering how we make decisions. Here we trained Recurrent Neural Networks (RNNs) on a Two-Alternative Forced-Choice task that requires the categorization of stimuli presented in a sequence exhibiting serial correlations. In particular, the probability, P_{rep} , that the correct answer at trial t is the same as at trial $t - 1$ alternates between $P_{rep} = 0.8$ (repeating block) and $P_{rep} = 0.2$ (alternating block), every 200 trials. This setup allowed us to investigate how RNNs can integrate decision-relevant information present at different temporal scales: a fast source of information, the current stimulus,

and a much slower one, the trial-to-trial correlations, that can be interpreted as the context in which the current trial is perceived. We found that RNNs developed a trial-history bias (transition bias, b): a tendency to repeat ($b > 0$) or to alternate ($b < 0$) the previous choice depending on the number of previous repetitions vs. alternations. We further characterized this transition bias by separating trials depending on the outcome of the last trial (b^+ and b^- for after-correct/-error biases, respectively) and found that trained networks follow two different strategies to solve the task: one in which the transition bias is present after correct responses but vanishes after error trials ($b^+ \gg b^- \approx 0$) (Fig. 1a), as has been found in rats (Hermoso-Mendizabal et al. 2019); and another strategy in which networks show a transition bias after correct and after error of comparable magnitude but with an opposite sign ($b^+ \approx -b^-$, Fig. 1b). Interestingly, the former strategy characterizes the behavior of all networks during the first stages of training and only at a later stage, a sub-population of networks are able to move to the second strategy (Fig. 1c), which has a positive impact in their performance. A more detailed characterization of these different behaviors revealed that the percentage of networks showing after-error reset increases when limiting the resources of the networks, such as reducing their size, the information they receive or the training time. Together, these results suggest that rats develop a sub-optimal but easier to reach strategy to solve the task due to some limiting factor such as lack of computational capacity or time constraints.



(a) and (b): Psychophysical curves examples. Legend is shown between the two panels.
(c) After-correct VS after-error transition biases during training (thick lines: median values). Histograms show the projected distribution. Inset: same data colored by network type (bars: percentage of each type).

Acknowledgements

Generalitat de Catalunya (grant 2017-BP-00305) and the European Research Council (ERC-2015-CoG – 683209-PRIORS).

References

- 1 Hermoso-Mendizabal, Ainhoa, et al. "Response outcomes gate the impact of expectations on perceptual decisions." bioRxiv (2019): 433409. [10.1101/433409](https://doi.org/10.1101/433409)

©(2019) Molano-Mazon M, Yang GR, Hermoso-Mendizabal A, de la Rocha J

Cite as: Molano-Mazon M, Yang GR, Hermoso-Mendizabal A, de la Rocha J (2019) RNNs develop history biases in an expectation-guided two-alternative forced choice task. Bernstein Conference 2019 Abstract.
doi: [10.12751/nncn.bc2019.0058](https://doi.org/10.12751/nncn.bc2019.0058)

[W 41] Swiss Swap Theorem; On Transaction, Endowment Effect, and Coase Theorem

Mohsen Falahi^{1,2}, Kerstin Preuschhoff^{1,2}

1. Geneva Finance Research Institute, University of Geneva, Bd du Pont d'Arve 40 1211 Geneva 4, Switzerland

2. Center for Affective Sciences, University of Geneva, Chemin des Mines 9, 1202 Geneva, Switzerland

Objective: In trading, people engage in transactions and exchange goods. Markets, regardless of their size, are built around the concept of "transaction". The entire market is nothing other than swapping goods or giving up on goods for cash. Transactions are the defining element of a market and without transaction, a market is just a storage place. In this research we propose a new theorem which can explain transactions and their driving mechanism which unites Coase theorem and the endowment effect. This theorem enables us to predict the engagement in transactions and also accounts for the satisfaction on the engagement.

Methods: In this theoretical research, we first explored the history of trading to investigate the initial need for men to engage in transactions. Then we compare different theories to explain the motivation and criteria for agents to engage in a transaction. After the theoretical comparison, we compared the existing data on endowment effect and the theories used to explain this cognitive bias to see which one fits best. Additionally, we have reviewed experiments on endowment effect to check for their validity and reasoning based on their data. Finally, we have proposed a mathematical model, by which we unite the explanation on transactions and endowment effect.

Results and Conclusion: Our analyses and results can be summarized as follows;

- 1) Evolution of commerce since civilization suggests that the aim for engaging in a transaction is survival, hence, loss minimization explains transactions better than wealth maximization.
- 2) Traditional transaction cost (as it has been explained by Coase) does not consider the biological costs of making a decision. However, in endowment experiments, researchers have considered this cost zero and consequently the results in such experiment does not match with the prediction from Coase theorem.
- 3) In many researches on endowment effect, experimenters considered Willing-to-Accept (WTA) equivalent to the subjective value of the owned good which is not accurate. This inaccurate assumption has resulted in misunderstanding of the gap for WTA and Willing-to-Pay (WTP). Our theorem explains how the biological limits on processing information in the brain can create WTP-WTA gap in addition to mathematically capturing the way we can reduce or increase this gap in experiments.

This theorem suggests that one crucial element for manipulating WTP-WTA gap is the similarity among existing options.

©(2019) Falahi M, Preuschhoff K

Cite as: Falahi M, Preuschhoff K (2019) Swiss Swap Theorem; On Transaction, Endowment Effect, and Coase Theorem.

Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0059](https://doi.org/10.12751/nncn.bc2019.0059)

[W 42] **Unexpectedly strong attentional modulation of V1/V2 activity implements a robust, contrast-invariant control mechanism for selective information processing**

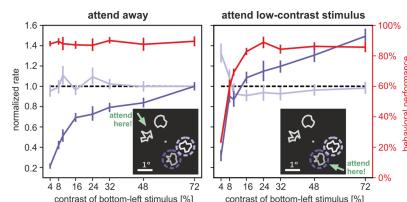
Maik Schünemann¹, Lukas-Paul Rausch², Eric Drebitz², Daniel Harnack³, Udo Ernst¹, Andreas Kreiter²

1. Institute for Theoretical Physics, University of Bremen, Hochschulring 18, Bremen, Germany

2. Brain Research Institute, University of Bremen, Leobener Str. 16, Bremen, Germany

3. Robotics Innovation Center, German Research Center for Artificial Intelligence, Robert-Hooke-Straße 1, Bremen, Germany

In the visual system, selective attention serves to focus on behaviorally relevant stimuli, while ignoring irrelevant stimulus information. When two stimuli, one of which is attended, are located within the receptive field (RF) of a neuron in area V4, attention modulates signal input originating from presynaptic populations in V1/V2 such that the V4 neuron acts as if only the attended stimulus was present. A recent computational model [1] explains this effect by assuming that attention first raises the firing rate of the presynaptic population representing the attended stimulus (target) slightly above the rates of populations representing stimuli to be ignored (distracter(s)). This rate bias can then be amplified by recurrent processes such as gamma-band synchronization [2], for selectively routing target information [3]. However, since modulation of firing rates in V1/V2 by attention is known to be rather small, this idea is challenged if the target stimulus evokes much less activity than a nearby distracter. In case of a low contrast target stimulus attention would have to overcome large rate differences to a nearby high contrast distracter. To investigate this particular situation we recorded multi-unit activity in areas V1/V2 of two macaque monkeys performing a demanding shape tracking task. Surprisingly, we found that attention is indeed able to compensate for the stimulus-induced activity difference by strongly increasing mean firing rates for the V1/V2 population encoding a low-contrast target by on average 61.5%, while moderately decreasing the rates of neurons representing the high-contrast distracter by on average 30.5%. We also observed distinct time courses for target facilitation and distracter suppression, suggesting different underlying mechanisms. For identifying the working range of attentional modulation we varied target contrast during recordings (see figure). When attention was directed to the opposite hemifield, rates for the low contrast stimulus depended only on its contrast (left panel). However, rates were strongly increased when the low contrast stimulus was attended (right panel). For a large contrast range from 16 to 72%, the target stimulus had a significant rate advantage and maximum performance levels were achieved. For error trials, no significant rate advantage was found. Taken together, our results significantly advance the understanding of control mechanisms orchestrating selective visual information processing.



Normalized rates (blue and light blue) and attentional modulation of V2 neurons whose RFs are indicated by dashed circles of same color as corresponding lines. Contrast of the bottom-right shape was always at 72%, while it varied between 4% and 72% for the bottom-left, "low-contrast" shape.

Acknowledgements

This work was supported by the BMBF (Bernstein Award Udo Ernst, Grant 01GQ1106) and the DFG (Priority Program 1665, Grants ER 324/3-2 and AK 1844/2-2).

References

- 1 Harnack et al. 2015, J Neurophysiol 114:1593-1605 [10.1152/jn.01038.2014](https://doi.org/10.1152/jn.01038.2014)
- 2 Grothe et al. 2012, J Neurosci 32:16172-16180 [10.1523/JNEUROSCI.0890-12.2012](https://doi.org/10.1523/JNEUROSCI.0890-12.2012)
- 3 Grothe et al. 2018, J Neurosci 38:3441-3452 [10.1523/JNEUROSCI.2221-17.2018](https://doi.org/10.1523/JNEUROSCI.2221-17.2018)

©(2019) Schünemann M, Rausch L, Drebitz E, Harnack D, Ernst U, Kreiter A

Cite as: Schünemann M, Rausch L, Drebitz E, Harnack D, Ernst U, Kreiter A (2019) Unexpectedly strong attentional modulation of V1/V2 activity implements a robust, contrast-invariant control mechanism for selective information processing. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0060](https://doi.org/10.12751/nncn.bc2019.0060)

Data analysis, machine learning, neuroinformatics

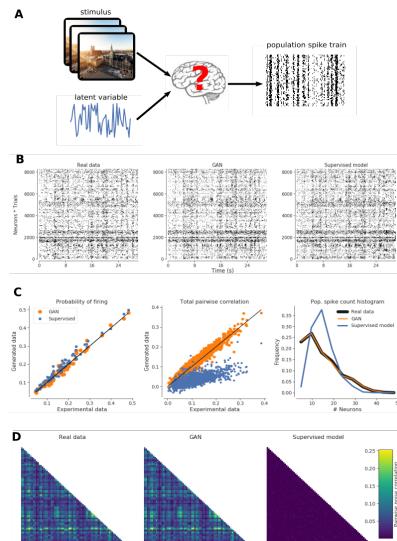
[W 43] Adversarial Training of Neural Encoding Models on Population Spike Trains

Poornima Ramesh¹, Mohamad Atayi¹, Jakob H Macke¹

1. Computational Neuroengineering, Technical University of Munich, Germany

Neural population responses to sensory stimuli can exhibit both stimulus-dependence and richly structured shared variability. An important challenge for neural encoding models is to generate spike trains that match the statistics of experimentally measured data. Most encoding models map the stimulus to average neural responses, neglecting the statistical structure of neural variability. Probabilistic encoding models trained with latent variables and typically fit with likelihood-based methods, may not yield realistic data. Here, we show how generative adversarial networks (GANs)[1, 2] conditioned on the input stimulus[3], can be used to optimize encoding models to capture both deterministic and stochastic components of neural population data. To deal with the discrete nature of neural spike trains, we use REBAR[4] to estimate unbiased gradients for adversarial optimization of encoding models. We illustrate our approach on population recordings from primary visual cortex. We show that by adding latent noise-sources to a convolutional neural network (CNN) we capture both the stimulus-dependence and noise correlations in population activity. We fit a 3-layer CNN generative model of binary spike counts to neural population data recorded in the macaque V1 area from [5, 6]. To capture the noise correlations between neurons, we add Gaussian white noise to the units of the CNN's intermediate layers, rescaled with a weight parameter for each unit.

We fit the network using adversarial training and REBAR. We find this approach to be more effective than previous approaches to train discrete GANs[7]. To compare, we also fit a CNN with a similar architecture to the GAN generator, but without shared noise, to the same dataset using supervised learning, by optimizing the cross-entropy between predicted firing probabilities and experimentally observed spike trains. On the training data, both approaches were able to accurately capture the firing rates. However, the supervised model did not reproduce total pairwise correlations between the neurons or histogram of population spike counts, as it has no model of correlated variability. The GAN generator, on the other hand, was able to capture both quantities. Thus, GANs could be used to capture higher-order structure in neural data. This approach may be extended to capture temporal features in neural population data like spike-history dependence or adaptation effects, or specifically capture data summary statistics of interest.



A) Goal: Encoding models capturing stimulus and response variability in neural population **(B)** Spike rasters for experimental data and models **(C)** Firing probability (left); correlation (middle); pop. spike histogram (right) for data, GAN and supervised model **(D)** Noise correlation for data and models

Acknowledgements

We thank Matthew Smith and Adam Kohn for sharing data via CRCNS.org

References

- 1 Goodfellow, I. J., Pouget-Abadie, J., Mirza, M., Xu, B., Warde-Farley, D., Ozair, S., . . . Bengio, Y. (2014). Generative Adversarial Nets. *arXiv*, 9781107015, 1–315
- 2 Mirza, M., & Osindero, S. (2014). Conditional generative adversarial nets. *arXiv:1411.1784*
- 3 Arakaki, T., Barello, G., & Ahmadian, Y. (2019). Inferring neural circuit structure from datasets of heterogeneous tuning curves. *PLoS Computational Biology*, 15 (4)

- 4 Tucker, G., Mnih, A., Maddison, C. J., Lawson, D., & Sohl-Dickstein, J. (2017). REBAR: Low-variance, unbiased gradient estimates for discrete latent variable models. In NIPS (pp. 1–17).
- 5 Kohn, A., & Smith, M. A. (2016). Utah array extracellular recordings of spontaneous and visually evoked activity from anesthetized macaque primary visual cortex (v1) . CRCNS.org. [10.6080/K0NC5Z4X](https://doi.org/10.6080/K0NC5Z4X)
- 6 Smith, M. A., & Kohn, A. (2008). Spatial and temporal scales of neuronal correlation in primary visual cortex. *Journal of Neuroscience* , 28 (48), 12591–12603.
- 7 Molano-Mazon, M., Onken, A., Piasini, E., & Panzeri, S. (2018). Synthesizing realistic neural population activity patterns using Generative Adversarial Networks. *ICLR*

©(2019) Ramesh P, Atayi M, Macke JH

Cite as: Ramesh P, Atayi M, Macke JH (2019) Adversarial Training of Neural Encoding Models on Population Spike Trains. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0061](https://doi.org/10.12751/nncn.bc2019.0061)

[W 44] Amortised inference for mechanistic models of neural dynamics

Jan-Matthis Lueckmann^{1,2}, Pedro J. Goncalves^{1,2}, Chaitanya Chintaluri³, William F. Podlaski³, Giacomo Bassetto^{1,2}, Tim P. Vogels³, Jakob H. Macke^{1,2}

1. Computational Neuroengineering, Technical University of Munich, Karlstr. 45, 80333 Munich, Germany

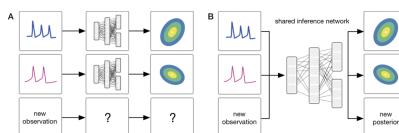
2. Max Planck Research Group Neural Systems Analysis, Center of Advanced European Studies and Research (caesar), Ludwig-Erhard-Allee 2, 53175 Bonn, Germany

3. Centre for Neural Circuits and Behaviour, University of Oxford, Mansfield Road, Oxford, OX1 3SR, England

Bayesian statistical inference provides a principled framework for linking mechanistic models of neural dynamics with empirical measurements. However, for many models of interest, in particular those relying on numerical simulations, statistical inference is difficult and requires bespoke and expensive inference algorithms. Furthermore, even within the same model class, each new measurement requires a full new inference – one can not leverage knowledge from past inferences to facilitate new ones. This limits the use of Bayesian inference in time-critical, large-scale, or fully-automated applications.

We overcome these limitations by presenting a method for statistical inference on simulation-based models which can be applied in a 'black box' manner to a wide range of models in neuroscience. The key idea is to generate a large number of simulations from the model of interest and use them to train a neural network to perform statistical inference. Once the network is trained, performing inference given any observed data is very fast, requiring only a single-forward pass through the network, i.e. inference is amortised.

We explain how our approach can be used to perform parameter-estimation, and illustrate it in the context of ion channel models. We train a network on a large diversity of simulated current responses to voltage-clamp protocols. After training, the network is able to instantaneously provide the posterior distribution over the channel model parameters given current responses from a publicly available database of ion channel models. The approach will enable neuroscientists to perform scalable Bayesian inference on large-scale data sets and complex models without having to design model-specific algorithms, closing the gap between mechanistic and statistical approaches to neural dynamics.



A. Classical approach: network for each observation. B. Amortised inference: shared network.

Acknowledgements

We are grateful for funding by the German Research Foundation (DFG) through SFB 1233 (276693517), SFB 1089 and SPP 2041, the German Federal Ministry of Education and Research (BMBF, project 'ADMIMEM', FKZ 01IS18052 A-D), and the Human Frontier Science Program (RGY0076/2018).

©(2019) Lueckmann J, Goncalves PJ, Chintaluri C, Podlaski WF, Bassetto G, Vogels TP, Macke JH

Cite as: Lueckmann J, Goncalves PJ, Chintaluri C, Podlaski WF, Bassetto G, Vogels TP, Macke JH (2019) Amortised inference for mechanistic models of neural dynamics. *Bernstein Conference 2019* Abstract.
doi: [10.12751/nncn.bc2019.0062](https://doi.org/10.12751/nncn.bc2019.0062)

[W 45] Amortized Variational Inference For Extracting Discrete Events From Imaging Data

Artur Speiser^{1,2}, Srinivas C. Turaga³, Jakob H. Macke^{1,2}

1. Computational Neuroengineering, Technical University of Munich, Karlstr. 45, 80333 München, Germany

2. Neural System Analysis, research center caesar, Ludwig-Erhard-Allee 2, 53175 Bonn, Germany

3. HHMI Janelia Research Campus, 19700 Helix Dr, Ashburn, VA 20147, USA

Modern imaging methods in neuroscience and biology often rely on algorithms for extracting variables of interest from the recorded raw data. A common problem is the spatial or temporal localization of discrete events from noisy observations, e.g. extracting spike timings from calcium imaging recordings or localizing particles for super resolution microscopy or particle tracking. We present a framework based on deep neural networks (DNN) for solving these kind of tasks with high accuracy and speed. In the scenarios we are interested in, ground truth data is often hard to obtain or completely unavailable, ruling out conventional approaches to training the DNN. However, we can instead utilize available biophysical models that describe how the discrete events lead to the observed measurements. The parameters of the network are adjusted together with the parameters of our biophysical model until the process of creating samples with our network and then applying the biophysical model to those samples recreates the observations accurately. To highlight the potential of this algorithmic approach we adapted our framework for two imaging methods, Two photon calcium imaging (2PCI) [1] and single molecule localization microscopy (SMLM) [2]. 2CPI is based on the fact that spiking activity in neurons leads to changes in intracellular calcium concentration which can be measured by fluorescence microscopy of calcium indicators. The data takes the form of fluorescence time series, or "traces". The variables we want to extract are the exact spike timings. To this end we use a simple biophysical model that describes how spiking activity produces the observed fluorescence. In the case of SMLM the data consists of 2D images of photon counts where the underlying latents are the activated fluorophores. The generative model describes the purely physical process of a point spread function that models the distribution of the number of photons that can be collected from a single photon emitter. Most algorithms that were developed for this

task process each image separately. We show that including information from other frames to account for the photo activation dynamics of the fluorophores results in a large increase of accuracy. In both applications inference amounts to simply applying the trained DNN to the observations without any need for iterative optimization or sampling, resulting in very short run times that would be compatible with real time applications.

Acknowledgements

This work was supported by the German Research Foundation (DFG) through SFB 1089, the German Federal Ministry of Education and Research (BMBF, project 'ADMIMEM', FKZ 01IS18052 A-D), and the Howard Hughes Medical Institute. A. Speiser was funded by an IMPRS for Brain & Behavior scholarship by the MPI

References

- 1 Fast amortized inference of neural activity from calcium imaging data with variational autoencoders
- 2 Teaching deep neural networks to localize sources in super-resolution microscopy by combining simulation-based learning and unsupervised learning

©(2019) Speiser A, Turaga SC, Macke JH

Cite as: Speiser A, Turaga SC, Macke JH (2019) Amortized Variational Inference For Extracting Discrete Events From Imaging Data. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0063](https://doi.org/10.12751/nncn.bc2019.0063)

[W 46] Assessing Global Shape Processing in Deep Convolutional Neural Networks using Mooney Face Images

Astrid Zeman¹, Tim Leers¹, Hans Op de Beeck¹

1. Brain and Cognition, KULeuven, Tiensestraat 102, Leuven 3000, Belgium

Deep Convolutional Neural Networks (DCNNs) are criticised for their reliance on local over global shape information processing. DCNNs display a preference for classifying visual objects using texture rather than borders or outlines, which differs from humans [1]. We test whether DCNNs are able to process global shape information in the absence of texture, using a large set of Mooney stimuli [2], which are face images thresholded to binary values. More specifically, we test whether DCNNs are able to perform perceptual completion, by assessing their ability to classify these abstract stimuli as face-like, and whether they exhibit the face inversion effect (FIE), where upright stimuli are classified positively at a higher rate compared to inverted stimuli.

We tested four top-performing object recognition networks and found that all are able to perform perceptual completion and all exhibit the FIE. Perceptual completion and the FIE decreases with network depth. We generated ROC curves of the best performing DCNN and found that the FIE is present over all levels of specificity. By matching the false positive rate of the DCNN to that of humans, we found that the network performed closer to the human average (85.73% for upright, 57.25% for inverted) for both conditions (60.12% for upright, 52.38% for inverted). Rank order correlation between the DCNN and humans shows a significant correlation in upright ($= 0.300$, $p < 0.0001$) and inverted ($= 0.269$, $p < 0.0001$) conditions, indicating a significant relationship in image difficulty between observers and the model. These results show that DCNNs exhibit both perceptual completion as well as the inversion effect for low information images of complex visual stimuli. We conclude that in spite of the texture bias of DCNNs, which makes their performance distinct from humans, they are still able to process object images holistically.

Acknowledgements

We thank Caspar Schwiedrzik for providing additional raw data and help in answering questions regarding his study [2]. This work was funded by grant C14/16/031 of the KULeuven Research Council.

References

- 1 Geirhos R, Rubisch P, Michaelis C, Bethge M, Wichmann FA, Brendel W (2019) ImageNet-trained CNNs are biased towards texture; increasing shape bias improves accuracy and robustness. International Conference on Learning Representations (ICLR).
- 2 Schwiedrzik CM, Melloni L, Schurger A (2018) Mooney face stimuli for visual perception research. PLoS ONE 13(7): e0200106. [10.1371/journal.pone.0200106](https://doi.org/10.1371/journal.pone.0200106)

©(2019) Zeman A, Leers T, Op de Beeck H

Cite as: Zeman A, Leers T, Op de Beeck H (2019) Assessing Global Shape Processing in Deep Convolutional Neural Networks using Mooney Face Images. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0064](https://doi.org/10.12751/nncn.bc2019.0064)

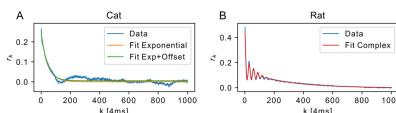
[W 47] A Toolbox for Inferring Dynamical Properties of Subsampled Networks

F. Paul Spitzner¹, Jonas Dehning¹, Jens Wilting¹, Viola Priesemann¹

1. Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany

Inferring system-wide dynamic properties when only observing a small subsystem remains a challenge in neuroscience: Even today, the most advanced millisecond-precision electrode measurements can only record a few hundred neurons out of millions. One dynamical property whose assessment is particularly biased by subsampling is the stability of a complex system. In case of neural networks, the collective stability depends on the average activity propagated by every single neuron. This can be well described by the branching parameter m , the average number of postsynaptic spikes triggered per presynaptic spike. This parameter serves not only as a proxy for activity propagation, but for the collective characteristic timescale, responses to stimuli, the fraction of recurrent activation and Fano factors. We have recently shown that conventional estimation of the branching parameter via linear regression can be severely biased under subsampling. This implies, for instance, that even small stimuli can lead to a much larger response than anticipated. To compensate the subsampling bias, we introduced a new multi-step regression (MR) estimator [1].

Here, we present Mr. Estimator, our lightweight open-source toolbox [2] that automates the multi-step regression; it provides the bias-corrected branching parameter and autocorrelation time. The toolbox supports a trial structure, offers built-in error estimation via bootstrap resampling and includes different methods for dealing with typical experimental conditions such as limited recording length. The underlying fit routines use physically motivated parameters that have been tried and tested. All functionality is wrapped in a well-documented interface that can produce publication-ready figures without the need for heavy coding — low-level customizations are possible but completely optional.



Toolbox applied to in vivo data. A: Primary visual cortex of anesthetized cat [3]. B: Right dorsal hippocampus of awake rat during open field task [4]. Our "complex" fit function contains an exponential and an oscillatory term that captures the prominent theta oscillations (fit result: 8.4 Hz).

References

1. J. Wilting and V. Priesemann, "Inferring collective dynamical states from widely unobserved systems", *Nat. Commun.* 9, 2325 (2018). [10.1038/s41467-018-04725-4](https://doi.org/10.1038/s41467-018-04725-4)
2. The toolbox is available online
3. T. Blanche, "Multi-neuron recordings in primary visual cortex", CRCNS.org, (2009). [10.6080/K0MW2F2J](https://doi.org/10.6080/K0MW2F2J)
4. K. Mizuseki, A. Sirota, E. Pastalkova, and G. Buzsaki, "Multi-unit recordings from the rat hippocampus made during open field foraging", CRCNS.org, (2009). [10.6080/K0Z60KZ9](https://doi.org/10.6080/K0Z60KZ9)

©(2019) Spitzner FP, Dehning J, Wilting J, Priesemann V

Cite as: Spitzner FP, Dehning J, Wilting J, Priesemann V (2019) A Toolbox for Inferring Dynamical Properties of Subsampled Networks. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0065](https://doi.org/10.12751/nncn.bc2019.0065)

[W 48] Bootstrapping strategies for assessing the dispersion of signal parameters in magnetoencephalography

Cezary Sielużycki¹, Artur Matysiak², Reinhard König², D. Robert Iskander¹

1. Department of Biomedical Engineering, Wrocław University of Science and Technology, Wyb. Wyspińskiego 27, 50-370 Wrocław, Poland
2. Special Lab Non-invasive Brain Imaging, Leibniz Institute for Neurobiology, Brennekestr. 6, 39118 Magdeburg, Germany

We examine the dependence of the dispersion of parameter estimates of the auditory M100 waveform acquired with magnetoencephalography (MEG) on the particular type of surrogate data generation. The MEG recording was from an auditory experiment in which a healthy subject was exposed to 500ms-long 1kHz acoustic stimuli. The stimulus onset interval between two consecutive tones was 2s and data were acquired with a 1017Hz sampling frequency. 20 out of 190 artefact-free trials were selected. A single channel with a large M100 peak amplitude is chosen. The peak amplitude and its latency are estimated. Since for MEG evoked responses a model-based approach incorporating the signal-plus-noise model does not yield residuals that are independent and identically distributed in time, we generate surrogate data composed of a sum of the signal model and a new residual that is resampled using phase spectral domain. Generation of surrogate data with non-parametric bootstrapping is contrasted with those based on uniformly distributed phase and permutation of the original phase. 1000 independent Monte Carlo replications were considered for all three strategies, each replication having 1000 surrogate realisations. This leads to the ability to estimate the distribution of not only the signal parameter estimates but also the distributions of their variances. The findings show that the non-parametric bootstrapping results in the smallest mean variance in peak amplitude estimates compared to the other two strategies (2613fT vs 3220fT and 3095fT). In terms of the estimates of the latency, similar mean variance results were obtained for all three strategies (29ms, 32ms, 31ms). The Friedman test showed statistically significant differences in variance of the estimates between the three

strategies for both peak amplitude and its latency ($\text{Chi}^2=1589$, $p=0$ and $\text{Chi}^2=994$, $p=0$, respectively). Subsequent post-hoc pairwise analyses with the Wilcoxon signed rank test showed statistically significant differences in all comparisons for the peak amplitude (all $p=0$), whereas for the latency, $p=0.094$ was achieved in the uniform sampling vs permuting comparison, and $p=0$ for the other two pairwise comparisons. The results indicate that for the considered data set, bootstrapping is superior, compared to the other two strategies of surrogate data generation. In conclusion, the choice of the method for generating such data is not obvious and may be application dependent.

Acknowledgements

The work of C. Sielużycki has received funding from the EU Horizon 2020 Research and Innovation Programme, Marie Skłodowska-Curie grant, no. 665778, National Science Centre, Poland, POLONEZ 2 Programme, 2016/21/P/ST7/03929. Authors acknowledge support by the DAAD PPP, 2018–2019, no 573 935 44.

©(2019) Sielużycki C, Matysiak A, König R, Iskander DR

Cite as: Sielużycki C, Matysiak A, König R, Iskander DR (2019) Bootstrapping strategies for assessing the dispersion of signal parameters in magnetoencephalography. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0066](https://doi.org/10.12751/nncn.bc2019.0066)

[W 49] Characterizing information processing of parietal cortex projections using vine copulas

Houman Safaai^{1,2}, Alice Wang¹, Stefano Panzeri², Christopher D. Harvey¹

1. Department of Neurobiology, Harvard Medical School, Boston, Massachusetts 02115, USA

2. Istituto Italiano di Tecnologia, 38068 Rovereto, Italy

A central focus of systems neuroscience is to relate neural activity to parameters of the sensory world, internal processing, and behavioral outputs. In complex and naturalistic tasks, behavioral and experimental variables can have complex statistical dependencies that make it difficult to isolate the relationships between neural activity and a specific variable of interest. With increasing complexity of experimental paradigms, a critical need has emerged for better analytical tools to probe neural activity's relationship to task and stimulus variables and to probe relationships within high dimensional activity and behavioral dimensions. Here we present an empirical probabilistic approach to probe the relationship between neural activity and behavior and experiment variables during a navigation-based decision-making task. Our approach is based on modelling neural activity using nonparametric vine copulas. We estimate the density function between neural activity and all measured task variables and use the estimated high dimensional density function to infer the information content of neural representations [1]. We tested our model on data collected from a novel navigation-based delayed match-to-sample task that allowed us to separate sensory- and motor-related activity patterns. Using two-photon calcium imaging methods, we analyzed the activity patterns during this task from posterior parietal cortex (PPC) neurons of mice. We also used retrograde labelling techniques to identify neurons with specific axonal projection patterns. PPC neurons were labeled based on their projections to anterior cingulate cortex, retrosplenial cortex, and contralateral PPC. We used vine copulas to quantify the information encoded in the neural activity of these groups of neurons relating to visual cues, movement patterns, locomotor choices, and mixing of task components. We studied differences and similarities between the information processing in neurons with different projection targets to understand whether PPC transmits information uniformly to its targets or specifically routes different types of information to distinct targets. Moreover, modelling

the noise correlation between pairs of neurons using copulas, we quantified the amount of information encoded in the interactions between different types of neurons with different projection targets and showed differences in how population interactions contribute to the information transmission to different projection targets.

Acknowledgements

This research was supported by the NIH BRAIN Initiative R01 NS108410, NINDS R01 NS089521, and NIMH R01 MH107620.

References

- 1 H Safaai, A Onken, CD Harvey, S Panzeri - Physical Review E, 2018 [10.1103/PhysRevE.98.053302](https://doi.org/10.1103/PhysRevE.98.053302)

©(2019) Safaai H, Wang A, Panzeri S, Harvey CD

Cite as: Safaai H, Wang A, Panzeri S, Harvey CD (2019) Characterizing information processing of parietal cortex projections using vine copulas. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0067](https://doi.org/10.12751/nncn.bc2019.0067)

[W 50] Detection and Removal of Artefacts in Multi-Channel Electrophysiology Recordings

Simon Essink^{1,2}, Alexander Kleinjohann^{1,2}, Frédéric Barthélémy^{1,3}, Junji Ito¹, Alexa Riehle^{1,3}, Thomas Brochier³, Sonja Grün^{1,2}

1. Institute of Neuroscience and Medicine (INM-6), Institute for Advanced Simulation (IAS-6) and JARA Brain Institute I (INM-10), Jülich Research Centre, Jülich, Germany

2. Theoretical Systems Neurobiology, RWTH Aachen University, Aachen, Germany

3. Institute of Neuroscience of la Timone (INT), CNRS - Aix Marseille University, Marseille, France

Modern electrophysiological experiments using multi-electrode arrays enable simultaneous access to the spiking activity of more than one hundred single neurons. However, these recordings reveal types of artefacts that have likely been overseen in conventional recordings with a small number of electrodes. One signature of such artefacts are hyper-synchronous putative spikes at sampling rate precision (synchrofacts [1]), sometimes involving a large number of channels, which are unlikely to represent neuronal activity. Detection and removal of synchrofacts can be performed on the spike-sorted data [2], but here we examine the raw signals for signatures of synchrofacts, aiming at artefact removal on these signals before spike-sorting. We currently explore datasets from a visuo-motor tracking experiment in monkeys [3] with four Utah arrays of 36 electrodes each inserted in V1, V2, DP and area 7A, and one array of 100 electrodes in M1/PMd. These recordings provide 224 active channels of raw signals (sampled at 30 kHz, filtered between 0.3 and 7500 Hz) from which we extract putative spikes by thresholding the high pass filtered (>250 Hz) raw signal. Signals passing the threshold are then spike-sorted into the activity of (multiple) single neurons recorded on each channel (200 single units in total). We searched for causes of the synchrofacts in the raw data in two ways: 1.) based on pairwise correlation analysis of any two channels, and 2.) based on the channel-averaged signal. The correlation-based analysis revealed that about 10% of channels show high pairwise correlations across frequency bands which directly cause synchrofacts. Furthermore, groups of channels are correlated in narrow frequency bands. The analysis of the channel-averaged signal showed low amplitude negative deflections at synchrofact times. The distribution of widths of these deflections is bi-modal indicating two distinct sources. We are able to suppress 2/3 of the synchrofacts in the data by removing cross-talking channels and the negative deflections from the raw signals. Remaining synchrofacts might be related to narrow-band oscillations, which we aim

to remove by using the Joint Decorrelation method [4]. As the detection of artefacts can be performed on the raw signals, we propose to clean the data before spike-sorting. We plan to integrate this procedure in a standardized and reproducible pre-processing workflow and compare the results of spike-sorting based on raw versus cleaned data.

Acknowledgements

We thank Bejamin Dann for valuable discussions. This project has received funding from Associated International Laboratory (LIA) between Research Center Jülich and INT, RTG2416 MultiSenses-MultiScales (Deutsche Forschungsgemeinschaft) and EU Grant 785907 (HBP).

References

- 1 Sprenger, J. Spatial Dependence of the Spike-Related Component of the Local Field Potential in Motor Cortex (Master's thesis, RWTH Aachen) (2014).
- 2 Torre et al. Synchronous Spike Patterns in Macaque Motor Cortex during an Instructed-Delay Reach-to-Grasp Task. *J. Neurosci.* 36(32):8329-8340 (2016). [10.1523/JNEUROSCI.4375-15.2016](https://doi.org/10.1523/JNEUROSCI.4375-15.2016)
- 3 de Haan, M. J., Brochier, T., Grün, S., Riehle, A. & Barthélémy, F. V. Real-time visuomotor behavior and electrophysiology recording setup for use with humans and monkeys. *J. Neurophysiol.* 120, 539–552 (2018). [10.1152/jn.00262.2017](https://doi.org/10.1152/jn.00262.2017)
- 4 de Cheveigné A, Parra LC. Joint decorrelation, a versatile tool for multichannel data analysis. *Neuroimage* 98:487-505 (2014). [10.1016/j.neuroimage.2014.05.068](https://doi.org/10.1016/j.neuroimage.2014.05.068)

©(2019) Essink S, Kleinjohann A, Barthélémy F, Ito J, Riehle A, Brochier T, Grün S

Cite as: Essink S, Kleinjohann A, Barthélémy F, Ito J, Riehle A, Brochier T, Grün S (2019) Detection and Removal of Artefacts in Multi-Channel Electrophysiology Recordings. *Bernstein Conference 2019* Abstract.
doi: [10.12751/ncnc.bn2019.0068](https://doi.org/10.12751/ncnc.bn2019.0068)

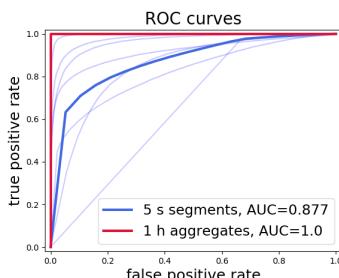
[W 51] Epileptogenesis prediction with deep neural networks

Diyuan Lu¹, Sebastian Bauer², Valentin Neubert³, Lara Sophie Costard^{2,4}, Felix Rosenow², Jochen Triesch¹

1. Frankfurt Institute for Advanced Studies, Goethe University, Ruth-Moufang Str. 1, Germany
2. Neurology and Epilepsy Center Frankfurt Rhine-Main, University Hospital Goethe-University, Schleusenweg 2-16 (Haus 95), Germany
3. Universitätsmedizin Rostock, Oscar-Langendorff-Institut für Physiologie, Gertrudenstraße 9, Germany
4. Tissue Engineering Research Group, Royal College of Surgeons Ireland, St Stephens Green 123 Dublin, D02, Ireland

Epilepsy is one of the most common neurological disorders. It is characterized by recurrent spontaneous seizures due to abnormally excessive or synchronized brain activity. Epileptogenesis (EPG) is the gradual process through which a brain develops epilepsy. This process often comprises a seizure-free latent period, which can last from weeks to years. Early diagnosis of EPG during this latent period might allow interventions delaying or even preventing the manifestation of epilepsy. Here we test the potential of deep neural networks (DNNs) to detect EPG in a rodent model of epilepsy. DNNs have recently obtained impressive results in various biomedical applications [1-3], suggesting them as a promising approach for EPG prediction. We used the temporal lobe epilepsy model proposed by Nordwood et al. [4]. Epilepsy was induced in seven rats by perforant pathway stimulation (PPS) and manifested after a latent period lasting between 9 and 51 days. We recorded intracranial electroencephalography (EEG) from the hippocampal granule cell layer. To detect EPG, we implemented a 34-layer residual convolutional neural network. The network was trained to distinguish five-second segments of raw EEG data from the pre-PPS vs. the EPG period. Training on raw EEG allowed the network to extract informative features in an unbiased fashion. To our knowledge, this is the first attempt to perform EPG prediction using DNNs trained on raw EEG data. We performed seven-fold leave-one-out cross-validation (LOO-CV) and report performance for the

classification of individual five second segments and after aggregating classification results from one hour through majority voting. The area under the curve (AUC) of the receiver operating characteristic (ROC) curve is shown in Fig. 1. Our network achieves 72% sensitivity and 92% specificity at the individual segment level and 100% sensitivity and 100% specificity after aggregation over one hour (see Fig. 1). Analysis of the learned features reveals that EPG is characterized by a reduction in theta band activity and an increase in delta band activity, spikes, and sharp waves, in line with recent experimental findings [5, 6, 7, 8]. Overall, our results demonstrate that DNNs can learn discriminative features for reliable EPG prediction in a rodent model of epilepsy. Future work should address to what extent these findings can be generalized to human EPG.



Result of epileptogenesis prediction. Individual (thin blue) and averaged (thick blue) ROC curves in 5 second segments classification in 7-fold LOO-CV. average ROC curve resulting from aggregating decisions from a continuous stretch of one hour of data through a majority vote.

Acknowledgements

This work is supported by the Chinese Scholarship Council (CSC), the Center for Personalized Translational Epilepsy Research (CePTER), and the Johanna Quandt Foundation.

References

- 1 Bi, X. and Wang, H., 2019. Early alzheimer's disease diagnosis based on EEG spectral images using deep learning. *Neural Networks*. [10.1016/j.neunet.2019.02.005](https://doi.org/10.1016/j.neunet.2019.02.005)
- 2 Hannun, A.Y., Rajpurkar, P., Haghpanahi, M., Tison, G.H., Bourn, C., Turakhia, M.P. and Ng, A.Y., 2019. Cardiologist-level arrhythmia detection and classification in ambulatory electrocardiograms using a deep neural network. *Nature medicine*, 25(1), p.65. [10.1038/s41591-018-0268-3](https://doi.org/10.1038/s41591-018-0268-3)
- 3 Kiral-Kornek, I., Roy, S., Nurse, E., Mashford, B., Karoly, P., Carroll, T., Payne, D., Saha, S., Baldassano, S., O'Brien, T. and Grayden, D., 2018. Epileptic seizure prediction using big data and deep learning: toward a mobile system. *EBioMedicine*, 27, pp.103-111. [10.1016/j.ebiom.2017.11.032](https://doi.org/10.1016/j.ebiom.2017.11.032)
- 4 Norwood, B.A., Bumanglag, A.V., Osculati, F., Sbarbati, A., Marzola, P., Nicolato, E., Fabene, P.F. and Sloviter, R.S., 2010. Classic hippocampal sclerosis and hippocampal-onset epilepsy produced by a single "cryptic" episode of focal hippocampal excitation in awake rats. *Journal of Comparative* [10.1002/cne.22406](https://doi.org/10.1002/cne.22406)
- 5 Douw, L., van Dellen, E., de Groot, M., Heimans, J.J., Klein, M., Stam, C.J. and Reijneveld, J.C., 2010. Epilepsy is related to theta band brain connectivity and network topology in brain tumor patients. *BMC neuroscience*, 11(1), p.103. [10.1186/1471-2202-11-103](https://doi.org/10.1186/1471-2202-11-103)
- 6 Amilhon, B., Huh, C.Y., Manseau, F., Ducharme, G., Nichol, H., Adamantidis, A. and Williams, S., 2015. Parvalbumin interneurons of hippocampus tune population activity at theta frequency. *Neuron*, 86(5), pp.1277-1289. [10.1016/j.neuron.2015.05.027](https://doi.org/10.1016/j.neuron.2015.05.027)
- 7 Staley, K.J. and Dudek, F.E., 2006. Interictal spikes and epileptogenesis. *Epilepsy Currents*, 6(6), pp.199-202. [10.1111/j.1535-7511.2006.00145.x](https://doi.org/10.1111/j.1535-7511.2006.00145.x)
- 8 Milikovsky, D.Z., Weissberg, I., Kamintsky, L., Lippmann, K., Schefenbauer, O., Frigerio, F., Rizzi, M., Sheintuch, L., Zelig, D., Ofer, J. and Vezzani, A., 2017. Electrocorticographic dynamics as a novel biomarker in five models of epileptogenesis. *Journal of Neuroscience*, 37(17), pp.4450-4461 [10.1523/JNEUROSCI.2446-16.2017](https://doi.org/10.1523/JNEUROSCI.2446-16.2017)

[W 52] **Estimation of neural network model parameters from local field potentials (LFPs)**

Alexander J. Stasik^{1,2}, Espen Hagen^{1,2}, Jan-Eirik W. Skaar³, Torbjørn V. Ness³, Gaute T. Einevoll^{1,2,3}

1. Center for Integrative Neuroplasticity, University of Oslo, Norway

2. Department of Physics, University of Oslo, Norway

3. Faculty of Science and Technology, Norwegian University of Life Sciences, Ås, Norway

Most modeling in systems neuroscience has been descriptive where neural representations, that is, 'receptive fields', have been found by statistically correlating neural activity to sensory input. In the traditional physics approach to modelling, hypotheses are represented by mechanistic models based on the underlying building blocks of the system, and candidate models are validated by comparing with experiments. Until now validation of mechanistic cortical network models has been based on comparison with neuronal spikes, found from the high-frequency part of extracellular electrical potentials. In this computational study we investigated to what extent the low-frequency part of the signal, the local field potential (LFP), can be used to infer properties of the neuronal network. In particular, we asked the question whether the LFP can be used to accurately estimate synaptic connection weights in the underlying network. We considered the thoroughly analysed Brunel network comprising an excitatory and an inhibitory population of recurrently connected integrate-and-fire (LIF) neurons. This model exhibits a high diversity of spiking network dynamics depending on the values of only three synaptic weight parameters. The LFP generated by the network was computed using a hybrid scheme where spikes computed from the point-neuron network were replayed on biophysically detailed multicompartmental neurons. We assessed how accurately the three model parameters could be estimated from power spectra of stationary 'background' LFP signals by application of convolutional neural nets (CNNs). All network parameters could be very accurately estimated, suggesting that LFPs indeed can be used for network model validation.

©(2019) Stasik AJ, Hagen E, Skaar JW, Ness TV, Einevoll GT

Cite as: Stasik AJ, Hagen E, Skaar JW, Ness TV, Einevoll GT (2019) Estimation of neural network model parameters from local field potentials (LFPs). Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0070](https://doi.org/10.12751/nncn.bc2019.0070)

[W 53] Frequency Domain Spatiotemporal Pattern Separation of Local Field Potential

Weiwei Chen¹, Anton Sirota¹

1. Department Biology II, Ludwig-Maximilians-Universität München, Großhaderner Straße 2 82152 Planegg-Martinsried, Germany

LFP signal reflects a mix of network dynamics and synaptic inputs from other areas. Once proper decomposition of different afferent sources and forward models of the LFP have been established, model inversion can be employed to infer the dynamics of local and upstream networks. However, robustly disentangling different sources remain challenging (Einevoll et al, 2013) due to violation of the independence assumption as multiple synaptic inputs emerge from generally correlated and non-sparse dynamics, and b) the over-complete ICA problems.

The Cable equation describes spatio-temporal evolution of membrane potential, providing the fundamental basis for non-linear mixing of incoming synaptic inputs in space and time. By reducing the complex nonlinear cable equation, we obtained a simplified linear model of the LFP signal, which could be solved as a linear system with an analytical input response pattern in the frequency domain. This model captures the main aspects of the cable equation mixing and linear spatial mixing process due to volume conduction. Based on this, we extend the Green's function based inference method (Gratiy et al, 2011) and used it to guide the frequency domain independent components analysis.

We then tested the performance of this method on simulated LFP data generated by two spatially overlapping and temporally correlated inputs. The frequency domain components match the input response patterns of forward-modeling, recovering the spatial amplitude structure and phase shift produced by neuronal cable. We proved that under the condition of high coherence in the lower frequency, our model still closely recovered true afferent inputs, while conventional ICA approach results in incompletely unmixed and temporally filtered activity. By inverting the Green's function, we recover the input current distribution from each pathway, respectively. We also tested our model on real LFP data from hippocampal recording and proved its advantage in transient population events detection.

Biophysical modeling of the LFP signal in the frequency domain enhances blind source separation by guiding the algorithm to find a biological proper pattern, therefore, improves the interpretability of such decomposition analysis.

References

- 1 Einevoll, G. T., Kayser, C., Logothetis, N. K., & Panzeri, S. (2013). Modelling and analysis of local field potentials for studying the function of cortical circuits. *Nature Reviews Neuroscience*, 14(11), 770. [10.1038/nrn3599](https://doi.org/10.1038/nrn3599)
- 2 Gratiy, S. L., Devor, A., Einevoll, G. T., & Dale, A. M. (2011). On the estimation of population-specific synaptic currents from laminar multielectrode recordings. *Frontiers in neuroinformatics*, 5, 32. [10.3389/fninf.2011.00032](https://doi.org/10.3389/fninf.2011.00032)

©(2019) Chen W, Sirota A

Cite as: Chen W, Sirota A (2019) Frequency Domain Spatiotemporal Pattern Separation of Local Field Potential. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0071](https://doi.org/10.12751/nncn.bc2019.0071)

[W 54] Inferring the parameters of neural simulations from high-dimensional observations

Marcel Nonnenmacher¹, Jan-Matthis Lueckmann¹, Giacomo Bassetto^{1,2}, Pedro J Goncalves^{1,2}, Jakob H Macke^{1,2}

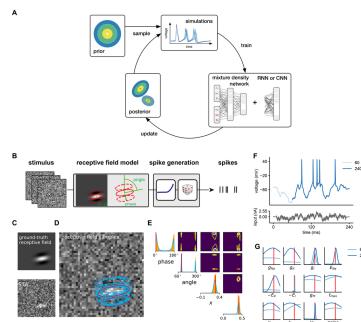
1. Computational Neuroengineering, Technical University of Munich, Munich, Germany

2. Max Planck Research Group Neural Systems Analysis, Center of Advanced European Studies and Research (caesar), Bonn, Germany

Many models in neuroscience, such as networks of spiking neurons or complex biophysical models, are defined as numerical simulators. This means one can simulate data from the model, but calculating the likelihoods associated with specific observations is hard or intractable, which in turn makes statistical inference challenging. So-called Approximate Bayesian Computation (ABC) aims to make Bayesian inference possible for likelihood-free models [1,2]. However, standard ABC algorithms do not scale to high-dimensional observations, e.g. inference of receptive fields from high-dimensional stimuli.

Here, we develop an approach to likelihood-free inference for high-dimensional data, where we train a neural network to perform statistical inference given adaptively simulated data sets. The network is composed of layers performing non-linear feature extraction, and fully connected layers for non-linear density estimation. Feature extraction layers are either convolutional or recurrent in structure, depending on whether the data is high-dimensional in space or time, respectively (panel A). This approach makes it possible to scale ABC to problems with high-dimensional inputs.

We illustrate this method in two canonical examples in neuroscience. First, we infer receptive field parameters of a V1 simple cell model from neural activity resulting from white-noise stimulation, a high-dimensional stimulus in the space domain (panels B-E). Second, we perform Bayesian inference on a Hodgkin-Huxley model of a single neuron [3], given full voltage traces resulting from intracellular current stimulation (panels F-G). On both applications, we retrieve the posterior distribution over the parameters, i.e. the manifold of parameters for which the model exhibits the same behaviour as the observations (panels E, G). Our approach will allow neuroscientists to leverage the power of deep neural networks to link high-dimensional data to complex simulations of neural dynamics.



A. Algorithm. B. Neuron model. C. Spike-triggered average. D. Posterior samples from estimated posterior (blue) and ground-truth receptive field (red). E. Inferred marginals for 4 parameters of the spatial filter. F. Hodgkin-Huxley model. G. Inferred posterior marginals for 240ms and 60ms traces.

References

- 1 Papamakarios, and Murray (2016). Fast ϵ -free Inference of Simulation Models with Bayesian Conditional Density Estimation. NeurIPS.
- 2 Lueckmann, Goncalves, Bassetto, Ocal, Nonnenmacher, and Macke (2017). Flexible statistical inference for mechanistic models of neural dynamics. NeurIPS.
- 3 Pospischil, Toledo-Rodriguez, Monier, Piwkowska, Bal, Fregnac, Markram, Destexhe (2008) Minimal Hodgkin-Huxley type models for different classes of cortical and thalamic neurons. Biol Cybern. [10.1007/s00422-008-0263-8](https://doi.org/10.1007/s00422-008-0263-8)

©(2019) Nonnenmacher M, Lueckmann J, Bassetto G, Goncalves PJ, Macke JH

Cite as: Nonnenmacher M, Lueckmann J, Bassetto G, Goncalves PJ, Macke JH (2019) Inferring the parameters of neural simulations from high-dimensional observations. Bernstein Conference 2019 Abstract.
doi: [10.12751/nncn.bc2019.0072](https://doi.org/10.12751/nncn.bc2019.0072)

[W 55] Knowledge transfer in coupled predictive coding networks

André Ofner¹, Sebastian Stober²

1. University of Potsdam, Potsdam, Germany

2. Otto von Guericke University, Magdeburg, Germany

Predictive coding offers a comprehensive explanation of human brain function through prediction error minimisation [1]. This idea has found traction in machine learning, where deterministic and stochastic inference allow efficient representation of sensory signals [2]. Recently, these artificial predictive coding networks have been coupled with the brain as its natural counterpart to develop co-adaptive brain-computer interfaces based on predictive coding as a shared principle [3].

However, it remains unclear how differences in prior knowledge affect information transfer between the coupled predictive coding networks. To address this question, this study introduces a sequential and hierarchical stochastic predictive coding model where predictions about future sensory states are conditioned on past states and top-down predictive signal for each layer.

Using synthetic visual stimuli, we demonstrate the model's capacity to incorporate knowledge from a coupled network by comparing the generated prediction error signature with the corresponding stimulus. Our results show that information from the coupled network aids the functional differentiation and can be used to encode aspects of the stimuli that are not visible to the model itself.

References

- 1 R. P. N. Rao and D. H. Ballard. Predictive coding in the visual cortex: a functional interpretation of some extra-classical receptive-field effects. Nature Neuroscience, 1999. [10.1038/4580](https://doi.org/10.1038/4580)
- 2 W. Lotter, G. Kreiman, and D. Cox. "Deep predictive coding networks for video prediction and unsupervised learning". In: arXiv preprint arXiv:1605.08104 (2016).
- 3 André Ofner & Sebastian Stober. Towards Bridging Human and Artificial Cognition: Hybrid Variational Predictive Coding of the Physical World, the Body and the Brain. In: NeurIPS 2018 Workshop on Modeling the Physical World, 2018.

©(2019) Ofner A, Stober S

Cite as: Ofner A, Stober S (2019) Knowledge transfer in coupled predictive coding networks. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0073](https://doi.org/10.12751/nncn.bc2019.0073)

[W 56] **Learning divisive normalization in primary visual cortex**

Max F. Günthner¹, Santiago A. Cadena^{1,2,3}, George H. Denfield^{3,4}, Edgar Y. Walker^{3,4}, Leon A. Gatys^{1,2}, Andreas S. Tolias^{2,3,4,5,6}, Matthias Bethge^{1,2,3,6}, Alexander S. Ecker^{1,2,3,6}

1. *Institute for Theoretical Physics and Werner Reichardt Center for Integrative Neuroscience, University of Tübingen, Tübingen, Germany*

2. *Bernstein Center for Computational Neuroscience, Tübingen, Germany*

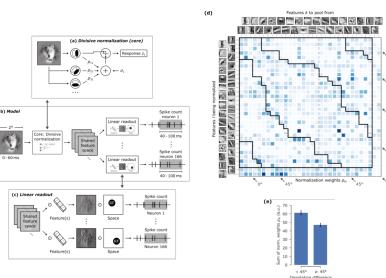
3. *Center for Neuroscience and Artificial Intelligence, Baylor College of Medicine, Houston, Texas, USA*

4. *Department of Neuroscience, Baylor College of Medicine, Houston, Texas, USA*

5. *Department of Electrical and Computer Engineering, Rice University, Houston, Texas, USA*

6. *These authors contributed equally.*

The data-driven state-of-the-art model for predicting single-unit monkey primary visual cortex (V1) responses to natural stimuli is a three-layer black-box convolutional neural network (CNN), outperforming classical linear-nonlinear and wavelet-based feature representations (Cadena et al., 2019). However, it is currently unknown what kind of nonlinear computations multilayer CNNs approximate, limiting our understanding of V1 function. A good candidate for such nonlinearities is divisive normalization (DN) (Fig. 1a; Heeger, 1992), which has been suggested as a canonical computation implemented throughout the neocortex. In primary visual cortex (V1), DN was found to be crucial to explain nonlinear response properties of neurons when presented with superpositions of simple stimuli such as gratings. (Heeger, 1992; Carandini & Heeger, 2012). Based on such studies, it is currently assumed that neuronal responses to stimuli restricted to the neuron's classical receptive field (RF) are normalized by a non-specific pool of nearby neurons with similar RF locations (Heeger, 1992; Busse et al., 2009). However, it is currently unknown whether DN operates in V1 when processing natural inputs and, if so, which nearby neurons contribute to any given neuron's normalization pool and with what weight. Here, we investigated DN in monkey V1 under stimulation with natural images with an end-to-end trainable model that learns the pool of normalizing neurons and the magnitude of their contribution directly from the data (Fig. 1a,b,c). Our model saves over 70% of the parameters compared to current state-of-the-art black-box models while maintaining a competitive accuracy of 48.5% fraction of explainable variance explained (FEV) compared to 49.8% FEV for the state-of-the-art (Cadena et al., 2019). This suggests that rectification, DN, and a combination of subunits resulting from DN are sufficient to account for V1 responses to localized stimuli. Taking advantage of our model's direct interpretable view of V1 computation, we found that oriented features were normalized preferentially by features with similar orientation preference rather than non-specifically (Fig. 1d,e).



(a) Divisive normalization (DN), (b) model incl. 32 DN mechanisms, (c) linear factorized readout, (d) normalization weights (blue squares) and learned features, lines: 45 deg orientation difference, (e) sum of normalization weights averaged across models (difference stat. significant, $p < 1.1 \times 10^{-7}$).

Acknowledgements

We thank Fabian H. Sinz and David Klindt for valuable discussions.

References

- 1 Busse, L., Wade, A. R., & Carandini, M. (2009). Representation of Concurrent Stimuli by Population Activity in Visual Cortex. *Neuron*, 64(6), 931–942.
- 2 Cadena, S. A., Denfield, G. H., Walker, E. Y., Gatys, L. A., Tolias, A. S., Bethge, M., & Ecker, A. S. (2019). Deep convolutional models improve predictions of macaque V1 responses to natural images. *PLOS Computational Biology*, 15(4), e1006897.
- 3 Carandini, M., & Heeger, D. J. (2012). Normalization as a canonical neural computation. *Nature Reviews Neuroscience*, 13(1), 51–62.
- 4 Heeger, D. J. (1992). Normalization of cell responses in cat striate cortex. *Visual Neuroscience*, 9(2), 181–197.

©(2019) Günthner MF, Cadena SA, Denfield GH, Walker EY, Gatys LA, Tolias AS, Bethge M, Ecker AS

Cite as: Günthner MF, Cadena SA, Denfield GH, Walker EY, Gatys LA, Tolias AS, Bethge M, Ecker AS (2019) Learning divisive normalization in primary visual cortex. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0074](https://doi.org/10.12751/nncn.bc2019.0074)

[W 57] Lightweight tools for safe and efficient management, processing and validation of research data

Michael Sonntag¹, Achilleas Koutsou¹, Jiří Vaněk¹, Christian Kellner¹, Christian Garbers¹, Jan Grewe², Thomas Wachtler¹

1. German Neuroinformatics Node, Ludwig-Maximilians-Universität München, Martinsried, Germany

2. Institute for Neurobiology, Eberhard-Karls-Universität Tübingen, Tübingen, Germany

Maintaining reproducible analysis workflows while keeping data in sync, backed up, and easily accessible from within and outside the lab is a key challenge in research. To minimize time and effort scientists have to spend on these tasks, we provide a suite of tools and services designed for comprehensive, reproducible and versioned management of scientific data.

Efficient selection and analysis require that metadata providing information about experimental conditions is available. The odML[1] metadata format is an easy to use method to flexibly collect and organize any kind of metadata. It enables comprehensive collection and automated processing of metadata[2]. Additionally, pre-defined templates and terminologies are available from an online service that also features a forum for usage discussions and exchange of metadata templates within the scientific community.

To keep data and metadata organized, the NIX[3] data format enables effectively linking data and corresponding analysis results as well as the associated metadata. It supports a wide range of data types, including electrophysiology and imaging data. NIX embeds the odML metadata format and integrates with the Neo[4] Python package for electrophysiology, enabling Neo users to store their data in a common open format.

The GIN[5] services provide versioned data management and collaborative data sharing. Using well established version control systems [6,7], GIN keeps track of changes and provides secure access, making it convenient to work from multiple workplaces while keeping all data available and in sync. Data can be managed from web and file browsers or a command line client, enabling integration into data acquisition or analysis procedures. This also makes it straightforward to share data within a lab or with off-site collaborators and to work on it together. The GIN services also feature automated data validation for various data types including the BIDS[8], NIX and odML formats, validation of CSV tables based on goodtables[9] is under development.

The tools presented are easy to use, are compatible with other approaches supporting reproducibility and data sharing [10,11], and enable efficient data management that supports the FAIR principles [12]. Combining them for data annotation, organization, and storage allows streamlining data workflows and efficiently sharing datasets within the lab, among collaborators, or with the larger scientific community.

Acknowledgements

Supported by BMBF (Grants 01GQ1302 and 01GQ1509)

References

- 1 Grewe et al (2011). A bottom-up approach to data annotation in neurophysiology. *Front. Neuroinform.* 5:16 [10.3389/fninf.2011.00016](https://doi.org/10.3389/fninf.2011.00016)
- 2 Zehl et al (2016) Handling metadata in a neurophysiology laboratory. *Frontiers in Neuroinformatics* 10:26 [10.3389/fninf.2016.00026](https://doi.org/10.3389/fninf.2016.00026)
- 3 NIX (RRID:SCR_016196)
- 4 NEO (RRID:SCR_000634)
- 5 GIN (RRID:SCR_015864)
- 6 git
- 7 git-annex
- 8 BIDS (RRID:SCR_016124)
- 9 goodtables
- 10 Sumatra
- 11 Datalad
- 12 Mark D. Wilkinson et al (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data* volume 3, Article number: 160018 [10.1038/sdata.2016.18](https://doi.org/10.1038/sdata.2016.18)

©(2019) Sonntag M, Koutsou A, Vaněk J, Kellner C, Garbers C, Grewe J, Wachtler T

Cite as: Sonntag M, Koutsou A, Vaněk J, Kellner C, Garbers C, Grewe J, Wachtler T (2019) Lightweight tools for safe and efficient management, processing and validation of research data. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0075](https://doi.org/10.12751/nncn.bc2019.0075)

[W 58] Neural activity classification with machine learning models trained on interspike interval series data

Ivan Lazarevich^{1,2}, Ilya Prokin^{3,4}, Pavel Esir², Boris Gutkin^{1,5}

1. Group for Neural Theory, Laboratoire de neurosciences cognitives et computationnelles, École normale supérieure, Paris, France

2. Department of Neurotechnology, Lobachevsky State University, Nizhny Novgorod, Russia

3. Dataswati, Orsay, France

4. Sysmo, Puteaux, France

5. Center for Cognition and Decision Making, NRU Higher School of Economics, Moscow, Russia

The flow of information through the brain is reflected by the activity patterns of neural cells. Indeed, these firing patterns are widely used as input data to predictive models that relate stimuli and animal behavior to the activity of neural populations. In this work, we focus on the role of individual neural spike trains as predictors in neural decoding. We introduce an approach to neuronal spike train data mining which enables effective classification and clustering of neuron types and network activity states based on single-cell spiking patterns. This approach is centered around creating interpretable vector representations of interspike interval sequences and building machine learning models on these representations. Such methods significantly outperform simple benchmarks in both tasks involving classification of neuron type (e.g. different subtypes of inhibitory neurons in the prefrontal cortex) and neural circuit activity state (e.g. quiet wakefulness or sleep state of the animal) on open-access cortical spiking activity data. We also demonstrate that these methods perform on par with deep learning approaches (while being interpretable) on established decoding tasks involving data from somatosensory cortex and hippocampus [1]. Furthermore, the achieved high accuracy in classification tasks indicates that individual neurons carry a substantial amount of information about the global neural network state as well as the neuron subtype.

Acknowledgements

This work was supported by The Russian Science Foundation (Grant No. 18-11-00294).

References

- 1 Glaser, Joshua I., et al. "Machine learning for neural decoding." arXiv preprint arXiv:1708.00909 (2017).

©(2019) Lazarevich I, Prokin I, Esir P, Gutkin B

Cite as: Lazarevich I, Prokin I, Esir P, Gutkin B (2019) Neural activity classification with machine learning models trained on interspike interval series data. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0076](https://doi.org/10.12751/nncn.bc2019.0076)

Neurotechnology and brain-machine-interfaces

[W 60] Excitability of cortical neurons by electrical stimulation from the cortical surface

Pierre Berthet¹, Gaute T Einevoll^{1,2}, Torbjørn V Ness²

1. Department of Physics, University of Oslo, Oslo, Norway

2. Faculty of Science and Technology, Norwegian University of Life Sciences, Ås, Norway

The development of high-resolution, non-penetrating electrode arrays for direct electric stimulation of sensory cortex, such as the BISC (Bioelectronic Interfacing to Sensory Cortex) chip, has the potential to lead to neuroprosthetic devices that can benefit people with various neurological troubles [1]. In the context of visual neuroprosthetic devices, the ability to target particular groups of neurons to create specific sensory perceptions is important, but how electric fields generated with devices such as BISC can affect the activation of the neurons has so far not been investigated thoroughly. Here we present a comprehensive modelling study determining optimal stimuli patterns that aim to guide experimentalists and electrode manufacturers in the design of protocols and hardware. We combine biophysically detailed multicompartment models of cortical neurons and electrostatic volume-conductor theory to investigate the generation of neuronal action potentials (APs) by electrical stimulation as could be delivered by BISC-like chips [2]. We optimize the stimulation protocol for selective activation of specific cell populations, and investigate the limits of the spatial resolution that it is possible to achieve with high density current stimulation at the cortical surface.

We explore different biphasic pulse parameters, including amplitude, polarity, asymmetry, individual pulse duration, and intra-pulse interval, in order to generate optimal simulation patterns for different targets. These parameters are first thoroughly analysed with simplified models and then confirmed to also apply for biologically detailed models [3]. Our findings reveal that for the stimulation protocol, a relatively long and weak amplitude positive pulse followed by a shorter and stronger negative pulse had the lowest current threshold for evoking APs, which were typically evoked in the axon terminals of surface projecting axons (and subsequently activating the entire axonal structure). For the neurons, our results indicate that the position and direction of the axon is the most critical factor, with the axon pointing toward stimulating electrodes as the most sensitive instance.

Acknowledgements

This research has received funding from the Neural Engineering System Design (NESD) program from the Defense Advanced Research Projects Agency (DARPA) and from the European Union Horizon 2020 Framework Programme for Research and Innovation under Specific Grant Agreements No. 785907 (HBP SGA2).

References

- 1 Bosking, W. H., Beauchamp, M. S. & Yoshor, D. Electrical Stimulation of Visual Cortex: Relevance for the Development of Visual Cortical Prosthetics. *Annu. Rev. Vis. Sci.* 3, 141–166 (2017)
- 2 Hagen, E., Næss, S., Ness, T. V. & Einevoll, G. T. Multimodal Modeling of Neural Network Activity: Computing LFP, ECoG, EEG, and MEG Signals With LFPy 2.0. *Front. Neuroinform.* 12, (2018)
- 3 Hallermann, S., Kock, C. P. J. De, Stuart, G. J. & Kole, M. H. P. State and location dependence of action potential metabolic cost in cortical pyramidal neurons. *Nat. Neurosci.* 15, 1007–1014 (2012)

[W 61] Learning Based Eye Action Recognition Using Harmonic Filtered EEG Signals

Çağatay Demirel¹, Uğur Girgin², Hatice Köse¹

1. Computer Engineering Department, Istanbul Technical University, Istanbul Technical University, Faculty of Computer Science and Informatics, Maslak, Istanbul, 34469, Turkey

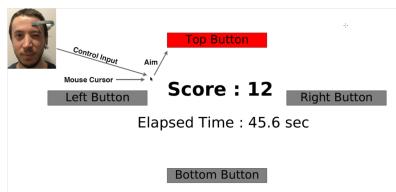
2. Faculty of Medicine, Bolu Abant Izzet Baysal University, Bolu Abant Izzet Baysal University Faculty of Medicine, 14030, Gölköy, Bolu, Turkey

It is known that extraocular muscle activity [1] is controlled by the prefrontal cortex [2]. These activities are observed significantly from FP1 and FP2 (Left and right frontal lobe) of brain sensor locations. The proposed system was created to navigate mouse cursor to left, right, up and down along with no action and clicking using only eye actions which are known as extraocular muscle movement.

At first, the dataset was created from 10 different subjects by recording raw EEG signals on FP1. Eye actions are left eye closed, right eye closed, angry facial expression, choked eyes, eyes blink and neutral glancing. Notch filter [3] and harmonic signals [4] were taken. Harmonic signals are known as decomposed from a percussive component of given signal in frequency domain to keep only energies of harmonic frequencies. Using harmonic filter in spectral-domain of EEG signals provided remarkably more information about eye actions in recorded EEG signals and it was found to be more effective rather than using only notch filtered raw data by comparing cross-validation results.

In the next step, various acoustic feature extraction algorithms were conducted to create handcrafted features from harmonic filtered EEG signals. There are 65 features were extracted from each windowed signal and 4 different classifiers which are Support Vector Machines (SVM), Linear Discriminant with Shrinkage (LDA), Randomized Trees and Artificial Neural Networks (ANN) were chosen to predict eye actions. All chosen algorithms were tried with different hyper-parameters and ANN selected as the best classifier using iterative hyperparameter selection algorithm [5]. 10-fold cross-validation score was found as 76.14 % for 6 classes.

The system was also tested in real-time with the graphical user interface (GUI) created using Python environment. There are 4 buttons are located near the edges of GUI panel and subjects were wanted to click a specific button that system chooses. All subjects were tested with the GUI for 5 minutes and their scores and elapsed time to reach their scores were recorded. Finally, all subjects were wanted to fill the survey and scored the efficiency, satisfying and convenience of the real-time system from range of 0 to 4. According to the real-time tests, the average productivity, satisfaction, and ease of use are indicated as 2.85, 3.02 and 2.78 respectively. Overall, positive correlation between GUI performance scores and questionnaire values is noteworthy.



Real Time Test GUI

Acknowledgements

We are thankful to our colleagues Murat Yalcin, Murat Bestami Kuyucak, Ugur Can Akkaya, Hasan Can Aydan and Mustafa Esengun who provided expertise that greatly assisted the research, moderated this paper and in that line improved the manuscript significantly.

References

- 1 J. D. Porter, R. S. Baker, R. J. et al., "Extraocular muscles: Basic and clinical aspects of structure and function" [10.1016/S0039-6257\(05\)80055-4](https://doi.org/10.1016/S0039-6257(05)80055-4)
- 2 C. Demirel, H. Kandemir and H. Köse, "Controlling a robot with extraocular muscles using EEG device," 2018 26th Signal Processing and Communications Applications Conference (SIU), Izmir, 2018, pp 1-4 [10.1109/SIU.2018.8404157](https://doi.org/10.1109/SIU.2018.8404157)
- 3 J. Chaochao, S. Yixin, Z. Huajun and L. Shilin, "Power System Frequency Estimation Based on Adaptive Notch Filter," 2016 International Conference on Industrial Informatics, Wuhan, 2016, pp. 191-194 [10.1109/ICIICI.2016.0054](https://doi.org/10.1109/ICIICI.2016.0054)
- 4 itzgerald, Derry. (2010). Harmonic/Percussive Separation using Median Filtering. 13th International Conference on Digital Audio Effects (DAFx-10).
- 5 S. S. Keerthi, "Efficient tuning of SVM hyperparameters using radius/margin bound and iterative algorithms," in IEEE Transactions on Neural Networks, vol. 13, no. 5, pp. 1225-1229, Sept. 2002. [10.1109/TNN.2002.1031955](https://doi.org/10.1109/TNN.2002.1031955)

©(2019) Demirel Ç, Girgin U, Köse H

Cite as: Demirel Ç, Girgin U, Köse H (2019) Learning Based Eye Action Recognition Using Harmonic Filtered EEG Signals. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0078](https://doi.org/10.12751/nncn.bc2019.0078)

Computational connectomics

[W 62] Bayesian inference for synaptic connectivity rules in anatomically realistic cortical connectomes

Jan Boelts¹, Philipp Harth², Felipe Yanez^{1,3}, Hans-Christian Hege², Marcel Oberlaender³, Jakob H. Macke¹

1. Department of Electrical and Computer Engineering, TU Munich, Munich, Germany

2. Department of Visual Data Analysis, Zuse Institute Berlin, Berlin, Germany

3. Max Planck Group: In Silico Brain Sciences, Center of Advanced European Studies and Research, Bonn, Germany

A key goal in connectomics research is to discover local synaptic connectivity rules which can explain the global organization of cortical circuits. Identifying and selecting such rules remains a challenging problem, as even advanced experimental techniques can only provide partial measurements of neural circuits. We approach identification and selection of synaptic connectivity rules as a Bayesian inference problem: Given partial measurements of structural features at different scales, we use Bayesian inference to identify which parameters of synaptic connectivity models are quantitatively consistent with experimental observations. One challenge of applying these approaches is the fact that the underlying models might not be tractable with conventional Bayesian approaches: In particular, when models are defined only indirectly through a complex simulator, or are constrained by aggregate data, it is often impossible to compute the likelihood $p(x|\theta)$ of the data x given model parameters θ . In contrast to classical likelihood-free approaches, recent advances based on conditional density estimation [1, 2, 3] can scale to high-dimensional observations. We use automatic posterior transformation (APT) [3] to estimate the posterior distribution of the parameters of hypothesized synaptic connectivity rules, given observed connectivity measurements. We illustrate the approach on a dense structural model of the rat barrel cortex. This model is based on anatomical measurements of geometry, soma distributions, and morphologies

[4]. We perform inference on a synaptic connectivity rule that predicts the presence of synapses based on pre- and postsynaptic target densities. In the tractable case of a small sub-volume with fully observed synapse counts the posterior is estimated accurately. When using only empirically measured connection probabilities the resulting posterior successfully reveals the underlying rule parameters and how they are constrained by the observed data. By scaling this inference to larger sub-volumes and by enabling the comparison of hypothesized synaptic connectivity rules, we will ultimately provide tools to relate structural features of neuronal networks to the underlying synaptic organization.

Acknowledgements

This work was supported by the German Research Foundation (DFG) through SPP 2041 Computational Connectomics and the German Federal Ministry of Education and Research (BMBF, project 'ADMIMEM', FKZ 01IS18052 A-D).

References

- 1 Papamakarios, G., & Murray, I. (2016). Fast -free inference of simulation models with Bayesian conditional density estimation. In Advances in Neural Information Processing Systems (pp. 1028-1036). [10.1109/ICML.2016.7530429](https://doi.org/10.1109/ICML.2016.7530429)
- 2 Lueckmann, J. M., Goncalves, P. J., Bassetto, G., Öcal, K., Nonnenmacher, M., & Macke, J. H. (2017). Flexible statistical inference for mechanistic models of neural dynamics. In Advances in Neural Information Processing Systems (pp. 1289-1299). [10.1109/ICML.2017.7955550](https://doi.org/10.1109/ICML.2017.7955550)
- 3 Greenberg, D. S., Nonnenmacher, M., & Macke, J. H. (2019). Automatic Posterior Transformation for Likelihood-Free Inference. arXiv preprint arXiv:1905.07488. [10.1109/ICML.2019.8952319](https://doi.org/10.1109/ICML.2019.8952319)
- 4 Egger, R., Dercksen, V. J., Udvary, D., Hege, H. C., & Oberlaender, M. (2014). Generation of dense statistical connectomes from sparse morphological data. *Frontiers in neuroanatomy*, 8, 129. [10.3389/fnana.2014.00129](https://doi.org/10.3389/fnana.2014.00129)

©(2019) Boelts J, Harth P, Yanez F, Hege H, Oberlaender M, Macke JH

Cite as: Boelts J, Harth P, Yanez F, Hege H, Oberlaender M, Macke JH (2019) Bayesian inference for synaptic connectivity rules in anatomically realistic cortical connectomes. Bernstein Conference 2019 Abstract.
doi: [10.12751/nncn.bc2019.0079](https://doi.org/10.12751/nncn.bc2019.0079)

[W 63] Contrast-invariant orientation tuning in mouse primary visual cortex probed via briefly flashed gratings

Simon Renner^{1,2}, Nataliya Kraynyukova³, Ann Hossam Kotkat⁴, Yannik Bauer^{1,2}, Gregory Born^{1,2}, Martin Spacek¹, Tatjana Tchumatchenko³, Laura Busse^{1,5}

1. Division of Neurobiology, Department Biology II, LMU Munich, 82151 Munich, Germany

2. Graduate School of Systemic Neuroscience (GSN), LMU Munich, 82151 Munich, Germany

3. Theory of neural dynamics group, MPI for Brain Research, 60438 Frankfurt am Main, Germany

4. ENB Elite Master of Science Program in Neuroengineering, Technical University of Munich, 80333 Munich, Germany

5. Bernstein Center for Computational Neuroscience, 82151 Munich, Germany

For neurons in primary visual cortex (V1) of carnivores [1, 2, 3, 4] and primates [5], the width of orientation tuning does not change with contrast, a phenomenon termed contrast-invariant orientation tuning. As classical feed-forward models [6] predict contrast-dependence, recent models of V1 use contrast-invariant orientation tuning as a critical anchor point. Amongst those, the stabilized supra-linear network, a framework capturing diverse features of visual processing [7, 8], employs contrast-invariant orientation tuning as a key emergent property. Contrary to carnivores, mice present conflicting evidence concerning contrast-invariance: while some studies report contrast-invariant orientation tuning [9], others show contrast-dependence for either individual neurons [10] or the population [11]. Additionally, contrast-invariant orientation tuning has primarily been probed with multi-second stimuli that optimally drive individual

neurons, neglecting responses to non-optimal stimuli as well as temporal adaptation effects [12]. To address these concerns, we probed contrast-invariant orientation tuning via extracellular silicon probe recordings in V1 of awake, head-fixed mice. To efficiently cover the wide parameter space spanned by spatial frequency, spatial phase, orientation and contrast, we used a stimulus of briefly (84 ms) flashed gratings [13]. By performing subspace reverse correlation [13] between extracted spike times and flashed gratings, we recovered temporal response profiles and spatial tuning properties of individual neurons for our entire parameter space. As inhibitory interneurons play a major role in computational models for contrast-invariant orientation tuning [14, 15, 16], we separated putative inhibitory and excitatory units based on their extracellular wave shapes [9, 17]. We found a significant proportion of orientation selective neurons, both putative excitatory and inhibitory, which showed contrast-invariant orientation tuning. We also observed complex neural response properties, such as contrast suppression and temporal on-off dynamics. In the future, we will combine the experimentally measured tuning curves for orientation and contrast with a stabilized supra-linear network model of inhibitory and excitatory V1 cell populations to infer possible cortical connectivity schemes.

Acknowledgements

This research was funded by the DFG SPP2041 "Computational Connectomics" and further supported by the DFG RTG2175 "Perception in Context". We thank M. Sotgia for technical assistance.

References

- 1 Sclar, G., & Freeman, R. D. (1982). Orientation selectivity in the cat's striate cortex is invariant with stimulus contrast. *Experimental brain research*, 46(3), 457-461.
- 2 Skottun, B. C., Bradley, A., Sclar, G., Ohzawa, I., & Freeman, R. D. (1987). The effects of contrast on visual orientation and spatial frequency discrimination: a comparison of single cells and behavior. *Journal of Neurophysiology*, 57(3), 773-786. [10.1152/jn.1987.57.3.773](https://doi.org/10.1152/jn.1987.57.3.773)
- 3 Alitto, H. J., & Usrey, W. M. (2004). Influence of contrast on orientation and temporal frequency tuning in ferret primary visual cortex. *Journal of neurophysiology*, 91(6), 2797-2808. [10.1152/jn.00943.2003](https://doi.org/10.1152/jn.00943.2003)
- 4 Finn, I. M., Priebe, N. J., & Ferster, D. (2007). The emergence of contrast-invariant orientation tuning in simple cells of cat visual cortex. *Neuron*, 54(1), 137-152. [10.1016/j.neuron.2007.02.029](https://doi.org/10.1016/j.neuron.2007.02.029)
- 5 Carandini, M., Heeger, D. J., & Movshon, J. A. (1997). Linearity and normalization in simple cells of the macaque primary visual cortex. *Journal of Neuroscience*, 17(21), 8621-8644. [10.1523/JNEUROSCI.17-21-08621.1997](https://doi.org/10.1523/JNEUROSCI.17-21-08621.1997)
- 6 Hubel, D. H., & Wiesel, T. N. (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *The Journal of physiology*, 160(1), 106-154. [10.1113/jphysiol.1962.sp006837](https://doi.org/10.1113/jphysiol.1962.sp006837)
- 7 Rubin, D. B., Van Hooser, S. D., & Miller, K. D. (2015). The stabilized supralinear network: a unifying circuit motif underlying multi-input integration in sensory cortex. *Neuron*, 85(2), 402-417. [10.1016/j.neuron.2014.12.026](https://doi.org/10.1016/j.neuron.2014.12.026)
- 8 Kraynyukova, N., & Tchumatchenko, T. (2018). Stabilized supralinear network can give rise to bistable, oscillatory, and persistent activity. *Proceedings of the National Academy of Sciences*, 115(13), 3464-3469. [10.1073/pnas.1700080115](https://doi.org/10.1073/pnas.1700080115)
- 9 Niell, C. M., & Stryker, M. P. (2008). Highly selective receptive fields in mouse visual cortex. *Journal of Neuroscience*, 28(30), 7520-7536. [10.1523/JNEUROSCI.0623-08.2008](https://doi.org/10.1523/JNEUROSCI.0623-08.2008)
- 10 Li, Y. T., Ma, W. P., Li, L. Y., Ibrahim, L. A., Wang, S. Z., & Tao, H. W. (2012). Broadening of inhibitory tuning underlies contrast-dependent sharpening of orientation selectivity in mouse visual cortex. *Journal of Neuroscience*, 32(46), 16466-16477. [10.1523/JNEUROSCI.3221-12.2012](https://doi.org/10.1523/JNEUROSCI.3221-12.2012)
- 11 Tring, E., & Ringach, D. L. (2018). On the Subspace Invariance of Population Responses. arXiv preprint arXiv:1811.03251.
- 12 Nowak, L.G., and Barone, P. (2009). Contrast Adaptation Contributes to Contrast-Invariance of Orientation Tuning of Primate V1 Cells. *PLOS ONE* 4, e4781. [10.1371/journal.pone.0004781](https://doi.org/10.1371/journal.pone.0004781)
- 13 Ringach, D.L., Hawken, M.J., and Shapley, R. (1997). Dynamics of orientation tuning in macaque primary visual cortex. *Nature* 387, 281284. [10.1038/387281a0](https://doi.org/10.1038/387281a0)
- 14 Ahmadian, Y., Rubin, D. B., & Miller, K. D. (2013). Analysis of the stabilized supralinear network. *Neural computation*, 25(8), 1994-2037. [10.1162/NECO_a_00472](https://doi.org/10.1162/NECO_a_00472)
- 15 Sadeh, S., & Rotter, S. (2015). Orientation selectivity in inhibition-dominated networks of spiking neurons: effect of single neuron properties and network dynamics. *PLoS computational biology*, 11(1), e1004045. [10.1371/journal.pcbi.1004045](https://doi.org/10.1371/journal.pcbi.1004045)
- 16 Dai, W. P., Zhou, D., McLaughlin, D. W., & Cai, D. (2018). Mechanisms underlying contrast-dependent orientation selectivity in mouse V1. *Proceedings of the National Academy of Sciences*, 115(45), 11619-11624. [10.1073/pnas.1719044115](https://doi.org/10.1073/pnas.1719044115)
- 17 Bortone, D. S., Olsen, S. R., & Scanziani, M. (2014). Translaminar inhibitory cells recruited by layer 6

corticothalamic neurons suppress visual cortex. *Neuron*, 82(2), 474-485. [10.1016/j.neuron.2014.02.021](https://doi.org/10.1016/j.neuron.2014.02.021)

©(2019) Renner S, Kraynyukova N, Kotkat AH, Bauer Y, Born G, Spacek M, Tchumatchenko T, Busse L

Cite as: Renner S, Kraynyukova N, Kotkat AH, Bauer Y, Born G, Spacek M, Tchumatchenko T, Busse L (2019)

Contrast-invariant orientation tuning in mouse primary visual cortex probed via briefly flashed gratings. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0080](https://doi.org/10.12751/nncn.bc2019.0080)

[W 64] Enriching the human connectome: BigBrain & The Virtual Brain now feature the newly digitized Economo & Koskinas human cytoarchitectonic atlas

Anastasia Brovkin¹, Rene Werner¹, Julia Michel¹, Alexandros Goulas¹, Timo Dickscheid², Katrin Amunts^{2,3}, Petra Ritter^{4,5}, Claus C. Hilgetag^{1,6}

1. Department of Computational Neuroscience, University Medical Center Hamburg-Eppendorf, Martinistra 52, Hamburg, Germany

2. C. and O. Vogt-Institute for Brain Research, University Hospital Düsseldorf, Düsseldorf, Germany

3. Institute of Neuroscience and Medicine (INM-1), Research Centre Jülich, 52425 Jülich, Germany

4. Brain Simulation Section, Department of Neurology Charité Universitätsmedizin Berlin & Berlin Institute of Health, Berlin, Germany

5. Bernstein Center for Computational Neuroscience Berlin, BCCN, Berlin, Germany

6. Department of Health Sciences, Boston University, 635 Commonwealth Avenue, Boston, USA

Fundamental relations between architecture, connectivity and function of the cerebral cortex still remain elusive. This is partly due to a lack of detailed, quantitative cytoarchitectonic data for the human brain. Currently, the only comprehensive source of such information is the classic work of von Economo and Koskinas (vEK) [1,2], which, however, is only available in a paper-based 2D atlas in non-standard space. Our project is aimed at constructing an extensive virtual 3D model of the von Economo and Koskinas atlas in stereotactic space (i.e. MNI-152, Colin-27).

Recent efforts [3-5] manually mapped the von Economo and Koskinas parcellation onto the FreeSurfer Desikan-Killiany atlas [6] based on the textual description and 2D drawings [1,2,7]. To overcome related problems, we aimed at explicitly defining a virtual 3D von Economo and Koskinas model independent of existing reference geometries – which became possible by 3D scanning 2 individual, well-preserved 3D plaster models of the cortical parcellation [1,2] manufactured in the era of von Economo. We will present our progress in reconstructing the 3D model and illustrate the integration of the extracted atlas into the BigBrain atlas - and by extension- its inclusion into the TVB (The Virtual Brain) neuroinformatics platform which is currently being merged with the Human Brain Project infrastructure as a comprehensive, complementary tool for large-scale brain network modelling.

This data, comprising systematic quantitative macroscopic as well as microscopic anatomical descriptors, such as layer thickness, cell density and cell sizes, is essential for linking fundamental aspects of macroscopic and microscopic cortical organization and connectivity and complements recent efforts [8]. The inclusion of the vEK atlas into the aforementioned, open-source, infrastructure offers the prospect of reliably mapping human cytoarchitectonic information into common cortical parcellation schemes, enabling and advancing the enrichment of the human connectome.

Acknowledgements

1) N. Reiner (of the Manufaktur Chirurgischer Instrumente Carl Reiner GmbH, Vienna, Austria) 2) The

Josephinum, Collections of the Medical University of Vienna, Austria 3) Prof. Lazaros C. Triarhou, of the University of Macedonia, Greece 4) Funding: Horizon 2020 SGA No. 785907 (HBP SGA2)

References

- 1 von Economo, CF, Koskinas, GN (1925). Die Cytoarchitektur der Hirnrinde des erwachsenen Menschen. Berlin: Springer.
- 2 von Economo, CF (1927). Zellaufbau der Grosshirnrinde des Menschen. Berlin: Springer.
- 3 Scholtens, LH, de Reus, MA, van den Heuvel, M (2015), 'Linking contemporary high resolution magnetic resonance imaging to the Von Economo legacy', Human Brain Mapping 36:3038-46.
- 4 van den Heuvel, M et al. (2015), 'Bridging cytoarchitectonics and connectomis in human cerebral cortex', The Journal of Neuroscience 35: 13943-8
- 5 Goulas, A et al. (2016) 'Cytoarchitectonic similarity as wiring principle of the human connectome', OHBM 2016 Annual Meeting.
- 6 Fischl, B et al. (2004), 'Automatically parcellating the human cerebral cortex.' Cerebral Cortex 14: 11-22.
- 7 von Economo, CF (2009), 'Cellular structure of the human cerebral cortex', Karger.
- 8 Wagstyl, K., Lepage, C., Bludau, S., Zilles, K., Fletcher, P. C., Amunts, K., & Evans, A. C. (2018). Mapping cortical laminar structure in the 3d bigbrain. Cerebral Cortex, 28(7), 2551-2562.

©(2019) Brovkin A, Werner R, Michel J, Goulas A, Dickscheid T, Amunts K, Ritter P, Hilgetag CC

Cite as: Brovkin A, Werner R, Michel J, Goulas A, Dickscheid T, Amunts K, Ritter P, Hilgetag CC (2019) Enriching the human connectome: BigBrain & The Virtual Brain now feature the newly digitized Economo & Koskinas human cytoarchitectonic atlas. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0081](https://doi.org/10.12751/nncn.bc2019.0081)

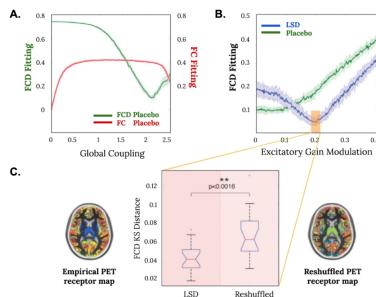
[W 65] Mechanisms of the non-linear interactions between the neuronal and neurotransmitter systems explained by causal whole-brain modeling

Josephine Cruzat¹, Joana Cabral², Gitte Moos Knudsen^{3,4}, Robin Carhart-Harris⁵, Peter C. Whybrow⁶, Nikos K. Logothetis^{7,8}, Morten L. Kringleback^{9,10}, Gustavo Deco^{1,11,12,13}

1. Center for Brain and Cognition, Universitat Pompeu Fabra, Spain
2. Life and Health Sciences Research Institute (ICVS), University of Minho, Portugal
3. Neurobiology Research Unit and Center for Integrated Molecular Brain Imaging, Rigshospitalet, Denmark
4. Faculty of Health and Medical Sciences, Copenhagen University, Denmark
5. Psychedelic Research Group, Centre for Psychiatry, Imperial College London, UK
6. Semel Institute for Neuroscience and Human Behavior, University of California, Los Angeles, USA
7. Max Planck Institute for Biological Cybernetics, Germany
8. Imaging Science and Biomedical Engineering, University of Manchester, UK
9. Department of Psychiatry, University of Oxford, UK
10. Center for Music in the Brain, Aarhus University, Denmark
11. Institucio Catalana de la Recerca i Estudis Avancats (ICREA), Spain
12. Department of Neuropsychology, Max Planck Institute for Human Cognitive and Brain Sciences, Germany
13. School of Psychological Sciences, Monash University, Australia

Although a variety of studies have shown the role of neurotransmitters at the neuronal level, their impact on the dynamics of the system at a macroscopic scale is poorly understood. Here, we provide a causal explanation using the first whole-brain model integrating multimodal imaging in healthy human participants undergoing manipulation of the serotonin system [1]. Specifically, we combined anatomical and functional data with a detailed map of the serotonin 2A receptor ($5-HT_{2A}R$) densities obtained with positron emission tomography (PET) [2]. This allowed us to model the resting state and mechanistically explain the functional effects of ($5-HT_{2A}R$) stimulation with lysergic acid diethylamide (LSD). The whole-brain model was composed of 90 anatomically delineated brain regions linked by the structural connectivity (SC) matrix of fiber densities obtained by tractography [3,4]. The activity of each region was represented by a dynamic neuronal mean-field model derived from the collective behavior

of empirically validated integrate-and-fire neurons [5,6]. The population responses for pools of excitatory neurons were given by independent sigmoid functions, regulated by a gain parameter s_E common in all brain regions and initially set to zero. Notably, the model only uses two parameters: a neuronal parameter scaling the global coupling of neuronal populations, G , and a neuromodulator parameter scaling the effects of neurotransmitters on the neuronal gain function weighted by the empirical regional receptor density. To take into account the spatiotemporal fluctuations in functional brain dynamics over time, the model was fitted to the spatiotemporal dynamics of the data (i.e., to the functional connectivity dynamics [FCD] [7,8]). The present results show that the precise distribution of $(5 - HT_{2A}R)$ is crucial to predict the neuromodulatory effects of LSD. The model identified the causative mechanisms for the non-linear interactions between the neuronal and neurotransmitter system, which are uniquely linked to (1) the underlying neuroanatomical network, (2) the modulation by the specific brain-wide distribution of neurotransmitter receptor density, and (3) the non-linear interactions between the two. Taking neuromodulatory activity into account when modeling global brain dynamics will lead to novel insights into human brain function in health and disease and opens exciting possibilities for drug discovery and design in neuropsychiatric disorders.



A) Estimation of the coupling parameter G to optimally fit the placebo, B) The neuromodulatory effects in the LSD condition were modeled by estimating the neuronal gain function (scaling the parameter s_E by the empirical $5-HT_{2A}R$ data). C) Results of randomly shuffling the empirical $5-HT_{2A}R$ densities

Acknowledgements

G.D. is supported by the ERC Advanced Grant DYSTRUCTURE (295129), the Spanish Research Project PSI2016-75688-P, and the European Union's Horizon 2020 Framework Programme for Research and Innovation under the Specific Grant Agreement No. 785907 (Human Brain Project SGA2).

References

- Deco, G., Cruzat, J., Cabral, J., Knudsen, G. M., Carhart-Harris, R. L., Whybrow, P. C., Logothetis, N.K., & Kringelbach, M. L. (2018) Current Biology, 28(19), 3065-3074. [10.1016/j.cub.2018.07.083](https://doi.org/10.1016/j.cub.2018.07.083)
- Beliveau, V., Ganz, M., Feng, L., Ozenne, B., Hojgaard, L., Fisher, P. M., . . . Knudsen, G. M. (2017). A High-Resolution In Vivo Atlas of the Human Brain's Serotonin System. *J Neurosci*, 37(1), 120-128. [10.1523/JNEUROSCI.2830-16.2016](https://doi.org/10.1523/JNEUROSCI.2830-16.2016)
- Cabral, J., Kringelbach, M. L., & Deco, G. (2014). Exploring the network dynamics underlying brain activity during rest. *Prog Neurobiol*, 114, 102-131. [10.1016/j.pneurobio.2013.12.005](https://doi.org/10.1016/j.pneurobio.2013.12.005)
- Hagmann, P., Cammoun, L., Gigandet, X., Meuli, R., Honey, C. J., Wedeen, V. J., & Sporns, O. (2008). Mapping the structural core of human cerebral cortex. *PLoS Biol*, 6(7), e159. [10.1371/journal.pbio.0060159](https://doi.org/10.1371/journal.pbio.0060159)

- 5 Brunel, N., & Wang, X.-J. (2001). Effects of neuromodulation in a cortical network model of object working memory dominated by recurrent inhibition. *Journal of computational neuroscience*, 11(1), 63-85. [10.1023/A:1011204814320](https://doi.org/10.1023/A:1011204814320)
- 6 Deco, G., Ponce-Alvarez, A., Hagmann, P., Romani, G. L., Mantini, D., & Corbetta, M. (2014). How local excitation-inhibition ratio impacts the whole brain dynamics. *Journal of neuroscience*, 34(23), 7886-7898. [10.1523/JNEUROSCI.5068-13.2014](https://doi.org/10.1523/JNEUROSCI.5068-13.2014)
- 7 Hansen, E. C., Battaglia, D., Spiegler, A., Deco, G., & Jirsa, V. K. (2015). Functional connectivity dynamics: modeling the switching behavior of the resting state. *Neuroimage*, 105, 525-535. [10.1016/j.neuroimage.2014.11.001](https://doi.org/10.1016/j.neuroimage.2014.11.001)

©(2019) Cruzat J, Cabral J, Knudsen GM, Carhart-Harris R, Whybrow PC, Logothetis NK, Krriegelbach ML, Deco G
Cite as: Cruzat J, Cabral J, Knudsen GM, Carhart-Harris R, Whybrow PC, Logothetis NK, Krriegelbach ML, Deco G (2019)
Mechanisms of the non-linear interactions between the neuronal and neurotransmitter systems explained by causal
whole-brain modeling. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0082](https://doi.org/10.12751/nncn.bc2019.0082)

[W 66] mEMbrain: an interactive deep learning tool for labeling and instance segmentation of EM datasets

Elisa Pavarino¹, Daniel R. Berger², Olga Morozova², Jeff W. Lichtman², Yaron Meirovitch^{2,3}

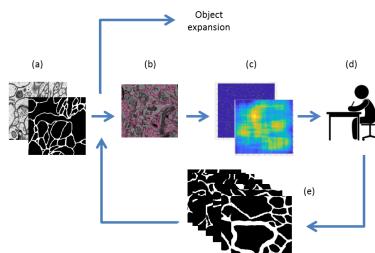
1. Department of Electrical and Computer Engineering, Technical University of Munich, Arcisstr. 21 D-80333 München, Germany

2. Department of Molecular and Cellular Biology and Center for Brain Science, Harvard University, 52 Oxford St, Cambridge, MA 02138, USA

3. Computer Science and Artificial Intelligence Laboratory, Massachusetts, 32 Vassar St, Cambridge, MA 02139, USA

One of the major bottlenecks in the field of Connectomics is the sheer amount of time required to manually annotate neuronal processes from electron micrographs for supervised learning of auto-segmentation pipelines. mEMbrain is an interactive deep learning tool which exploits methods of active learning. It allows researchers to accelerate ground truth preparation and to segment datasets on commodity hardware with a single GPU, thus abolishing the need for expensive clusters [1]. By feeding it only a few (e.g., less than 10) labeled images, mEMbrain allows researchers to train state-of-the-art deep neural networks to predict membranes on whole datasets, which can be visualized on-the-fly in Connectomics' annotation tools [2]. The key idea then is to use these predictions with minimal human intervention to improve network performance and produce high-quality ground truth maps of the micro-circuitry. Thus, the user is directed by mEMbrain to revise output membrane predictions in regions of the dataset where network performance was poor according to an internal evaluation function. The selection of such critical regions is based on the morphological principle that cell membranes are closed curves. As a consequence, images that present a high number of discontinuities are deemed problematic for the network and thus ought to be corrected with a higher priority. By leveraging on this intuitive and simple, yet effective active learning paradigm embedded in an interactive deep learning framework, mEMbrain enables a user to generate large amounts of ground truth in much less time compared to the standard manual pipeline (i.e., time reduction on the order of a factor of 10). mEMbrain also supports transfer learning approaches, which can significantly reduce both training time and the necessary amount of ground truth for a great network performance. mEMbrain was tested on the mouse cortex Kasthuri dataset [3], on the unpublished octopus and mouse datasets from the Lichtman Lab. Furthermore, together with the Vast annotation tool, mEMbrane allows to automatically expand neuronal

processes based on a geodesic criterion by deploying the predicted cell membranes and manually annotated seed points. Hence, in a semi-automatic fashion, whole volumes of EM neural tissues can be segmented without requiring precise, time-consuming manual labelling.



Workflow using mEMbrain. (a) Few labeled images and their EM as input. (b) Membrane predictions in pink. (c) Membrane discontinuities computed on predictions. (d) Human corrections of critical predictions. (e) Fast and large amount of ground truth incorporated in the training dataset.

Acknowledgements

The authors would like to acknowledge Flavie Bidel and Benny Hochner for lending their octopus dataset on which mEMbrane was tested.

References

- 1 Januszewski, M., Kornfeld, J., Li, P.H., Pope, A., Blakely, T., Lindsey, L., Maitin-Shepard, J., Tyka, M., Denk, W. and Jain, V., 2018. High-precision automated reconstruction of neurons with flood-filling networks. *Nature methods*, 15(8), p.605.
- 2 [2] Berger, D.R., Seung, H.S. and Lichtman, J.W., 2018. VAST (Volume Annotation and Segmentation Tool): efficient manual and semi-automatic labeling of large 3D image stacks. *Frontiers in neural circuits*, 12 [10.3389/fncir.2018.00088](https://doi.org/10.3389/fncir.2018.00088)
- 3 [3] Kasthuri, N., Hayworth, K.J., Berger, D.R., Schalek, R.L., Conchello, J.A., Knowles-Barley, S., Lee, D., Vázquez-Reina, A., Kaynig, V., Jones, T.R. and Roberts, M., 2015. Saturated reconstruction of a volume of neocortex. *Cell*, 162(3), pp.648–661. [10.1016/j.cell.2015.06.054](https://doi.org/10.1016/j.cell.2015.06.054)

©(2019) Pavarino E, Berger DR, Morozova O, Lichtman JW, Meirovitch Y

Cite as: Pavarino E, Berger DR, Morozova O, Lichtman JW, Meirovitch Y (2019) mEMbrain: an interactive deep learning tool for labeling and instance segmentation of EM datasets. *Bernstein Conference 2019 Abstract*.
doi: [10.12751/nncn.bc2019.0083](https://doi.org/10.12751/nncn.bc2019.0083)

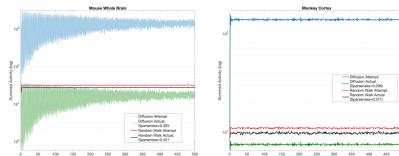
[W 67] **Nonlinear collision rules on the mammal connectome produce different behavior in diffusion processes compared to random walk models**

Daniel Graham¹, Yan Hao²

1. Psychology, Hobart and William Smith Colleges, Geneva, NY, USA

2. Mathematics and Computer Science, Hobart and William Smith Colleges, Geneva, NY, USA

Connectomics has demonstrated that most brain parts possess paths of a few synapses between a given neuron and just about any other neuron in the brain. This level of interconnectivity—and the whole-brain communication it can support—prompts new questions about connectodynamics ("dynamics").^{1–3} One question concerns signal collisions. Recent approaches have adopted probabilistic models (typically Markovian random walks).^{4–7} As such, current models do not account for collisions, nor do they fully capture diffusion processes. Others have avoided the collision problem by employing models with biologically implausible node buffers.^{8,9} We present a synchronous agent-based zero-buffer model to simulate activity on the mammal connectome. We use a nonlinear, biologically plausible collision rule, "all colliding messages destroyed," which approximates widespread inhibitory/excitatory collisions in neuronal networks. To investigate differences between random walk (RW) models and diffusion processes (DF), we employ a diffusion rule in DF, namely "all output edges pass copies of the incoming message." Given the same number of signals injected per time step, with randomly chosen sending and receiving nodes, we find that the collision rule has different effects on global activity for RW versus DF. RW models have high average activity, which is rather densely distributed over nodes. Essentially, signals in a random walk model wander the network for a considerable time before being delivered or destroyed. As such, substantial numbers of nodes are active in a given time window. In contrast, DF models with the same collision rule, while making many more attempts, have lower actual activity (i.e., fewer signals are passed without being destroyed, compared to RW) due to collisions, and are sparser (i.e., fewer nodes are highly active within a given time window, compared to RW). Somewhat counter-intuitively, DF models appear to be efficient in terms of activity cost because they are highly redundant. These results hold in tracer-based connectomes of both the monkey cortex¹⁰ and the mouse whole-brain.¹¹ We also investigate varieties of collision rules and dynamics (e.g., LTD-like rules for nodes). We suggest that in the seeming absence of an addressing system or central control of signals in the brain, a nonlinear global collision rule plus signal redundancy produces systems capable of efficiently routing communication traffic across the entire network.



Simulated activity over time in mouse whole brain (L) and monkey cortex (R). Each time step p signals are injected ($p=0.1 \times N_{\text{nodes}}$). Population sparseness¹² of the activity distribution (0=max sparseness; 1.0=Gaussian) across nodes in 5 timestep windows is given in legend (mean of 10 runs).

References

- 1 Kopell, N. J., Gritton, H. J., Whittington, M. A., & Kramer, M. A. (2014). Beyond the connectome: the dynome. *Neuron*, 83(6), 1319-1328. [10.1016/j.neuron.2014.08.016](https://doi.org/10.1016/j.neuron.2014.08.016)
- 2 Bassett, D. S., & Gazzaniga, M. S. (2011). Understanding complexity in the human brain. *Trends in cognitive sciences*, 15(5), 200-209. [10.1016/j.tics.2011.03.006](https://doi.org/10.1016/j.tics.2011.03.006)
- 3 Graham, D. (2017). Building brains that communicate like machines. *Behavioral and Brain Sciences*, e266, 37-38. [10.1017/S0140525X17000152](https://doi.org/10.1017/S0140525X17000152)
- 4 Betzel, R. F., Griffa, A., Avena-Koenigsberger, A., Goñi, J., Thiran, J. P., Hagmann, P., & Sporns, O. (2013). Multi-scale community organization of the human structural connectome and its relationship with resting-state functional connectivity. *Network Science*, 1(3), 353-373. [10.1017/nws.2013.19](https://doi.org/10.1017/nws.2013.19)
- 5 Abdelnour, F., Voss, H. U., & Raj, A. (2014). Network diffusion accurately models the relationship between structural and functional brain connectivity networks. *Neuroimage*, 90, 335-347. [10.1016/j.neuroimage.2013.12.039](https://doi.org/10.1016/j.neuroimage.2013.12.039)
- 6 Goñi, J., van den Heuvel, M. P., Avena-Koenigsberger, A., de Mendizabal, N. V., Betzel, R. F., Griffa, A., ... & Sporns, O. (2014). Resting-brain functional connectivity predicted by analytic measures of network communication. *Proceedings of the National Academy of Sciences*, 111(2), 833-838. [10.1073/pnas.1315529111](https://doi.org/10.1073/pnas.1315529111)
- 7 Avena-Koenigsberger, A., Yan, X., Kolchinsky, A., Hagmann, P., & Sporns, O. (2019). A spectrum of routing strategies for brain networks. *PLoS computational biology*, 15(3), e1006833-e1006833. [10.1371/journal.pcbi.1006833](https://doi.org/10.1371/journal.pcbi.1006833)
- 8 Mišić, B., Sporns, O., & McIntosh, A. R. (2014). Communication efficiency and congestion of signal traffic in large-scale brain networks. *PLoS computational biology*, 10(1), e1003427. [10.1371/journal.pcbi.1003427](https://doi.org/10.1371/journal.pcbi.1003427)
- 9 Mišić, B., Goñi, J., Betzel, R. F., Sporns, O., & McIntosh, A. R. (2014). A network convergence zone in the hippocampus. *PLoS computational biology*, 10(12), e1003982. [10.1371/journal.pcbi.1003982](https://doi.org/10.1371/journal.pcbi.1003982)
- 10 Markov, N. T., Ercsey-Ravasz, M. M., Ribeiro Gomes, A. R., Lamy, C., Magrou, L., Vezoli, J., ... & Sallet, J. (2012). A weighted and directed interareal connectivity matrix for macaque cerebral cortex. *Cerebral cortex*, 24(1), 17-36. [10.1093/cercor/bhs270](https://doi.org/10.1093/cercor/bhs270)
- 11 Oh, S. W., Harris, J. A., Ng, L., Winslow, B., Cain, N., Mihalas, S., ... & Mortrud, M. T. (2014). A mesoscale connectome of the mouse brain. *Nature*, 508(7495), 207. [10.1038/nature13186](https://doi.org/10.1038/nature13186)
- 12 Rolls, E. T., & Tovee, M. J. (1995). Sparseness of the neuronal representation of stimuli in the primate temporal visual cortex. *Journal of neurophysiology*, 73(2), 713-726. [10.1152/jn.1995.73.2.713](https://doi.org/10.1152/jn.1995.73.2.713)

©(2019) Graham D, Hao Y

Cite as: Graham D, Hao Y (2019) Nonlinear collision rules on the mammal connectome produce different behavior in diffusion processes compared to random walk models. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0084](https://doi.org/10.12751/nncn.bc2019.0084)

[W 68] Spatiotemporal ontogeny of brain wiring

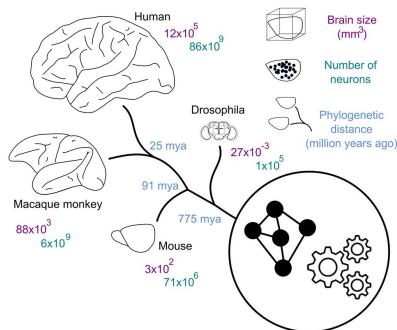
Alexandros Goulas¹, Richard F Betzel², Claus C Hilgetag^{1,3}

1. University Medical Center Hamburg- Eppendorf, Institute of Computational Neuroscience, Martinistra 52
20246 Hamburg, Germany

2. University of Pennsylvania, 2Department of Bioengineering, PA 19104, USA

3. Department of Health Sciences, Boston University, MA 02215 Boston, USA

The wiring of vertebrate and invertebrate brains provides the anatomical skeleton for cognition and behavior. Connections among brain regions are characterized by heterogeneous strength that is parsimoniously described by the wiring cost and homophily principles. Moreover, brains exhibit a characteristic global network topology, including modules and hubs. However, the mechanisms resulting in the observed interregional wiring principles and network topology of brains are unknown. Here, with the aid of computational modeling, we demonstrate that a mechanism based on heterochronous and spatially ordered neurodevelopmental gradients, without the involvement of activity-dependent plasticity or axonal guidance cues, can reconstruct a large part of the wiring principles (on average, 83%) and global network topology (on average, 80%) of diverse adult brain connectomes, including fly and human connectomes. In sum, space and time are key components of a parsimonious, plausible neurodevelopmental mechanism of brain wiring with a potential universal scope, encompassing vertebrate and invertebrate brains.



Universal principles and mechanisms of wiring in vertebrate and invertebrate brains

Acknowledgements

We would like to thank P. Vértes for helpful comments on previous drafts of the manuscript. This work was supported by the Humboldt Research Fellowship from the Alexander von Humboldt Foundation (to A.G.), and grants from DFG SFB 936/A1, Z3, SPP 2041 Computational Connectome.

©(2019) Goulas A, Betzel RF, Hilgetag CC

Cite as: Goulas A, Betzel RF, Hilgetag CC (2019) Spatiotemporal ontogeny of brain wiring. Bernstein Conference 2019
Abstract. doi: [10.12751/nncn.bc2019.0085](https://doi.org/10.12751/nncn.bc2019.0085)

Sensory processing and perception

[W 69] Acute Pain Temporal Dynamics Are Explained by Markovian Brain States

Andrew D. Vigotsky¹, A. Vania Apkarian^{2,3}, Marwan N. Baliki^{3,4}

1. Departments of Biomedical Engineering and Statistics, Northwestern University, Evanston, IL, USA

2. Departments of Physiology and Anesthesia, Northwestern University, Chicago, IL, USA

3. Department of Physical Medicine & Rehabilitation, Northwestern University, Chicago, IL, USA

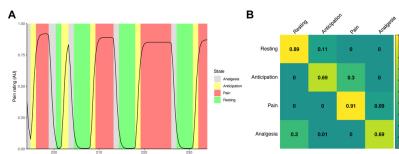
4. Shirley Ryan AbilityLab, Chicago, IL, USA

Acute pain is a conscious experience that arises from the integration of peripheral stimuli with higher-level brain networks (1). Multiple linear models have been used to identify pain-specific neural correlates. Most famously, population multi-voxel pattern analyses have been used to identify the acute pain signature (2). In this study, we utilize a Markovian approach to model the temporal phases of acute pain, including anticipation, pain perception, and analgesia. Compared to previous quasi-static models, this approach allows us to investigate the transitions and relationships between states that vary over time.

20 healthy subjects were scanned using fMRI while performing an acute heat pain task (3). Functional images were pre-processed using standardized FSL pipelines and registered into standard space using FNIRT. Nodes of the brain functional network were defined using a parcellation schema containing 264 regions that are 10-mm diameter spheres centered on the coordinates reported previously that were identified using both a multiple task fMRI meta-analyses and a cross-validated rs-fMRI functional connectivity parcellation technique (4,5). Markov models were constructed using the Viterbi algorithm

with fMRI activity as observations and 4 hidden states. Markovian states were compared to states that were identified from convolved pain ratings. The bootstrap was used to generate confidence intervals.

The Markov model was able to identify 4 unique states, which mapped to pain perception, anticipation, analgesia, and rest with high accuracy (mean = 99.6%; 95%CI = 46–100%) (Fig 1A). The Markov matrix showed state and transition probabilities that were consistent with the task (Fig 1B). Preliminary investigation of the underlying fMRI activity in each state reveals that pain has high activity in regions associated with salience and fronto-parietal networks; anticipation has low activity in regions associated with the default mode and sensorimotor networks; and analgesia is associated with increased visual and cingulo-opercular network activity. Future work will investigate these networks further and validate this approach in an independent sample.



Representative sample of model performance (A) and the Markov matrix of probabilities of state transitions (B).

Acknowledgements

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-1324585.

References

- Baliki, Marwan N, and A. Vania Apkarian. "Nociception, pain, negative moods, and behavior selection." *Neuron* 87, no. 3 (2015): 474-491. [10.1016/j.neuron.2015.06.005](https://doi.org/10.1016/j.neuron.2015.06.005)
- Wager, Tor D., Lauren Y. Atlas, Martin A. Lindquist, Mathieu Roy, Choong-Wan Woo, and Ethan Kross. "An fMRI-based neurologic signature of physical pain." *New England Journal of Medicine* 368, no. 15 (2013): 1388-1397. [10.1056/NEJMoa1204471](https://doi.org/10.1056/NEJMoa1204471)
- Baliki, Marwan N., P. Y. Geha, and A. V. Apkarian. "Parsing pain perception between nociceptive representation and magnitude estimation." *Journal of neurophysiology* 101, no. 2 (2009): 875-887. [10.1016/j.jneurosci.2015.06.005](https://doi.org/10.1016/j.jneurosci.2015.06.005)
- Power, Jonathan D., Alexander L. Cohen, Steven M. Nelson, Gagan S. Wig, Kelly Anne Barnes, Jessica A. Church, Alecia C. Vogel et al. "Functional network organization of the human brain." *Neuron* 72, no. 4 (2011): 665-678. [10.1016/j.neuron.2011.09.006](https://doi.org/10.1016/j.neuron.2011.09.006)
- Cohen, Alexander L., Damien A. Fair, Nico UF Dosenbach, Francis M. Miezin, Donna Dierker, David C. Van Essen, Bradley L. Schlaggar, and Steven E. Petersen. "Defining functional areas in individual human brains using resting functional connectivity MRI." *Neuroimage* 41, no. 1 (2008): 45-57. [10.1016/j.neuroimage.2008.01.066](https://doi.org/10.1016/j.neuroimage.2008.01.066)

©(2019) Vigotsky AD, Apkarian AV, Baliki MN

Cite as: Vigotsky AD, Apkarian AV, Baliki MN (2019) Acute Pain Temporal Dynamics Are Explained by Markovian Brain States. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0086](https://doi.org/10.12751/nncn.bc2019.0086)

[W 70] A Functional Model for Neuronal Response Variability in the Primary Visual Cortex

Dylan Festa¹, Ruben Coen-Cagli^{1,2}, Amir Aschner², Adam Kohn²

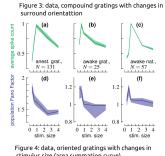
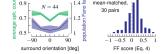
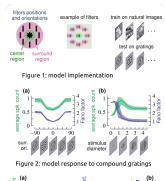
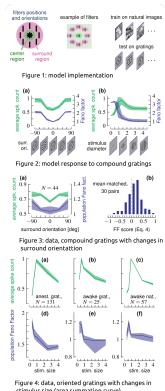
1. System and Computational Biology, Albert Einstein College of Medicine, 1300 Morris Park Ave, Bronx, NY, USA

2. Dominick P. Purpura Department of Neuroscience, Albert Einstein College of Medicine, 1300 Morris Park Ave, Bronx, NY, USA

Neural communication relies largely on the transmission of actions potentials. Those firing sequences display high variability, even in response to identical stimuli. A common approach is to treat response variability effectively as noise [Zohary et al 1994]. Recent studies suggest that the brain performs operations of probabilistic inference, and that neuronal activity is tuned to allow for efficient implementations of those inferences [Pouget et al 2013]. In this framework, one attractive hypothesis is that neuronal variability represents uncertainty over the variable encoded by the neuron [Hoyer and Hyvärinen 2003].

We test this theory with computational modeling and experimental neurophysiology in macaque primary visual cortex (V1). We assume that the inference relies on a generative model of natural images [Coen-Cagli et al, 2015], in which visual inputs are generated as linear combinations of latent local features (oriented edges), multiplied by a global modulator (contrast); we then follow the hypothesis that neurons represent the latent features, and that variability reflects uncertainty about those features, due to the mixing with the global modulator [Orban et al 2016].

In this framework, model neurons show supra-Poisson variability consistent with existing data [Goris et al 2014]. The model further predicts that spatial context (i.e. image regions surrounding the receptive field of V1 neurons) should reduce variability, reflecting that the addition of contextual information generally reduces uncertainty. Our V1 recordings support this prediction, for both artificial and natural images, as well as detailed predictions about stimulus tuning of contextual modulation of variability. We also report a similar effect in area MT. Our results offer strong evidence for the theory that cortical variability has a precise functional role.



Captions are included at the base of each figure. If the figure appears too small, download it as image file.

Acknowledgements

We wish to thank all other Coen-Cagli and Kohn lab members for the useful discussion and constructive feedback.

References

- 1 Coen-Cagli, R., Kohn, A., and Schwartz, O. (2015). Flexible gating of contextual influences in natural vision. *Nat Neurosci* 18, 1648–1655. [10.1038/nn.4128](https://doi.org/10.1038/nn.4128)
- 2 Goris, R.L.T., Movshon, A.J., and Simoncelli, E.P. (2014). Partitioning neuronal variability. *Nat Neurosci* 17, 858–865. [10.1038/nn.3711](https://doi.org/10.1038/nn.3711)
- 3 Hoyer, P.O., and Hyvärinen, A. (2003). Interpreting neural response variability as Monte Carlo sampling of the posterior. In *Advances in Neural Information Processing Systems*, pp. 293–300.
- 4 Orbán, G., Berkes, P., Fiser, J., and Lengyel, M. (2016). Neural Variability and Sampling-Based Probabilistic Representations in the Visual Cortex. *Neuron* 92, 530–543. [10.1016/j.neuron.2016.09.038](https://doi.org/10.1016/j.neuron.2016.09.038)
- 5 Pouget, A., Beck, J.M., Ma, W.J., and Latham, P.E. (2013). Probabilistic brains: knowns and unknowns. *Nat Neurosci* 16, 1170–1178. [10.1038/nn.3495](https://doi.org/10.1038/nn.3495)
- 6 Zohary, E., Shadlen, M.N., and Newsome, W.T. (1994). Correlated neuronal discharge rate and its implications for psychophysical performance. *Nature* 370, 140.

©(2019) Festa D, Coen-Cagli R, Aschner A, Kohn A

Cite as: Festa D, Coen-Cagli R, Aschner A, Kohn A (2019) A Functional Model for Neuronal Response Variability in the Primary Visual Cortex. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0087](https://doi.org/10.12751/nncn.bc2019.0087)

[W 71] A meta-analysis of current DNNs as models of low-level visual processing

Tiago Marques^{1,2,3}, James J. DiCarlo^{1,2,3}

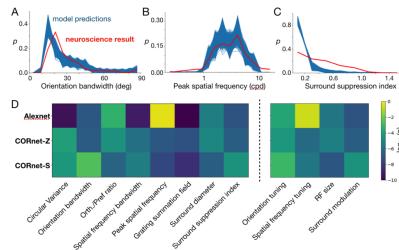
1. McGovern Institute for Brain Research, MIT, Cambridge, MA 02139, USA

2. Department of Brain and Cognitive Sciences, MIT, Cambridge, MA 02139, USA

3. Center for Brains, Minds and Machines, MIT, Cambridge, MA 02139, USA

Human visual abilities, though intuitive to us, are extremely complex from a computational point of view. Deep artificial neural networks (DNNs) are the most accurate model class to describe primate visual processing for tasks such as object recognition. However, their ability to explain a wide range of neurobehavioral effects across the primate ventral stream has not been quantified, yet. Here, we present a framework to produce quantitative comparisons – brain-benchmarks – between DNN models and neurobiological phenomena from published studies. Each benchmark produces a score reflecting the probability that the reported data could have been obtained from a candidate model. This type of quantification allows not only to rank candidate models according to their predictive power but also to estimate how far they are from fully explaining current neuroscience results in the context of experimental and neuronal noise. Finally, since the scores are computed as probabilities, they can be combined across phenomena to obtain composite scores for each candidate model. We have used this approach to evaluate different DNNs in their ability to explain known functional properties of primate V1 neurons such as orientation bandwidth, peak spatial frequency, and surround suppression index (Fig. 1A-C). Given its position in the visual system, only two synapses away from retinal ganglion cells, neuronal responses in V1 have been extensively studied, resulting in a rich and varied set of quantifications. Our results show that while spatial tuning properties in DNN models qualitatively match those of primate V1, there are significant quantitative differences that our method can detect (Fig. 1D). Extending this approach to evaluate hundreds of different DNN architectures will uncover which of their properties are required for explaining specific phenomena of primate low-level vision. Furthermore, studying the correlations between these V1

benchmarks with others reflecting mid- and high-level vision phenomena, such as those included in Brain-Score – a composite of multiple neurobehavioral comparison scores – will provide invaluable insight about which aspects of cortical computations depend on each other and how they relate to behavior. Together, these analyses will point the way to a deeper understanding of the mechanisms underlying visual perception in the brain.



V1 spatial tuning benchmarks for three candidate DNN models. A. Empirical (red) and model-generated (blue; Alexnet) distributions of orientation bandwidth. B, C. Same as in A but for peak SF and SSI. D. Individual (left) and composite (right) scores for V1 spatial tuning benchmarks

Acknowledgements

We thank M. Schrimpf for support in using Brain-Score to run DNN models

References

- 1 DiCarlo, Zoccolan, and Rust, 2012 [10.1016/j.neuron.2012.01.010](https://doi.org/10.1016/j.neuron.2012.01.010)
- 2 Yamins, Hong, et. al., 2014 [10.1073/pnas.1403112111](https://doi.org/10.1073/pnas.1403112111)
- 3 Cadieu et. al., 2014 [10.1371/journal.pcbi.1003963](https://doi.org/10.1371/journal.pcbi.1003963)
- 4 Khaligh-Razavi and Kriegeskorte, 2014 [10.1371/journal.pcbi.1003915](https://doi.org/10.1371/journal.pcbi.1003915)
- 5 Güçlü and van Gerven, 2015 [10.1523/JNEUROSCI.5023-14.2015](https://doi.org/10.1523/JNEUROSCI.5023-14.2015)
- 6 Schrimpf, Kubilius, et. al., 2018 [10.1101/407007](https://doi.org/10.1101/407007)
- 7 Ringach et. al., 2002 [10.1523/JNEUROSCI.22-13-05639.2002](https://doi.org/10.1523/JNEUROSCI.22-13-05639.2002)
- 8 De Valois et. al., 1982 [10.1016/0042-6989\(82\)90113-4](https://doi.org/10.1016/0042-6989(82)90113-4)
- 9 Cavanaugh, Bair, and Movshon, 2002 [10.1152/jn.00692.2001](https://doi.org/10.1152/jn.00692.2001)

©(2019) Marques T, DiCarlo JJ

Cite as: Marques T, DiCarlo JJ (2019) A meta-analysis of current DNNs as models of low-level visual processing. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0088](https://doi.org/10.12751/nncn.bc2019.0088)

[W 72] **A minimal neural oscillator model of auditory streaming**

Andrea Ferrario¹, James Rankin¹

1. College of Engineering, Mathematics and Physical Sciences, University of Exeter, United Kingdom

What neural mechanisms underlie the brain's ability to detect and distinguish between sound sources in the environment? The auditory streaming provides a valuable paradigm to explore this question. Subjects listening to stimuli formed by alternating high frequency A and a lower frequency B tones may perceive a segregated precept - two separate but simultaneous A-A-A and B-B-B streams - or a unique integrated ABAB stream. During long stimulus presentations listeners alternate between integrated and segregated perceptual interpretations (auditory bistability) [1].

Evidence from experiments (behaviour, imaging in humans, animal neurophysiology) and theoretical models suggests that the perception of such patterns arises through the synchronisation between neural populations in auditory and motor cortices [2]. In the absence of auditory stimuli these populations act as non-linear oscillators that can dynamically adapt their natural frequencies to synchronise with input patterns [3]. Such synchronisation phenomena have been widely studied, but their implications for our ability to segregate auditory streams remains unclear. Previous models of auditory streaming were able to predict some of the characteristics of auditory streaming, but a simple and biologically plausible model based on synchronisation has yet to be developed.

We propose a minimal oscillatory model of auditory streaming, consisting of mutually inhibitory Wilson-Cowan oscillators representing neural activity in the motor cortex. Periodic inputs to this motor network are derived from the neural activity at A and B tonotopic locations in the primary auditory cortex (mimicking parameter dependent responses from neurophysiology). A key innovation is that the main frequencies in the spectrum of the input are learned by the oscillators through Hebbian learning, allowing the oscillators to dynamically modify their frequency and synchronise to periodic inputs at any frequency.

Using bifurcation analysis and numerical simulations we provide a detailed investigation of the system when varying critical stimulus and network parameters. We show that the model can support stable oscillations with an integration-like state where at least one motor unit responds to every A and B tone, and a segregation-state where each unit responds to either every A or every B tone. The stability regions of these states qualitatively match those found in behavioural experiments, including a region of bistable perception.

Acknowledgements

AF and JR acknowledge support from an Engineering and Physical Sciences Research Council (EPSRC) New Investigator Award (EP/R03124X/1) and from the EPSRC Centre for Predictive Modelling in Healthcare (EP/N014391/1).

References

- 1 Bregman, A.S., 1978. Auditory streaming is cumulative. *Journal of Experimental Psychology: Human Perception and Performance*, 4(3), p.380. [10.1037/0096-1523.4.3.380](https://doi.org/10.1037/0096-1523.4.3.380)
- 2 Large, E.W., Herrera, J.A. and Velasco, M.J., 2015. Neural networks for beat perception in musical rhythm. *Frontiers in systems neuroscience*, 9, p.159. [10.3389/fnins.2015.00159](https://doi.org/10.3389/fnins.2015.00159)
- 3 Escabi, M.A. and Schreiner, C.E., 2002. Nonlinear spectrotemporal sound analysis by neurons in the auditory midbrain. *Journal of Neuroscience*, 22(10), pp.4114-4131. [10.1523/JNEUROSCI.22-10-04114.2002](https://doi.org/10.1523/JNEUROSCI.22-10-04114.2002)

©(2019) Ferrario A, Rankin J

Cite as: Ferrario A, Rankin J (2019) A minimal neural oscillator model of auditory streaming. *Bernstein Conference 2019*
Abstract. doi: [10.12751/nncn.bc2019.0089](https://doi.org/10.12751/nncn.bc2019.0089)

[W 73] A model explaining perceptual stability and motion illusions under fixational eye movements

Felix Schrader¹, Thomas Wachtler^{1,2}

1. Department of Biology II, Ludwig-Maximilians-Universität München, Martinsried, Germany

2. Bernstein Center for Computational Neuroscience, Munich, Germany

The existence of fixational eye movements (FEM), which can lead to retinal image shifts well above detection threshold, imposes two problems for visual perception: how to stabilize the image and how to differentiate between motion in the visual environment and retinal motion due to self-movements of body and eyes. We proposed a model to discern between local retinal motion, as typically elicited by object motion, and global motion, as elicited by eye movements, and to suppress motion signals arising from the latter type at early visual stages [1]. The model utilizes the properties of linear midget and non-linear parasol retinal ganglion cells in combination with a detection mechanism for global motion. It dramatically reduced the error in position estimates introduced by eye movements, enabling reliable object position tracking. Furthermore, the model also predicted illusory motion percepts in certain static image patterns like the Ouchi-Spillmann illusion [2].

To further investigate this mechanism of image stabilization, we applied the model to stimuli used in psychophysical studies investigating perceptual stability during or without FEM [3]. We simulated the responses to visual input consisting of moving or static dot stimuli with or without visual references, and with or without compensation of retinal motion due to FEM, and derived object motion estimates from the model's responses. Motion responses by the model were high for conditions in which human observers reported perceiving motion, and were low for conditions in which observers did not perceive motion. The correlation between the simulation results and the psychophysical data across all conditions was 0.85.

We further applied the model to flickering random-dot stimuli eliciting illusory motion percepts in human observers [4]. The simulations showed that the model produced motion responses to these stimuli, and moreover the dependence of the motion signal strength on the stimulus flicker frequency paralleled the results from human observers in the psychophysical experiments.

Based on the experimental data we estimated the aperture of motion detection units and found it to be comparable to the receptive field size of parasol ganglion cells. This result is in line with recent experimental findings [5]. Our model thus provides a simple,

biologically plausible, explanation for the perceptual insensitivity of vision to FEM as well as the occurrence of FEM-induced motion illusions.

Acknowledgements

Supported by the Bernstein Center for Computational Neuroscience Munich (BMBF Grant 01GQ1004A).

References

- 1 Greene G, Gollisch T, Wachtler T (2016) Non-linear retinal processing supports invariance during fixational eye movements. *Vision Res* 118:158-170 [10.1016/j.visres.2015.10.012](https://doi.org/10.1016/j.visres.2015.10.012)
- 2 Spillmann L (2013) The Ouchi-Spillmann illusion revisited. *Perception* 42:413–429 [10.1088/p7384](https://doi.org/10.1088/p7384)
- 3 Poletti M, Listorti C, Rucci M (2010) Stability of the visual world during eye drift. *J Neuroscience* 30:11143–11150 [10.1523/JNEUROSCI.1925-10.2010](https://doi.org/10.1523/JNEUROSCI.1925-10.2010)
- 4 Murakami I (2003) Illusory jitter in a static stimulus surrounded by a synchronously flickering pattern. *Vision Res* 43:957–969 [10.1016/S0042-6989\(03\)00070-1](https://doi.org/10.1016/S0042-6989(03)00070-1)
- 5 Manookin MB, Patterson SS, Linehan CM (2018) Neural mechanisms mediating motion sensitivity in parasol ganglion cells of the primate retina. *Neuron* 97:1327–1340 [10.1016/j.neuron.2018.02.006](https://doi.org/10.1016/j.neuron.2018.02.006)

©(2019) Schrader F, Wachtler T

Cite as: Schrader F, Wachtler T (2019) A model explaining perceptual stability and motion illusions under fixational eye movements. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0090](https://doi.org/10.12751/nncn.bc2019.0090)

[W 74] An early vision-inspired visual recognition model improves robustness against image distortions compared to a standard convolutional neural network

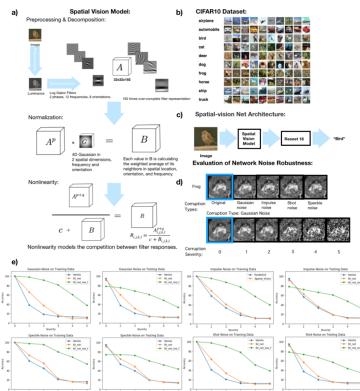
Shuchen Wu¹, Robert Geirhos^{2,3}, Felix A. Wichmann²

1. Institute of Neuroinformatics, ETH & University Zurich

2. Neural Information Processing Group, University of Tübingen

3. International Max Planck School for Intelligent Systems

Convolutional neural networks (CNNs) have been proposed as models for human ventral stream object recognition due to excellent performance on image recognition tasks and representational similarities with monkey neural recordings and human fMRI data [1,2]. At the same time, CNNs differ from human visual recognition in substantial ways. For example, CNN image recognition performance deteriorates much faster with image distortions compared to human observers [3]. Computationally, deep convolutional networks lack neurally-inspired components of local gain control which are ubiquitous in biological sensory systems [4]. We here test whether these two key differences between human and machine vision might be linked: Does incorporating mechanisms of human early visual processing lead to an improvement in CNN distortion robustness? To this end, we build a hybrid model consisting of an early vision inspired front end combined with a standard CNN back end, and train it on an object recognition task (the CIFAR-10 dataset). The front end is an image-computable model of human early visual processing with an overcomplete set of spatial frequency filters and divisive normalization followed by a nonlinearity, which has previously been shown to be a good fit for human psychophysical data [5]. The back end is ResNet-18, a standard CNN. Interestingly, this hybrid network leads to robustness improvements on various types of image distortions compared to a vanilla CNN that lacks an early vision front end. This model could serve as a starting point to better understand the benefits of biologically plausible components and their potential for today's machine vision systems.



a) Description of Spatial Vision Model Component b) CIFAR 10 Dataset c) Spatial-vision Net Architecture d) Evaluation of Network Robustness e) Network Performance on Increasing Levels of Noise Corruption Intensity

Acknowledgements

This research was supported by SMARTSTART I training program, it also benefits from hardware support from the Bethge lab.

References

- Yamins, D. L., Hong, H., Cadieu, C. F., Solomon, E. A., Seibert, D., & DiCarlo, J. J. (2014). Performance-optimized hierarchical models predict neural responses in higher visual cortex. *Proceedings of the National Academy of Sciences*, 111(23), 8619-8624.
- Kriegeskorte, N. (2015). Deep neural networks: a new framework for modeling biological vision and brain information processing. *Annual review of vision science*, 1, 417-446.
- Robert Geirhos, Carlos R. Medina Temme, Jonas Rauber, Heiko H. Schütt, Matthias Bethge, and Felix A. Wichmann. Generalisation in humans and deep neural networks. NeurIPS 2018
- Carandini, M., & Heeger, D. J. (2012). Normalization as a canonical neural computation. *Nature Reviews Neuroscience*, 13(1), 51.
- Heiko H. Schütt, Felix A. Wichmann; An image-computable psychophysical spatial vision model. *Journal of Vision* 2017;17(12):12. doi: 10.1167/17.12.12.

©(2019) Wu S, Geirhos R, Wichmann FA

Cite as: Wu S, Geirhos R, Wichmann FA (2019) An early vision-inspired visual recognition model improves robustness against image distortions compared to a standard convolutional neural network. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0091](https://doi.org/10.12751/nncn.bc2019.0091)

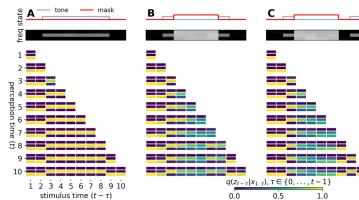
[W 75] A neurally plausible model for online recognition and postdiction

Li Kevin Wenliang¹, Maneesh Sahani¹¹. Gatsby Computational Neuroscience Unit, University College London, Gower St, Bloomsbury, London WC1E 6BT, United Kingdom

Humans and other animals are frequently near-optimal in their ability to integrate noisy and ambiguous sensory data to form robust percepts - which are informed both by sensory evidence and by prior experience about the causal structure of the environment. It is hypothesised that the brain establishes these prior structures using an internal model of how the observed patterns can arise from relevant but unobserved causes. This internal model facilitates the inferential process that produces beliefs about the latent causes conditioned on observations. In dynamic environments, such integration often takes the form of postdiction, wherein later sensory evidence affects inferences about earlier percepts. As the brain must operate in current time, how does such postdictive inference come about? Here, a general framework for neural probabilistic inference in dynamic environments is proposed based on the distributional code (DDC) representation of uncertainty [1], naturally extending the underlying encoding to incorporate implicit probabilistic beliefs about both present and past. Mathematically, neurons are assumed to represent beliefs about the latent variables given observations $q(z_{1:t}|x_{1:t})$ by moments r of nonlinear encoding functions $\psi(z_{1:t})$

$$r_i = \mathbb{E}_{q(z_{1:t}|x_{1:t})}[\psi_i(z_{1:t})], i \in \{1, \dots, K\}$$

where ψ is a biological recurrent function, such as an RNN. An inferential model can be learnt efficiently using samples from the internal model by the delta rule. Applied to stimuli used in the context of psychophysics experiments, the framework provides an online and plausible mechanism for inference, including postdictive effects. In the auditory continuity illusion, the perceived state of a tone during loud noise depends on whether a second tone follows immediately after the noise or does so with a delay [2]. We train the DDC inferential model on spectrogram data generated from an internal model for the evolution of amplitude levels of the noise and tone, and decode the distributions of the perceived states in the past (Fig.). During the noise period, the beliefs about the tone level are uncertain, but becomes concentrated in a way dependent on whether the onset of the second tone is immediate (Fig. B) or delayed (Fig. C), consistent with the continuity illusion. Our model can also reproduce other illusions, including the cutaneous rabbit effect [3] and the smoothing in flash-lag effect with direction reversal [4].



The auditory continuity illusion, showing decoded marginal distribution for perceived tone level in the past at each stimulus presentation time. The tone is well localised in time (A). The perceive tone level during noise changes depending on the onset of the second tone (B,C)

Acknowledgements

This work is supported by the Gatsby Charitable Foundation.

References

- 1 Vértes, Eszter, and Maneesh Sahani. "Flexible and accurate inference and learning for deep generative models." *Advances in Neural Information Processing Systems*. 2018.
- 2 Bregman, Albert S. *Auditory scene analysis: The perceptual organization of sound*. MIT press, 1994.
- 3 Geldard, Frank A., and Carl E. Sherrick. "The cutaneous" rabbit": a perceptual illusion." *Science* 178.4057 (1972): 178-179.
- 4 Whitney, David, and Ikuya Murakami. "Latency difference, not spatial extrapolation." *Nature neuroscience* 1.8 (1998): 656.

©(2019) Wenliang LK, Sahani M

Cite as: Wenliang LK, Sahani M (2019) A neurally plausible model for online recognition and postdiction. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0092](https://doi.org/10.12751/nncn.bc2019.0092)

[W 76] **Approximate causal inference based cue integration**

Sabyasachi Shivkumar¹, Madeline S. Cappelloni^{2,3}, Ross K. Maddox^{2,3,4,5}, Ralf M. Haefner^{1,4}

1. *Brain and Cognitive Sciences, University of Rochester, United States of America*

2. *Biomedical Engineering, University of Rochester, United States of America*

3. *Del Monte Institute for Neuroscience, University of Rochester, United States of America*

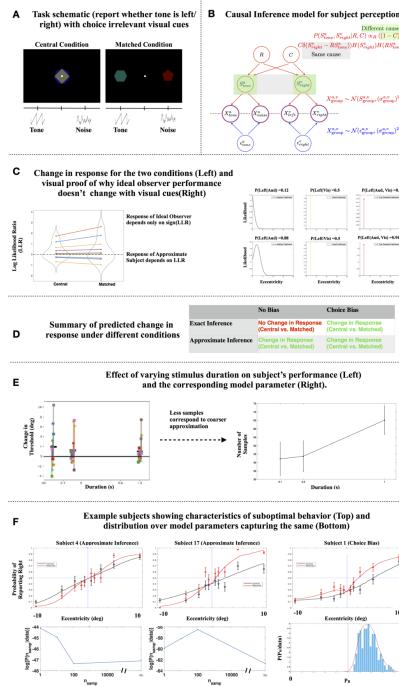
4. *Centre for Visual Science, University of Rochester, United States of America*

5. *Neuroscience, University of Rochester, United States of America*

The brain combines noisy and incomplete signals from multiple sources according to their reliability to infer the state of the outside world [1]. The brain's implementation of this process of "probabilistic inference" is necessarily approximate and understanding its computational and neural basis requires a paradigm that can dissociate the three principal sources of suboptimality in perceptual decision-making tasks: sensor noise, model mismatch (mistaken assumptions about the structure of the world), and approximate inference computations [2].

While these sources of suboptimality trade off against each other in traditionally studied behavioral tasks, we present theoretical insights and experimental results from a new causal inference [3] task involving two auditory and two visual cues that allows such a dissociation (Fig. A) [4]. While the auditory cues contain information about the correct choice, the visual cues only contain information about the eccentricity at which the auditory cues are presented. As a result, an ideal observer's uncertainty about the correct choice changes in their presence, but since they do not change the choice with the higher posterior mass, they do not change its choice, nor performance (Fig. C). An approximate inference observer, on the other hand, benefits from higher certainty and, as a result is expected to improve in performance in relation how approximate its inferences are (Fig. D) – the more approximate, the larger the improvement. Since the performance of human subjects does improve, we can use this task to constrain the "coarseness" of a subject's inference computations based on their psychophysical data and the fit parameters in our model (Fig. B) that correspond to the approximate computations and model mismatch (Fig. F). Importantly, if the brain employs an approximation scheme like sampling that improves over time, we predict that the benefit due to the presence of the visual cues should decrease over time. We tested this prediction by varying the stimulus presentation time and – in agreement with the neural sampling hypothesis – found that as stimulus duration increased, both the performance benefit from the visual

cues decreased and the inferred number of samples from our model fits to the data increased (Fig. E).



A: 2AFC task. B: Causal inference model. C: Visual cues change posterior but not side with higher mass, hence performance of ideal observer. D: Model mismatch/approximate inference benefits from visual cues. E: Data shows diminishing benefit with increasing stimulus duration. F: 3 example subjects.

References

- Ernst, M. O., & Banks, M. S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature*, 415(6870), 429. [10.1038/415429a](https://doi.org/10.1038/415429a)
- Drugowitsch, J., Wyart, V., Devauchelle, A. D., & Koechlin, E. (2016). Computational precision of mental inference as critical source of human choice suboptimality. *Neuron*, 92(6), 1398-1411. [10.1016/j.neuron.2016.11.005](https://doi.org/10.1016/j.neuron.2016.11.005)
- Kording, K. P., Beierholm, U., Ma, W. J., Quartz, S., Tenenbaum, J. B., & Shams, L. (2007). Causal inference in multisensory perception. *PLoS one*, 2(9), e943. [10.1371/journal.pone.0000943](https://doi.org/10.1371/journal.pone.0000943)
- Anonymous, bioRxiv 2019

©(2019) Shivkumar S, Cappelloni MS, Maddox RK, Haefner RM

Cite as: Shivkumar S, Cappelloni MS, Maddox RK, Haefner RM (2019) Approximate causal inference based cue integration. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0093](https://doi.org/10.12751/nncn.bc2019.0093)

[W 77] Auditory Brainstem Responses from Single Neurons in the Auditory Brainstem of the Barn Owl

Paula Tuulia Kuokkanen^{1,2}, Anna Kraemer², Nadine Thiele³, Christine Köppl³, Richard Kempter^{1,4}, Catherine E Carr²

1. Institute for Theoretical Biology, Humboldt-Universität zu Berlin, Philippstrasse 13, 10115 Berlin, Germany

2. Department of Biology, University of Maryland, College Park, College Park, MD 20742, U.S.

3. Department of Neuroscience, Carl von Ossietzky Universität, 26109 Oldenburg, Germany

4. BCCN Berlin, 10115 Berlin, Germany

The auditory brainstem response (ABR) is an extracranially recorded potential, which is used for diagnosis of hearing loss, especially among newborns. The ABR is generated in the auditory brainstem by local current sources, which also give rise to extracellular field potentials (EFPs). The origins of both the ABR and the EFP are not well understood. Traditionally, synaptic dipoles have been attributed as the main sources for both. We have recently found that EFPs, especially their dipole behavior, may be dominated by the branching patterns and the activity of axonal terminal zones in the nucleus laminaris of the barn owl (McColgan et al., 2017). Furthermore, our model suggests that the dipoles from axonal terminal zones can be strong enough to contribute to extracranial potentials. To test the hypothesis that axonal arbors also shape the ABR, we used the well-described barn owl early auditory system. We recorded the ABR and a series of EFPs between the brain surface and nucleus laminaris (NL) in response to binaural clicks. We furthermore recorded extracellular single-cell responses within the nucleus magnocellularis (NM), which could be assigned to auditory nerve (AN) fibers and NM cells. The AN responses were related to the ABR wave I, and NM responses mainly to the ABR wave II, with minor contributions to the ABR wave III. Together, our data and model suggest that axonal dipoles within the barn owl nucleus laminaris can contribute to the ABR wave III.

Acknowledgements

We acknowledge the help of G.Ashida and L. Kettler. Supported by NSF CRCNS IOS1516357, NIH DC00436, NIH P30 DC0466 to the UMD Center for the Evolut. Biol. of Hearing, the Bundesministerium fuer Bildung und Forschung (BMBF): as part of the NSF/NIH/ANR/BMBF/BSF CRCNS program, 01GQ1505A and 01GQ1505B

References

- 1 McColgan, T., Liu, J., Kuokkanen, P. T., Carr, C. E., Wagner, H., & Kempter, R. (2017). Dipolar extracellular potentials generated by axonal projections. *eLife*, 6 [10.7554/eLife.26106](https://doi.org/10.7554/eLife.26106)

©(2019) Kuokkanen PT, Kraemer A, Thiele N, Köppl C, Kempter R, Carr CE

Cite as: Kuokkanen PT, Kraemer A, Thiele N, Köppl C, Kempter R, Carr CE (2019) Auditory Brainstem Responses from Single Neurons in the Auditory Brainstem of the Barn Owl. *Bernstein Conference 2019* Abstract.
doi: [10.12751/nncn.bc2019.0094](https://doi.org/10.12751/nncn.bc2019.0094)

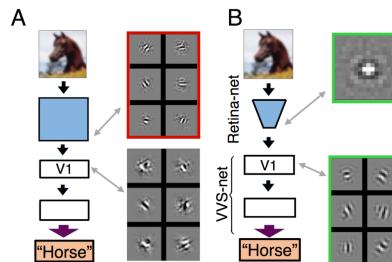
[W 78] A Unified Theory of Early Visual Representations from Retina to Cortex through Anatomically Constrained Deep CNNs

Jack Lindsey¹, Samuel A. Ocko¹, Surya Ganguli^{1,2}, Stephane Deny¹

¹. Applied Physics, Stanford University, Stanford, USA

². Google Brain, Google, Mountain View, USA

The visual system is hierarchically organized to process visual information in successive stages. Neural representations vary drastically across the first stages of visual processing: at the output of the retina, ganglion cell receptive fields (RFs) exhibit a clear antagonistic center-surround structure, whereas in the primary visual cortex, typical RFs are sharply tuned to a precise orientation. There is currently no unified theory explaining these differences in representations across layers. Here, using a deep convolutional neural network trained on image recognition as a model of the visual system, we show that such differences in representation can emerge as a direct consequence of different neural resource constraints on the retinal and cortical networks, and we find a single model from which both geometries spontaneously emerge at the appropriate stages of visual processing. The key constraint is a reduced number of neurons at the retinal output, consistent with the anatomy of the optic nerve as a stringent bottleneck. Second, we find that, for simple cortical networks, visual representations at the retinal output emerge as nonlinear and lossy feature detectors, whereas they emerge as linear and faithful encoders of the visual scene for more complex cortices. This result predicts that the retinas of small vertebrates should perform sophisticated nonlinear computations, extracting features directly relevant to behavior, whereas retinas of large animals such as primates should mostly encode the visual scene linearly and respond to a much broader range of stimuli. These predictions could reconcile the two seemingly incompatible views of the retina as either performing feature extraction or efficient coding of natural scenes, by suggesting that all vertebrates lie on a spectrum between these two objectives, depending on the degree of neural resources allocated to their visual system.



Effects of a bottleneck constraint on receptive fields (RFs). Examples of RFs of cells at selected layers of (A) a control network with no bottleneck, (B) a network with an anatomically inspired bottleneck.

©(2019) Lindsey J, Ocko SA, Ganguli S, Deny S

Cite as: Lindsey J, Ocko SA, Ganguli S, Deny S (2019) A Unified Theory of Early Visual Representations from Retina to Cortex through Anatomically Constrained Deep CNNs. Bernstein Conference 2019 Abstract.
doi: [10.12751/nncn.bc2019.0095](https://doi.org/10.12751/nncn.bc2019.0095)

[W 79] Behaviorally relevant sound source locations are differentially encoded by single neurons in the primary auditory cortex

Diana Amaro¹, Michael Pecka¹

1. Division of Neurobiology - Department Biology II, Ludwig-Maximilians-Universität München, Großhaderner Straße 2 D-82152 Planegg-Martinsried, Germany

The presence of sounds is ubiquitous in our lives and sounds are essential for navigation in complex sensory environments, such as while crossing a busy road. In a realistic situation, we simultaneously move and are exposed to several sounds while selective listening to a sound source of interest. These sounds arrive at our ears as air pressure waves that our brains must decompose into their different properties, such as the spatial location of their sources. The situationally relevant properties must then be appropriately grouped in order to create meaningful auditory objects, a process known as auditory scene analysis (ASA). When moving, the continuously changing position of the sound source of interest relative to our heads must additionally be taken into account. Given that most studies have been using head-fixed animals (egocentric reference frame) in passive conditions (presenting sounds without behavioral relevance), the underlying neuronal mechanisms behind natural ASA remain poorly understood, regardless of its crucial importance for auditory perception. The cues the brain uses for localizing a sound source in space are egocentric (comparison of sound arrival times at the two ears or sound loudness between the ears); however, during movement (e.g. rotation), these can change abruptly. This suggests that an allocentric-based neuronal code representing the relevant sound source would be advantageous. Yet, it is unclear whether such a neuronal representation exists in the auditory cortex. To investigate it, we developed a new task: HINT – hidden island navigation task - implemented in a sound localization version and combined with multiple tetrodes recordings in the auditory cortex. This task introduces behavioral relevance to different sound sources and requires constant change of the position of the animal relative to them. After constructing egocentric spatial tuning functions, we find that, as expected, some neurons have similar tuning functions for sound sources of different relevance. Interestingly, however, some neurons show differential tuning to the behaviorally relevant sound source, whose only difference to the other source is its position in space. Taken together, our findings suggest that there is allocentric information already at the level of the primary auditory cortex. This could be a mechanism that facilitates the localization of relevant sound sources during ASA.

Acknowledgements

This work was supported by DFG, IMPRS for Molecular Life Sciences and Graduate School of Systemic Neurosciences.

©(2019) Amaro D, Pecka M

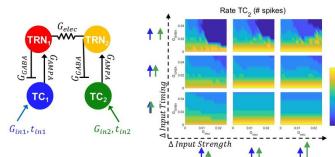
Cite as: Amaro D, Pecka M (2019) Behaviorally relevant sound source locations are differentially encoded by single neurons in the primary auditory cortex. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0096](https://doi.org/10.12751/nncn.bc2019.0096)

[W 80] Electrical synapses, plasticity, and thalamocortical relay

Tuan Pham¹, Julie S Haas¹¹. Biological Sciences, Lehigh University, 111 Research Drive, Bethlehem PA, US

As multimodal sensory information proceeds to the cortex, it is intercepted and processed by nuclei of the thalamus. The main source of inhibition within thalamus is the reticular nucleus (TRN), which collects input both from thalamocortical relay neurons and from thalamocortical feedback. Within the TRN, neurons are primarily and densely interconnected by connexin36-based gap junctions known as electrical synapses. Electrical synapses have been shown to coordinate neuronal rhythms, including thalamocortical spindle rhythms, but their role in shaping or modulating transient activity as it propagates across the brain is far less understood. Recent experimental demonstrations of long-term depression (1) and potentiation (2) of electrical synapses in TRN led us to investigate the impact of changes in electrical synapse strength on the circuit that embeds them.

We constructed a four-cell single-compartment Hodgkin-Huxley model comprising thalamic relay and TRN neurons, and used it to investigate the impact of electrical synapses on closely timed and similarly-sized inputs delivered to thalamic relay cells. We showed that the electrical synapses of the TRN enable cortical discrimination of these inputs through effects of truncation, delay or inhibition of thalamic spike trains. Electrical synapses lead to increased temporal separation and independence of relay-cell spike trains when inputs to the thalamus are dissimilar in strength and arrival timing. Conversely, electrical synapses can impose fusion of thalamocortical spiking by masking smaller strength and/or temporal differences between the incoming synaptic inputs. Thus, electrical synapses within the thalamocortical circuit strongly influence what the cortex receives from thalamus, and whether the information relayed to cortex is amenable to discrimination. Further, the modest changes in electrical synapse strength that we observe experimentally result in functional differences in circuit output. We expect that these are general principles whereby electrical synapses play similar roles in regulating the processing of transient activity in excitatory neurons across the brain. Our simulations provide specific predictions regarding the impact of electrical synapses, and their bidirectional plasticity, in thalamocortical processing.



A. Thalamocortical circuit model used to study the impact of electrical synapses on TC spiking and relay to cortex. B. Spiking in TC2 shown for varied sets of inputs (subpanels), strengths of electrical synapses (abscissa of each subpanel), and inhibitory synapses (ordinate of each subpanel).

Acknowledgements

NSF IOS 1557474, Whitehall Foundation

References

- 1 [10.1126/science.1207502](https://doi.org/10.1126/science.1207502)
- 2 [10.1101/570101](https://doi.org/10.1101/570101)

©(2019) Pham T, Haas JS

Cite as: Pham T, Haas JS (2019) Electrical synapses, plasticity, and thalamocortical relay. *Bernstein Conference 2019*
Abstract. doi: [10.12751/nncn.bc2019.0097](https://doi.org/10.12751/nncn.bc2019.0097)

[W 81] Emergence of Motion Direction Selective Neurons in Primate Visual Cortex through Spike Timing Dependent Plasticity

Alexandre Montlibert^{1,2}, Timothee Masquelier^{1,2}, Benoit Cottereau^{1,2}

1. Centre de Recherche Cerveau et Cognition, Université de Toulouse, Toulouse, France

2. Centre National de la Recherche Scientifique, Toulouse, France

A visual neuron is direction selective (DS) when it responds preferentially to one motion direction within its receptive field. To do so, it needs to process the spatial and temporal properties of moving stimuli. In macaques, where the first motion-direction selective cells are found in primary area V1, the mechanisms underlying this processing remain unclear.

Single-cell recordings have suggested that motion-direction selective cells could result from a combination of neurons with monophasic and biphasic temporal responses (because their latencies are different, with a response peak 100ms after stimuli onset for the monophasic and 70ms for the biphasic) [1]. This view is supported by the co-existence of these monophasic and biphasic neurons in the 4C layer of V1 [2]. Here, we tested this hypothesis with a spiking neural network equipped with a biologically plausible learning rule: the spike-timing dependent plasticity (STDP).

Stimuli consisted of 2000 sequences of a bar moving along 8 directions at constant speed. They were convolved with ON/OFF-center difference-of-Gaussian that mimicked the spatial properties of neurons in the lateral geniculate nucleus (Fig 1A). The product of these convolutions were filtered by impulse-response functions whose temporal properties matched those of monophasic and biphasic neurons. The resulting responses were integrated by Leaky-Integrate-and-Fire neurons (LIF) whose output spikes were sent to the spiking neural network. This neural network consisted in a simple layer of LIF neurons whose synaptic weights were ruled by the STDP rule. We characterized directional selectivity of these neurons by recording the maximal membrane potential of each neuron in response to 16 directions.

After learning, the membrane potential of each neuron was above threshold for only one direction (Fig 1B). In other words, the neurons have developed directional selectivity (DS). This result suggests that in primates, DS could arise from an unsupervised combination of outputs from monophasic and biphasic neurons.

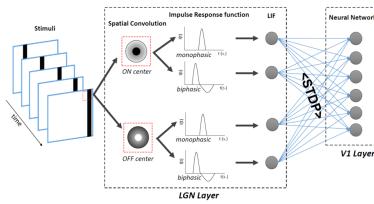


Figure 1A: Model's processing pipeline

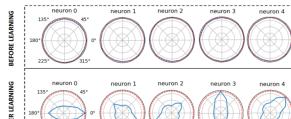


Figure 1B: Maximum membrane potential of neurons before and after learning. The direction of the bar is coded by the angle, blue lines represent the maximum membrane potential, and red dashed lines the neuron's threshold.

Before Learning, each neuron responds to every direction.

After Learning, neurons have developed directional selectivity; their membrane potentials are above threshold for only one particular direction.

References

- De Valois, R. L. & Cottaris, N. P. Inputs to directionally selective simple cells in macaque striate cortex. *Neurobiology* 95, (1998) [10.1073/pnas.95.24.14488](https://doi.org/10.1073/pnas.95.24.14488)
- Saul, A. B., Carras, P. L. & Humphrey, A. L. Temporal Properties of Inputs to Direction-Selective Neurons in Monkey V1. *J. Neurophysiol.* 94, 282–294 (2005) [10.1152/jn.00868.2004](https://doi.org/10.1152/jn.00868.2004)

©(2019) Montlibert A, Masquelier T, Cottereau B

Cite as: Montlibert A, Masquelier T, Cottereau B (2019) Emergence of Motion Direction Selective Neurons in Primate Visual Cortex through Spike Timing Dependent Plasticity. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0098](https://doi.org/10.12751/nncn.bc2019.0098)

[W 82] Encoding object transformations across distinct areas of rodent visual cortex

Juliana Y Rhee^{1,2}, Cesar Echavarria^{1,3}, Javier Masis^{1,2}, David D Cox^{1,2}

1. Center for Brain Science, Harvard University, Cambridge, MA, USA

2. Department of Molecular and Cellular Biology, Harvard University, Cambridge, MA, USA

3. Program in Neuroscience, Harvard University, Boston, MA, USA

Invariant object recognition is the ability to recognize objects despite the enormous variation with which they can appear, e.g., due to viewing angle, scale, or lighting. It is a computational feat so challenging it is widely believed to be unique to the primate visual system. However, increasing evidence suggests rodents possess far more sophisticated visual machinery than previously assumed. Rats, in particular, can perform invariant object recognition tasks [1,2,3], and their visual cortex, specifically, areas V1, LM, LI, and LL, exhibits properties similar to that of primates [4,5,6]. Here, we take advantage of optical methods, which allow simultaneous access to multiple brain regions with single-cell resolution, and present their first application to an animal model of invariant object recognition. Rats were trained on a visual task which required them to discriminate between two objects. In addition to accurate object classification across changes in scale and rotation, rats made predictable choices in response to novel, untrained objects that were parametrically varied to create a morph continuum between the two original

objects. To understand how neural circuits encode shape variations that preserve versus alter object identity, we built a custom two-photon microscope that allows simultaneous large-scale recordings ($1\text{-}2\text{ mm}^2$) with single-cell resolution. We characterize responses to object transformations in areas V1, LM, and LI of awake, head-fixed rats. We find that simple linear regressors can accurately decode size and morph level from V1 populations, consistent with the small receptive fields and edge sensitivity characteristic of early-stage visual processing. Primate studies and computational models predict this view-specific information is reduced at later processing stages in favor of more tolerant object representations that support classification and recognition behavior [4, 7, 8]. However, we find that linear readout of size is well-preserved in LI. Though rats' behavior choices reflect the morph continuum, linear regressors were worse at predicting morph level from LI populations. Aspects of our study, such as receptive field estimates and orientation tuning, are consistent with previous studies in rats [4, 5, 6] and computational models of visual processing [7, 8]. However, we also find surprising differences that may provide new insight into the computations underlying shape processing and object recognition.

Acknowledgements

We thank Ed Soucy, Joel Greenwood, and Brett Graham for microscope design and engineering, software support, and helpful discussions.

References

- 1 D. Zoccolan, N. Oertelt, J. J. DiCarlo, D. D. Cox, A rodent model for the study of invariant visual object recognition. *Proceedings of the National Academy of Sciences.* 106, 8748–8753 (2009). [10.1073/pnas.0811583106](https://doi.org/10.1073/pnas.0811583106)
- 2 A. Alemi-Neissi et al., Multifeatural Shape Processing in Rats Engaged in Invariant Visual Object Recognition. *Journal of Neuroscience.* 33, 5939–5956 (2013). [10.1523/JNEUROSCI.3629-12.2013](https://doi.org/10.1523/JNEUROSCI.3629-12.2013)
- 3 V. Djurdjevic et al., Accuracy of Rats in Discriminating Visual Objects Is Explained by the Complexity of Their Perceptual Strategy. *Current Biology.* 28, 1005–1015.e5 (2018). [10.1016/j.cub.2018.02.037](https://doi.org/10.1016/j.cub.2018.02.037)
- 4 S. Tafazoli et al., Emergence of transformation-tolerant representations of visual objects in rat lateral extrastriate cortex. *eLife.* 6 (2017). [10.7554/eLife.22794](https://doi.org/10.7554/eLife.22794)
- 5 Vermaercke B, Van den Bergh G, Gerich F, Op de Beeck H. Neural discriminability in rat lateral extrastriate cortex and deep but not superficial primary visual cortex correlates with shape discriminability. *Front Neural Circuits.* 2015;9:24. Published 2015 May 20. [10.3389/fncir.2015.00024](https://doi.org/10.3389/fncir.2015.00024)
- 6 G. Matteucci, R. Bellacosa Marotti, M. Riggi, F. B. Rosselli, D. Zoccolan, Nonlinear processing of shape information in rat lateral extrastriate cortex. *The Journal of Neuroscience,* 1938–18 (2019). [10.1523/JNEUROSCI.1938-18.2018](https://doi.org/10.1523/JNEUROSCI.1938-18.2018)
- 7 J. J. DiCarlo, D. Zoccolan, N. C. Rust, How does the brain solve visual object recognition? *Neuron.* 73, 415–34 (2012). [10.1016/j.neuron.2012.01.010](https://doi.org/10.1016/j.neuron.2012.01.010)
- 8 M. Riesenhuber, T. Poggio, Hierarchical models of object recognition in cortex. *Nature Neuroscience.* 2, 1019–1025 (1999). [10.1038/14819](https://doi.org/10.1038/14819)

©(2019) Rhee JY, Echavarria C, Masis J, Cox DD

Cite as: Rhee JY, Echavarria C, Masis J, Cox DD (2019) Encoding object transformations across distinct areas of rodent visual cortex. *Bernstein Conference 2019 Abstract.* doi: [10.12751/nncn.bc2019.0099](https://doi.org/10.12751/nncn.bc2019.0099)

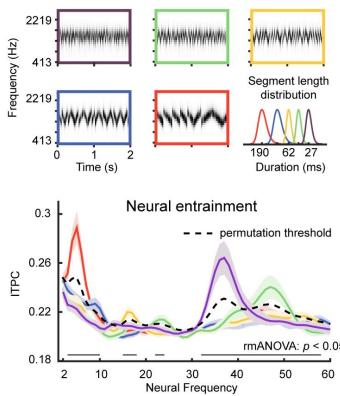
[W 83] Experimental evidence on computational mechanisms of concurrent temporal channels for auditory processing

Xiangbin Teng¹, David Poeppel^{1,2}

1. Max-Planck-Institute for Empirical Aesthetics, Grüneburgweg 14 60322 Frankfurt am Main, Germany

2. Department of Psychology, New York University, 6 Washington Place New York, NY, USA

Correctly perceiving behaviourally significant sounds—speech, music, and the acoustic environment—requires integrating acoustic information over time to extract relevant regularities. A fundamental question about this process is: How does the auditory brain integrate information of continuously varying sounds, typical of many natural auditory signals? To derive the appropriate perceptual representations, the auditory system must extract rapidly varying information on a scale of milliseconds (approximately 10–50 ms), operating with high temporal resolution, and concurrently analyse more slowly varying signal attributes on a scale of hundreds of milliseconds (about 150–300 ms), enabling sufficient spectral resolution (Poeppel, 2003). Here, we first present behavioural evidence that the human auditory system extracts fine-grained acoustic details at the timescale of 30 ms and integrates auditory information over a timescale of 200 ms to abstract global acoustic features (Teng, Tian, & Poeppel, 2016). We then looked for neural correlates for the behavioural finding by entraining the human auditory system using sounds with acoustic modulations across a wide-ranging timescales. Indeed, we found robust neural coding in the theta (4–7 Hz) and gamma (30 – 45 Hz) bands, but in between (8 – 30 Hz) (Teng & Poeppel, 2019; Teng, Tian, Rowland, & Poeppel, 2017). We then propose an computational approach to investigate how the cortical auditory system implements canonical computations at the two prominent timescales – the auditory system constructs a multi-timescale feature space to achieve sound recognition.



The upper panel shows examples of spectrograms for sounds with modulations in various temporal ranges. The lower panel shows the finding of neural entrainment.

Acknowledgements

The studies were supported by NIH 5R01DC005660 to DP and the Max-Planck-Society.

References

- Poeppel, D. (2003). The analysis of speech in different temporal integration windows: cerebral lateralization as “asymmetric sampling in time.” *Speech Commun.*, 41(1), 245–255. [10.1016/S0167-6393\(02\)00107-3](https://doi.org/10.1016/S0167-6393(02)00107-3)
- Teng, X., Tian, X., & Poeppel, D. (2016). Testing multi-scale processing in the auditory system, 6, 34390. [10.1038/srep34390](https://doi.org/10.1038/srep34390)

- 3 Teng, X., & Poeppel, D. (2019). Theta and Gamma Bands Encode Acoustic Dynamics over Wide-ranging Timescales. *bioRxiv*, 547125. [10.1101/547125](https://doi.org/10.1101/547125)
- 4 Teng, X., Tian, X., Rowland, J., & Poeppel, D. (2017). Concurrent temporal channels for auditory processing: Oscillatory neural entrainment reveals segregation of function at different scales. *PLOS Biology*, 15(11), e2000812. [10.1371/journal.pbio.2000812](https://doi.org/10.1371/journal.pbio.2000812)

©(2019) Teng X, Poeppel D

Cite as: Teng X, Poeppel D (2019) Experimental evidence on computational mechanisms of concurrent temporal channels for auditory processing. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0100](https://doi.org/10.12751/nncn.bc2019.0100)

[W 84] Fine-scale functional organization of the mouse superior colliculus

Jérémie Sibille^{1,2,3,4}, Leiron Ferrarese⁵, Carolin Gehr^{1,2,3,4}, Hiroki Asari⁵, Jens Kremkow^{1,2,3,4}

1. Bernstein Center for Computational Neuroscience Berlin, Berlin, Germany

2. Neuroscience Research Center, Charité-Universitätsmedizin Berlin, Berlin, Germany

3. Institute for Theoretical Biology, Humboldt-Universität zu Berlin, Berlin, Germany

4. Einstein Center for Neurosciences Berlin, Berlin, Germany

5. Epigenetics & Neurobiology Unit, European Molecular Biology Laboratory (EMBL Rome), Monterotondo, Italy

The superior colliculus (SC) is a layered midbrain structure that plays a central role in visual processing in the mouse. About 90% of the retinal ganglion cells (RGC) project to the SC (Kremkow & Alonso 2018) and show cell-type specific axonal projection patterns within and across different SC layers (e.g. Huberman et al. 2008). This suggests that the parallel streams of visual information, originating in the retina (Baden et al. 2016), are processed and integrated within functionally specific neuronal circuits in the SC. Recent studies have identified the functional organization of the mouse SC, such as orientation columns (Feinberg & Meister 2015, Ahmadlou & Heimel 2015) and regionally specific motion processing (de Malmazet et al. 2018). However, the fine-scale functional architecture of the SC, in particular within the deeper visual layers (lower stratum griseum superficial “ISGS”), still remains unclarified. Here we targeted the visual layers of the SC by introducing a Neuropixels probe (Jun et al. 2017) tangentially to its surface along the anterior-posterior axis. The high-density recording sites on this probe - 384 recording channels over about 4mm - gave us measurements of visually evoked signals over unprecedentedly large parts of the SC, covering response areas up to 1 to 2 mm long. To visually stimulate the full retinotopy covered by our recording sites, we presented visual stimuli in a dome (Denman et al. 2017), and to characterize the functional response properties, we presented a series of stimuli, e.g. sparse noise, moving bars and gratings, looming, and chirp stimuli. In addition to these electrophysiological recordings, we started to investigate the SC circuits using two-photon calcium imaging of SC cells and RGC axons at different depths of the SC (100-300µm below the surface). Here we will present our preliminary data suggesting that the fine-scale functional organization of the mouse superior colliculus is more elaborate than previously thought.

Acknowledgements

DFG Emmy-Noether KR 4062/4-1, EMBL Interdisciplinary Postdoc fellowship (EI3POD) and Marie Skłodowska-Curie Actions COFUND (grant number 18858)

References

- 1 Kremkow, J., & Alonso, J.-M. (2018). Thalamocortical Circuits and Functional Architecture. *Annual Review of Vision Science*, 4, 263–285. [10.1146/annurev-vision-091517-034122](https://doi.org/10.1146/annurev-vision-091517-034122)
- 2 Huberman, A. D., Manu, M., Koch, S. M., Susman, M. W., Lutz, A. B., Ullian, E. M., et al. (2008). Architecture and activity-mediated refinement of axonal projections from a mosaic of genetically identified retinal ganglion cells. *Neuron*, 59(3), 425–438. [10.1016/j.neuron.2008.07.018](https://doi.org/10.1016/j.neuron.2008.07.018)

- 3 Baden, T., Berens, P., Franke, K., Román Rosón, M., Bethge, M., & Euler, T. (2016). The functional diversity of retinal ganglion cells in the mouse. *Nature*, 529(7586), 345–350. [10.1038/nature16468](https://doi.org/10.1038/nature16468)
- 4 Feinberg, E. H., & Meister, M. (2015). Orientation columns in the mouse superior colliculus. *Nature*, 519(7542), 229–232. [10.1038/nature14103](https://doi.org/10.1038/nature14103)
- 5 Ahmadlou, M., & Heimel, J. A. (2015). Preference for concentric orientations in the mouse superior colliculus. *Nature Communications*, 6, 6773. [10.1038/ncomms7773](https://doi.org/10.1038/ncomms7773)
- 6 de Malmazet, D., Kühn, N. K., & Farrow, K. (2018). Retinotopic Separation of Nasal and Temporal Motion Selectivity in the Mouse Superior Colliculus. *Current Biology* : CB, 28(18), 2961–2969.e4. [10.1016/j.cub.2018.07.001](https://doi.org/10.1016/j.cub.2018.07.001)
- 7 Jun, J. J., Steinmetz, N. A., Siegle, J. H., Denman, D. J., Bauza, M., Barbarits, B., et al. (2017). Fully integrated silicon probes for high-density recording of neural activity. *Nature*, 551(7679), 232–236. [10.1038/nature24636](https://doi.org/10.1038/nature24636)
- 8 Denman, D. J., Siegle, J. H., Koch, C., Reid, R. C., & Blanche, T. J. (2017). Spatial Organization of Chromatic Pathways in the Mouse Dorsal Lateral Geniculate Nucleus. *Journal of Neuroscience*, 37(5), 1102–1116. [10.1523/JNEUROSCI.1742-16.2016](https://doi.org/10.1523/JNEUROSCI.1742-16.2016)

©(2019) Sibile J, Ferrarese L, Gehr C, Asari H, Kremkow J

Cite as: Sibile J, Ferrarese L, Gehr C, Asari H, Kremkow J (2019) Fine-scale functional organization of the mouse superior colliculus. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0101](https://doi.org/10.12751/nncn.bc2019.0101)

[W 85] Fitting a Computational Model of Perceptual Inference to Principal Component Weights of ERP Responses

Lukas Vogelsang^{1,2}, Lilian Weber², Sara Tomiello², Dario Schöbi², Katharina V. Wellstein², Sandra Iglesias², Klaas Enno Stephan^{2,3,4}

1. Institute of Neuroinformatics, University of Zurich & ETH Zurich, Zurich, Switzerland

2. Translational Neuromodeling Unit, University of Zurich & ETH Zurich, Zurich, Switzerland

3. Wellcome Centre for Human Neuroimaging, University College London, London, United Kingdom

4. Max Planck Institute for Metabolism Research, Cologne, Germany

The mismatch negativity (MMN), a well-studied electrophysiological response to irregularities in the sensory input stream, has often been used to examine how the brain learns the statistics of its environment. Deviations in this response have further been proposed to be indicative of certain pathologies. Patients with schizophrenia, for example, were shown to exhibit weaker MMN amplitudes [1,2]. These deviations in electrophysiology, however, cannot easily be linked to inter-individual differences in cognitive processing style due to the lack of direct behavioral readouts, which limits the paradigm's usefulness for computational psychiatry.

To bridge this gap, we here seek to relate EEG recordings acquired as part of a new variant of the roving auditory MMN paradigm to a generative model of learning and inference, the Hierarchical Gaussian Filter (HGF) [3]. We thereby draw on data from a total of 81 healthy volunteers from a previous pharmacological EEG study, which examined the effect of dopaminergic and cholinergic antagonism on MMN expression (Weber et al., in prep.). As the high level of noise in the electrophysiological data and its high dimensionality render a direct mapping from beliefs of our cognitive model to observable EEG responses challenging, we first engaged in dimensionality reduction based on multilinear principal component analysis (MPCA) and feature selection based on domain knowledge about the MMN. Subsequently, we constructed a response model for the HGF that generates trial-wise predictions of principal component weights for recorded electrophysiological responses.

Our results represent a first step towards successfully estimating parameters of the HGF based on EEG recordings. In the future, we wish to refine our response model to reduce

the parameter correlations and noise estimates in our model. We hope that our approach will increase the utility of the MMN for cognitive neuroscience and computational psychiatry by helping to reveal the nature and time course of perceptual inference in schizophrenia and other illnesses.

Acknowledgements

This study was supported by the University of Zurich and the Rene and Susanne Braginsky Foundation.

References

- 1 Avissar, M., Xie, S., Vail, B., Lopez-Calderon, J., Wang, Y., & Javitt, D. C. (2018). Meta-analysis of mismatch negativity to simple versus complex deviants in schizophrenia. [10.1016/j.schres.2017.07.009](https://doi.org/10.1016/j.schres.2017.07.009)
- 2 Schizophrenia research, 191, 25–34. Erickson, M. A., Ruffle, A., & Gold, J. M. (2016). A meta-analysis of mismatch negativity in schizophrenia: from clinical risk to disease specificity and progression. Biological psychiatry, 79(12), 980–987 [10.1016/j.biopsych.2015.08.025](https://doi.org/10.1016/j.biopsych.2015.08.025)
- 3 Mathys, C., Daunizeau, J., Friston, K. J., and Stephan, K. E. (2011). A bayesian foundation for individual learning under uncertainty. Frontiers in human neuroscience, 5:39 [10.3389/fnhum.2011.00039](https://doi.org/10.3389/fnhum.2011.00039)

©(2019) Vogelsang L, Weber L, Tomiello S, Schöbi D, Wellstein KV, Iglesias S, Stephan KE

Cite as: Vogelsang L, Weber L, Tomiello S, Schöbi D, Wellstein KV, Iglesias S, Stephan KE (2019) Fitting a Computational Model of Perceptual Inference to Principal Component Weights of ERP Responses. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0102](https://doi.org/10.12751/nncn.bc2019.0102)

[W 86] Functional brain activity underlying spontaneous reversals of kinetic depth (KDE)

Adam Ponzi^{1,2}, Ehsan Kakaei^{1,2,3}, Stepan Aleshin^{1,2}, Jochen Braun^{1,2}

1. Institute of Biology, Otto-von-Guericke University, Leipzigerstr.,44, Magdeburg, Germany

2. Center for Behavioral Brain Sciences, Leipzigerstr.,44, Magdeburg, Germany

3. ESF graduate school ABINEP, Otto-von-Guericke University, Leipziger str. 44, Magdeburg, Germany

To investigate the neural dynamics underlying reversals in multistable perception, we established fMRI signal time-courses while observers viewed ambiguous KDE displays with either spontaneous or forced reversals. After preprocessing in MNI152 space (voxel size 2mm, Siemens 3T Prisma, TR 1s, 4800s per condition), BOLD activity was pooled into 758 functional clusters (MD758 parcellation, cluster size approximately 12mm). An event-based analysis of activity before and after reversals revealed several groups of clusters with characteristic time-courses, some differing significantly between spontaneous and forced reversals. Analysis of Hilbert-transformed activity revealed elevated phase coherence up to 8s prior to spontaneous reversals near temporoparietal junction (TPJ) and intraparietal sulcus (IPS), among other areas. A correlational analysis of pairwise functional connectivity (FC) between clusters revealed numerous differences between spontaneous and forced reversals (2×10^4 pairs at $p < 0.05$, after false discovery correction). A graph theoretical analysis of these differences again highlighted temporoparietal junction (TPJ) and intraparietal sulcus (IPS). We conclude that functional pooling of fMRI signals reveals the dynamics underlying multistable reversals in novel detail.

Acknowledgements

The project was funded by the federal state Saxony-Anhalt and the European Structural and Investment Funds (ESF, 2014-2020), project number ZS/2016/08/80645.

©(2019) Ponzi A, Kakaei E, Aleshin S, Braun J

Cite as: Ponzi A, Kakaei E, Aleshin S, Braun J (2019) Functional brain activity underlying spontaneous reversals of kinetic depth (KDE). Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0103](https://doi.org/10.12751/nncn.bc2019.0103)

[W 87] Functional properties of mouse ganglion cells across retinal space

Larissa Höfling^{1,2,3}, Katrin Franke^{3,4}, Klaudia Szatko^{3,4}, Philipp Berens^{1,3,4}, Matthias Bethge^{1,4}, Thomas Euler^{1,3,4}

1. Centre for Integrative Neuroscience, University of Tübingen, Germany

2. Graduate Training Centre of Neuroscience, University of Tübingen, Germany

3. Institute for Ophthalmic Research, University of Tübingen, Germany

4. Bernstein Centre for Computational Neuroscience, University of Tübingen, Germany

Efficient coding theory (1,2) predicts that an organism's sensory systems in general, and thus its visual system in particular, should be built in a way to efficiently encode sensory inputs. The retinal code, in order to be efficient and ecologically adapted, is therefore expected to depend on the statistics of the visual environment the animal lives in and that it samples with its eyes (3). These statistics differ between species, but may also vary across visual space within one species, which appears to be reflected in regional specializations of retinal circuits (see for example (4–7)) Here, we aim to systematically analyze the nature and extent of such regional specializations in the mouse across many different retinal ganglion cell (RGC) types using a large dataset of two-photon calcium imaging data of RGC activity. The dataset consists of RGC responses to a diverse set of stimuli, including a chirp stimulus, moving bars and natural movies recorded from the mouse perspective (see abstract/poster by Qiu et al.), extending the dataset of Baden, Berens, Franke et al. (2016) (8) by sampling from all regions of the retina. Using Datajoint, a hybrid of data analysis pipeline and database (9), we are currently curating and analyzing this dataset, and investigate whether specific features such as receptive field size vary depending on retinal location, and whether and how such regional variations can be disentangled from inter-cell-type variability. Furthermore, based on statistical analyses of the natural movies performed in a closely related project (see poster by Qiu et al.), we generate predictions about regional specializations in the framework of the efficient coding theory and test whether we find these predictions satisfied in our dataset.

Acknowledgements

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Projektnummer 276693517 – SFB 1233. This study is part of the research program of the Bernstein Center for Computational Neuroscience, Tuebingen, funded by BMBF, FKZ: 01GQ1002; MPG M.FE.A.KYBE0004

References

- 1 Attnave F. Some informational aspects of visual perception. *Psychol Rev.* 1954;61(3):183–93 [10.1037/h0054663](https://doi.org/10.1037/h0054663)
- 2 Barlow HB. Possible Principles Underlying the Transformations of Sensory Messages. *Sens Commun.* 1961;218–34 [10.7551/mitpress/9780262518420.003.0013](https://doi.org/10.7551/mitpress/9780262518420.003.0013)
- 3 Simoncelli EP, Olshausen BA. Natural Image Statistics and Neural Representation. *Annu Rev Neurosci.* 2001;24:1193–216 [10.1146/annurev.neuro.24.1.1193](https://doi.org/10.1146/annurev.neuro.24.1.1193)
- 4 Szél A, Röhlich P, Caffé AR, Juliusson B, Aguirre G, Van Veen T. Unique topographic separation of two spectral classes of cones in the mouse retina. *J Comp Neurol* 1992;325(3):327–42 [10.1002/cne.903250302](https://doi.org/10.1002/cne.903250302)
- 5 Baden T, Schubert T, Chang L, Wei T, Zaichuk M, Wissinger B, et al. A tale of two retinal domains: Near-Optimal sampling of achromatic contrasts in natural scenes through asymmetric photoreceptor distribution. *Neuron*. 2013;80(5):1206–17 [10.1016/j.neuron.2013.09.030](https://doi.org/10.1016/j.neuron.2013.09.030)
- 6 Bleckert A, Schwartz GW, Turner MH, Rieke F, Wong ROL. Visual space is represented by non-matching topographies of distinct mouse retinal ganglion cell types. *Curr Biol*. 2014;24(3):310–5 [10.1016/j.cub.2013.12.020](https://doi.org/10.1016/j.cub.2013.12.020)
- 7 Warwick RA, Kaushansky N, Sarid N, Golan A, Rivlin-Etzion M. Inhomogeneous Encoding of the Visual Field in the Mouse Retina. *Curr Biol*. 2018;28(5):655–665.e3 [10.1016/j.cub.2018.01.016](https://doi.org/10.1016/j.cub.2018.01.016)
- 8 Baden T, Berens P, Franke K, Román Rosón M, Bethge M, Euler T. The functional diversity of retinal ganglion cells in the mouse. *Nature*. 2016;529(7586):345–50 [10.1038/nature16468](https://doi.org/10.1038/nature16468)
- 9 Yatsenko D, Reimer J, Ecker AS, Walker EY, Sinz F, Berens P, et al. DataJoint: managing big scientific data using MATLAB or Python. *bioRxiv*. 2015;031658. [10.1101/031658](https://doi.org/10.1101/031658)

Neurons, networks, dynamical systems

[W 88] A bridge from large deviation theory to statistical field theory

Alexander van Meegen^{1,2}, Tobias Kühn^{1,2}, Moritz Helias^{1,2}

1. Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA-Institute Brain Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany

2. Faculty 1, RWTH Aachen University, Aachen, Germany

Understanding collective phenomena in large-scale recurrent networks is a notoriously difficult problem which is approached along different lines of attack. On the mathematical side, large deviation theory yields rigorous results for the leading order behavior as the network size N tends to infinity. Methods from statistical physics, on the other hand, provide highly efficient schemes to obtain systematic approximations, including finite N corrections. Particularly the latter methods recently evoked considerable interest in the computational neuroscience community [1-5]. However, it is still unclear if both approaches lead to consistent results.

We bridge between these two descriptions starting from both sides. First, we show that the result of the large deviation principle obtained by Arous & Guionnet [6], i.e. the measure which extremizes the rate function, is equivalent to the result of a saddle-point approximation as pioneered by Sompolinsky and coworkers [7, 8]. Second, we re-derive the rate function from [6] using statistical field theory, again employing a saddle-point approximation. As a byproduct, we show that the rate function can be simplified to a Kullback-Leibler divergence (relative entropy).

A bridge between these different approaches is important to expose the relative strengths and weaknesses of either approach and to obtain a set of tools that can handle a larger variety of problems than a single method could provide.

Acknowledgements

Partly supported by the Helmholtz young investigator's group VH-NG-1028 and European Union Horizon 2020 grant 785907 (Human Brain Project SGA2).

References

- 1 F. Mastrogiovanni, and S. Ostoic, *Neuron* 99.3, 609-623 (2018) [10.1016/j.neuron.2018.07.003](https://doi.org/10.1016/j.neuron.2018.07.003)
- 2 D. Dahmen, S. Grün, M. Diesmann, and M. Helias, *PNAS* 116.26, 13051-13060 (2019) [10.1073/pnas.1818972116](https://doi.org/10.1073/pnas.1818972116)
- 3 J. Schuecker, S. Goedeke, and M. Helias, *Phys. Rev. X* 8, 041029 (2018) [10.1103/PhysRevX.8.041029](https://doi.org/10.1103/PhysRevX.8.041029)
- 4 A. van Meegen, and B. Lindner, *Phys. Rev. Lett.* 121, 258302 (2018) [10.1103/PhysRevLett.121.258302](https://doi.org/10.1103/PhysRevLett.121.258302)
- 5 S. P. Muscinelli, W. Gerstner, and T. Schwalger, *PLoS CB* 15.6, e1007122 (2019) [10.1371/journal.pcbi.1007122](https://doi.org/10.1371/journal.pcbi.1007122)
- 6 G. B. Arous and A. Guionnet, *Probabil. Theory Related Fields* 102.4, 455-509 (1995) [10.1007/BF01198846](https://doi.org/10.1007/BF01198846)
- 7 H. Sompolinsky and A. Zippelius, *Phys. Rev. B* 25, 6860 (1982) [10.1103/PhysRevB.25.6860](https://doi.org/10.1103/PhysRevB.25.6860)
- 8 H. Sompolinsky, A. Crisanti, and H. J. Sommers, *Phys. Rev. Lett.* 61, 259 (1988) [10.1103/PhysRevLett.61.259](https://doi.org/10.1103/PhysRevLett.61.259)

©(2019) van Meegen A, Kühn T, Helias M

Cite as: van Meegen A, Kühn T, Helias M (2019) A bridge from large deviation theory to statistical field theory. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0105](https://doi.org/10.12751/nncn.bc2019.0105)

[W 89] A Cortical Microcircuit Model with Three Critical Interneuron Groups

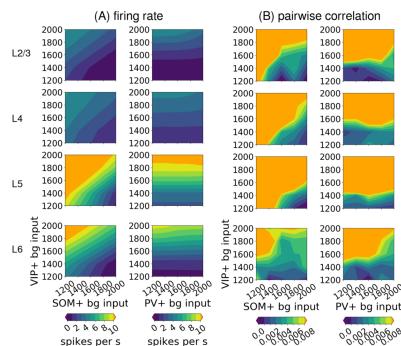
Han-Jia Jiang¹, Sacha J van Albada¹

1. Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA Institute Brain Structure-Function Relationships (INM-10), Jülich Research Centre, Wilhelm-Johnen-Straße, Germany

Three non-overlapping GABAergic interneuron subtypes, parvalbumin-positive (PV+) cells, somatostatin-positive (SOM+) cells, and vasoactive intestinal peptide-positive (VIP+) cells, account for >80 % of all interneurons in cerebral cortex and have important regulatory functions in the microcircuit. To study their roles in microcircuit dynamics and signal processing, we incorporate these three groups in a layered microcircuit model adjusted from [1].

The cell populations and dimensions of our model are according to the rat C2 barrel column. The specific connection probabilities between populations are determined from data of rat S1 and V1 cortices collected from paired recording experiments. For this we assume: 1. the connection probability between any two neurons decays exponentially with a length constant of 160 m, and 2. all experimental data are sampled with intersoma distances of 100 m. For connections where experimental data are not available, we use algorithmic estimates from [2]. Synaptic strengths are distributed lognormally, and short-term plasticity is included for certain connections according to [3]. The model is then tested with various levels of background input (1200 to 2000 connections per cell) to the three interneuron subtypes to study their contributions to the firing pattern of excitatory cells.

The results of 10-s simulations using NEST show that the firing pattern changes with the combined effect of background inputs to SOM+ and VIP+ cells (see figure). Specifically, sparser input to SOM+ cells and denser input to VIP+ cells cooperatively cause stronger and more synchronous (higher pairwise correlation) firing, and the opposite causes less and asynchronous firing according to criteria established from *in vivo* data (pairwise correlation <0.008 [4]). In contrast, PV+ cells show less interaction with VIP+ cells in terms of affecting the firing pattern. These results are consistent with the disinhibitory function of VIP+ cells [5], which releases the excitatory cells from the inhibition by SOM+ cells to make them more responsive. This shows that the current model can reflect circuit mechanisms proposed in animal studies. Further modifications such as using multi-compartment neurons and neuromodulator effects, may disclose how the interneurons are involved in critical mechanisms such as dendritic signal processing and state-dependent regulation of sensory responses.



Firing pattern of excitatory cells under the effects of three interneuron subtypes. (A) Firing rates. (B) Average pairwise correlations. Each column shows the data of varying background input densities for VIP+ and SOM+ or PV+ cells. The unit of the coordinates is connections per cell.

Acknowledgements

This work received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under the Specific Grant Agreement No. 785907 (Human Brain Project SGA2).

References

- 1 Potjans, T. C., & Diesmann, M. (2014). The cell-type specific cortical microcircuit: relating structure and activity in a full-scale spiking network model. *Cerebral Cortex*, 24(3), 785–806. [10.1093/cercor/bhs358](https://doi.org/10.1093/cercor/bhs358)
- 2 Markram, H., Müller, E., Ramaswamy, S., Reimann, M. W., Abdellah, M., Sanchez, C. A., ... & Kahou, G. A. A. (2015). Reconstruction and simulation of neocortical microcircuitry. *Cell*, 163(2), 456–492. [10.1016/j.cell.2015.09.029](https://doi.org/10.1016/j.cell.2015.09.029)
- 3 Litwin-Kumar, A., Rosenbaum, R., & Doiron, B. (2016). Inhibitory stabilization and visual coding in cortical circuits with multiple interneuron subtypes. *Journal of Neurophysiology*, 115(3), 1399–1409. [10.1152/jn.00732.2015](https://doi.org/10.1152/jn.00732.2015)
- 4 Maksimov, A., Diesmann, M., & van Albada, S. J. (2018) Criteria on balance, stability, and excitability in cortical networks for constraining computational models. *Frontiers in Computational Neuroscience*, 12:44. [10.3389/fncom.2018.00044](https://doi.org/10.3389/fncom.2018.00044)
- 5 Fu, Y., Tucciarone, J. M., Espinosa, J. S., Sheng, N., Darcy, D. P., Nicoll, R. A., ... & Stryker, M. P. (2014). A cortical circuit for gain control by behavioral state. *Cell*, 156(6), 1139–1152. [10.1016/j.cell.2014.01.050](https://doi.org/10.1016/j.cell.2014.01.050)

©(2019) Jiang H, van Albada SJ

Cite as: Jiang H, van Albada SJ (2019) A Cortical Microcircuit Model with Three Critical Interneuron Groups. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0106](https://doi.org/10.12751/nncn.bc2019.0106)

[W 90] Action potential propagation in long-range axonal fibre bundles

Helmut Schmidt¹, Thomas R. Knösche^{1,2}

1. Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstr. 1a, 04103 Leipzig, Germany

2. Institute of Biomedical Engineering and Informatics, Technische Universität Ilmenau, Gustav-Kirchhoff-Str. 2, 98693 Ilmenau, Germany

With the advent of advanced MRI techniques, it has become possible to study the structure of cerebral white matter non-invasively and in great detail. Measuring the various parameters of long-range axonal connections in the brain opens up the possibility to build and refine whole brain models that incorporate delays specific to the white matter structure. One particular challenge is to find a mathematical description of action potential propagation that is sufficiently simple, yet still biologically plausible to study the effect of model parameters on action potential velocity efficiently and in great detail. We develop a mathematical framework that can achieve this by replacing the Hodgkin-Huxley dynamics with a spike-diffuse-spike framework with passive sub-threshold dynamics and explicit, threshold-activated ion currents.

Specifically, we recover known results regarding the influence of axon diameter, node of Ranvier length and internode length on the velocity of action potentials [1]. The velocity scales approximately linearly with the diameter in myelinated axons, and with the square root of the diameter in unmyelinated axons. The velocity shows a maximum at values of node and internode length in myelinated axons that correspond to experimentally observed values, thus suggesting that the axonal microstructure is optimised for high velocities. Furthermore, we find that the velocity depends more strongly on the thickness of the myelin sheath than was suggested by previous theoretical studies [2]. In addition to the parameter dependence in single axons, we explain the slowing down and synchronisation of action potentials in ephaptically coupled fibres through changes in the effective electrotonic length constant. We observe the same effect of threshold perturbation within passive fibres by action potentials passing through neighbouring axons that has been observed experimentally [3].

Acknowledgements

HS was supported by the German Research Foundation (DFG Priority Program 2041 ‘Computational Connectomics’, awarded to TRK)

References

- 1 IL Arancibia-Cárcamo, MC Ford, L Cossell, et. al. Node of Ranvier length as a potential regulator of myelinated axon conduction speed. *Elife*, 6: e23329, 2017.
- 2 WAH Rushton. A theory of the effects of fibre size in medullated nerve. *Journal of Physiology*, 115: 101 – 122, 1951.
- 3 B Katz, O Schmitt. Electric interaction between two adjacent nerve fibres. *Journal of Physiology*, 97: 471 – 488, 1940.

©(2019) Schmidt H, Knösche TR

Cite as: Schmidt H, Knösche TR (2019) Action potential propagation in long-range axonal fibre bundles. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0107](https://doi.org/10.12751/nncn.bc2019.0107)

[W 91] Activity-constrained full-scale cortical microcircuit models of macaque higher-order cortices

Aitor Morales-Gregorio^{1,2}, Paulina Dąbrowska^{1,2}, Bjørg Kilavik³, Georgia G. Gregoriou^{4,5}, Thomas Brochier³, Markus Diesmann^{1,6,7}, Sonja Grün^{1,8}, Johanna Senk¹, Sacha J. van Albada¹

1. Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA-Institut Brain Structure-Function Relationships (INM-10), Forschungszentrum Jülich, Jülich, Germany

2. RWTH Aachen University, Aachen, Germany

3. Institut de Neurosciences de la Timone (INT), CNRS & Aix-Marseille Université, Marseille, France

4. Institute of Applied and Computational Mathematics, Foundation for Research and Technology Helios, Heraklion, Crete, Greece

5. Department of Basic Sciences, Medical School, University of Crete, Heraklion, Crete, Greece

6. Department of Physics, Faculty 1, RWTH Aachen University, Aachen, Germany

7. Department of Psychiatry, Psychotherapy and Psychosomatics, School of Medicine, RWTH Aachen University, Aachen, Germany

8. Theoretical Systems Neurobiology, RWTH Aachen University, Aachen, Germany

The primate brain is a complex system and many aspects of the relation between its cortical structure and network activity remain to be understood. Networks with closely similar structures can perform very different tasks [1]. Conversely, very different network structures can lead to similar activity [2].

A bottom-up cortical point neuron network model of early sensory cortices is able to recover realistic first-order spike train statistics [3], giving some insight into the relationship between structure and activity. This model can be constructed owing to the availability of extensive anatomical and physiological data from visual and somatosensory areas. However, such measurements are less abundant for higher-order areas (motor, prefrontal, parietal). Thus, the bottom-up modeling approach cannot be applied to all cortical areas until further biological measurements are published.

In order to overcome this limitation, we construct spiking models of macaque higher-order cortical areas by joining bottom-up modeling with a top-down method. The models are first characterized using the available anatomical and physiological data for the corresponding brain regions, after which the missing information is completed with observations from other areas and species. Subsequently, we explore the parameter space within biological ranges by comparing the simulated dynamics against electrophysiological *in vivo* single-unit activity. Standardized statistical test metrics enable the quantitative assessment of similarity between the network models and experimental recordings, on the level of the single-unit spike train dynamics [4]. This enables parameter sets to be identified for which the models produce realistic dynamics.

Extracellular recordings from macaque motor (M1, PMd) [5], prefrontal (FEF) and visual (V4) [6] cortices are used to construct models of the respective areas. A quantitative assessment of the model parameters provides insight into whether communication within higher cortical areas shares comparable principles with sensory areas or follows different schemes. Future work will integrate these models into a single large-scale cortical multi-area model, extending previous work [7, 8].

Acknowledgements

This project has received funding from the DFG Priority Program (SPP 2041 "Computational Connectomics") [S.J. van Albada: AL 2041/1-1]; the EU's Horizon 2020 Framework Grant Agreement No. 785907 (HBP-SGA2) and the DFG (RTG 2416 "MultiSenses-MultiScales").

References

- 1 R. J. Douglas, K. A. C. Martin and D. Whitteridge. A canonical microcircuit for neocortex. *Neural computation* 1(4), 480-488 (1989) [10.1162/neco.1989.1.4.480](https://doi.org/10.1162/neco.1989.1.4.480)
- 2 A. A. Prinz, D. Bucher and E. Marder. Similar network activity from disparate circuit parameters. *Nature Neuroscience* 7, 1345-1352 (2004) [10.1038/nn1352](https://doi.org/10.1038/nn1352)
- 3 T. C. Potjans and M. Diesmann. The cell-type specific cortical microcircuit: Relating structure and activity in a full-scale spiking network model. *Cerebral Cortex* 24(3), 785-806 (2014) [10.1093/cercor/bhs358](https://doi.org/10.1093/cercor/bhs358)
- 4 R. Gutzen, M. von Papen, G. Trensch, P. Quaglio, S. Grün, and M. Denker. Reproducible neural network simulations: Statistical methods for model validation on the level of network activity data. *Frontiers in Neuroinformatics*, 12:90, (2018) [10.3389/fninf.2018.00090](https://doi.org/10.3389/fninf.2018.00090)
- 5 B. E. Kilavik. Directional selectivity across macaque motor cortical layers during reach planning and execution. Program No. 587.19. 2018 Neuroscience Meeting Planner. San Diego, CA: Society for Neuroscience, 2018. Online.
- 6 G.G. Gregoriou, S.J. Gotts and R. Desimone (2012) Cell-type-specific synchronization of neural activity in FEF with V4 during attention. *Neuron* 73:581-594 [10.1016/j.neuron.2011.12.019](https://doi.org/10.1016/j.neuron.2011.12.019)
- 7 M. Schmidt, R. Bakker, C. C. Hilgetag, M. Diesmann, and S. J. van Albada. Multi-scale account of the network structure of macaque visual cortex. *Brain Structure and Function* 223(3), 1409-1435 (2018) [10.1007/s00429-017-1554-4](https://doi.org/10.1007/s00429-017-1554-4)
- 8 M. Schmidt, R. Bakker, K. Shen, G. Bezgin, M. Diesmann, and S. J. van Albada. A multi-scale layer-resolved spiking network model of resting-state dynamics in macaque visual cortical areas. *PLOS Computational Biology* 14(10), e1006359 (2018) [10.1371/journal.pcbi.1006359](https://doi.org/10.1371/journal.pcbi.1006359)

©(2019) Morales-Gregorio A, Dąbrowska P, Kilavik B, Gregoriou GG, Brochier T, Diesmann M, Grün S, Senk J, van Albada SJ

Cite as: Morales-Gregorio A, Dąbrowska P, Kilavik B, Gregoriou GG, Brochier T, Diesmann M, Grün S, Senk J, van Albada SJ (2019) Activity-constrained full-scale cortical microcircuit models of macaque higher-order cortices. *Bernstein Conference 2019* Abstract. doi: [10.12751/ncnc.bc2019.0108](https://doi.org/10.12751/ncnc.bc2019.0108)

[W 92] **Adaptation in auditory cortex explained as a modulation of the network dynamics of coupled damped harmonic oscillators**

Aida Hajizadeh¹, Artur Matysiak¹, Matthias Wolfrum², Patrick J.C. May³, Reinhard König¹

1. Special Lab Non-Invasive Brain Imaging, Leibniz Institute for Neurobiology, Magdeburg, Germany

2. Laser Dynamics, Weierstrass Institute for Applied Analysis and Stochastics, Berlin, Germany

3. Department of Psychology, Lancaster University, Lancaster, United Kingdom

Neural responses in the auditory cortex (AC), measured on the microscopic as well as on the macroscopic level, adapt to the temporal structure of stimulus presentation. In the magnetoencephalogram, this adaptation manifests itself most clearly in the N1m response, the most prominent deflection of the auditory event-related field. The magnitude of the N1m attenuates with stimulus repetition and is inversely related to stimulation rate. It has been suggested that short-term synaptic depression, reflecting vesicle depletion due to pre-synaptic activity, accounts for neural adaptation. Here, we address this phenomenon by a computational model which is based on the hierarchical core-belt-parabelt structure of the AC. The computational unit of the model is a simplified description of the cortical column and comprises one excitatory and one inhibitory cell population characterized by linear firing rates. In this framework, we can explain the dynamics of AC in terms of uncoupled damped harmonic oscillators, i.e., normal modes. To investigate neural adaptation, a sequence of isochronous stimuli was presented to the model, and the connection weights between the excitatory cell populations adapted in a way depending on the level of pre-synaptic activation. We show that the distribution of the damping frequency of the normal modes shifts to higher values in the adapted states compared to the non-adapted states. Furthermore, in the adapted states the input is distributed to a smaller set of preponderant normal modes

than when no adaptation is present. Our results suggest that adaptation is not just a simple attenuation of cortical responsiveness but, rather, it reconfigures the dynamics of the entire auditory cortex.

Acknowledgements

We are grateful for an MMS seed money grant of the Leibniz Association. Further, we also acknowledge the support by the European Union's Horizon 2020 research and innovation programme (Grant Agreement 763959).

©(2019) Hajizadeh A, Matysiak A, Wolfrum M, May PJ, König R

Cite as: Hajizadeh A, Matysiak A, Wolfrum M, May PJ, König R (2019) Adaptation in auditory cortex explained as a modulation of the network dynamics of coupled damped harmonic oscillators. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0109](https://doi.org/10.12751/nncn.bc2019.0109)

[W 93] A draft cell atlas for the mouse spinal cord

Ihor Kuras¹, Marc-Oliver Gewaltig¹, Henry Markram¹

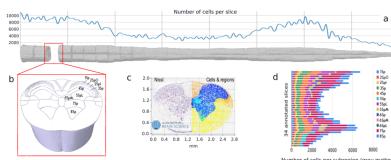
1. Blue Brain Project, Ecole Polytechnique Federale de Lausanne (EPFL), Campus Biotech, Chemin des Mines, 9 CH, 1202 Geneva, Switzerland

The Allen Institute for Brain Science (AIBS) has published a data-set with high-resolution Nissl staining images of the mouse spinal cord (AIBS, 2008) along with annotations, outlining its major nuclei. Here we present a first draft Cell Atlas for the Mouse Spinal Cord, obtained by integrating data from the AIBS and other data sets.

Our draft Spinal Cord Cell Atlas has three parts: 1. the 3D reference volumes (outlines) of the complete spinal cord and its 84 subregions. 2. Estimates of the total number of cells in the spinal cord as well as the number and positions of cells in each subregion. 3. Gene expression levels for about 23,000 genes present in the Allen Spinal Cord data, aligned to our reference volume.

To generate our draft Cell Atlas, we followed a similar workflow as Erö et al. (2018): First, the spinal cord annotations from the AIBS were aligned and then interpolated to obtain a continuous mesh of the spinal cord (figure a,b). Second, cell densities were extracted from the Nissl staining images (figure c), interpolated along the whole spinal cord, and assigned to their respective spinal subregion. Thus, we could determine the number of cells in each subregion (figure d). Third, all cells were assigned to one of the main types (neurons, glia, endothelial), according to the distribution of the respective cell type. Cell type distributions were estimated by analyzing the shape, size, and saturation of specs in the Nissl images (García-Cabezas et al., 2016). Finally, the detected cells were also labeled with the estimated gene expression levels at the respective position.

The estimated numbers of cells (figure a) are in good agreement with the literature (Bjuggn, 1993). Labels (assigned to cells) provide us with information for further classification of cells by subtypes such as interneuron types (Delile et al., 2018).



A draft cell atlas for the mouse spinal cord (SC): a. 3D mesh of SC with number of cells; b. nuclei segment of SC with labeled main subregions of gray matter; c. cell densities extracted from Nissl staining images and assigned to SC subregions; d. number of cells within subregion per slice

Acknowledgements

We acknowledge the excellent data of the Allen Institute for Brain Science (mousespinal.brain-map.org). Funding was received from the European Commission H2020 Specific Grant Agreement No.785907 (Human Brain Project SGA2) and the Blue Brain Project at the EPFL, from the Swiss government's ETH Board

References

- 1 Allen Institute for Brain Science "Mouse spinal cord Atlas", 2008
- 2 Csaba Erő, Marc-Oliver Gewaltig, Daniel Keller and Henry Markram "A Cell Atlas for the Mouse Brain", *Front. Neuroinform.*, 28 November 2018 [10.3389/fninf.2018.00084](https://doi.org/10.3389/fninf.2018.00084)
- 3 Miguel Á. García-Cabezas, Yohan J. John, Helen Barbas and Basilis Zikopoulos "Distinction of Neurons, Glia and Endothelial Cells in the Cerebral Cortex: An Algorithm Based on Cytological Features", *Front. Neuroanat.*, 01 November 2016 [10.3389/fnana.2016.00107](https://doi.org/10.3389/fnana.2016.00107)
- 4 Roger Bjørgen "The use of the optical disector to estimate the number of neurons, glial and endothelial cells in the spinal cord of the mouse - with a comparative note on the rat spinal cord", *Brain research*, ISSN: 0006-8993, Vol: 627, Issue: 1, Page: 25-33, 1993 [10.1016/0006-8993\(93\)90744-8](https://doi.org/10.1016/0006-8993(93)90744-8)
- 5 Julien Delile, Teresa Rayon, Manuela Melchionda, Amelia Edwards, James Briscoe and Andreas Sagner "Single cell transcriptomics reveals spatial and temporal dynamics of gene expression in the developing mouse spinal cord", *bioRxiv* 472415, 2018 [10.1101/472415](https://doi.org/10.1101/472415)

©(2019) Kuras I, Gewaltig M, Markram H

Cite as: Kuras I, Gewaltig M, Markram H (2019) A draft cell atlas for the mouse spinal cord. *Bernstein Conference 2019*
Abstract. doi: [10.12751/nnccn.bc2019.0110](https://doi.org/10.12751/nnccn.bc2019.0110)

[W 94] Anatomically embedded scaffold model of the mouse cerebellar cortex

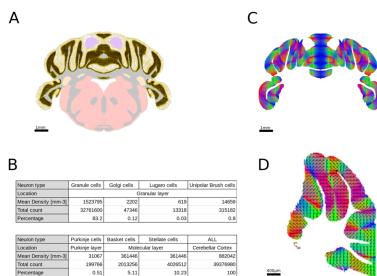
Dimitri Rodarie¹, Csaba Erő¹, Alberto Antonietti², Marc-Oliver Gewaltig¹, Henry Markram¹

1. Blue Brain Project, Campus Biotech, Chemin des Mines 9, 1202 Geneva, Switzerland

2. Nearlab - NeuroEngineering and Medical Robotics Laboratory, Department of Electronics, Information and Bioengineering, Politecnico di Milano - Piazza Leonardo da Vinci, 32, 20133 Milano, Italy

Casali et al. (2019) have recently published a point neuron network model of the cerebellar cortex of the mouse, representing a $400 \times 400 \times 900 \mu\text{m}^3$ volume of cerebellar tissue, with 96,737 neurons and 4,220,752 synapses. Here, we demonstrate, how this model can be used to create a 3D representation of the mouse cerebellar cortex, embedded into an anatomically realistic whole mouse brain structure. We based our scaffold model on the freely available cell positions of Blue Brain Cell Atlas (Erő et al. 2018), which we extended with the Purkinje layer at the boundary between Granular and Molecular layers. We also added Unipolar brush cells and Lugaro cells based on regional densities from Sekerkova et al. (2014) and Dieudonné and Dumoulin (2000), respectively. The remaining cell types and their numbers were estimated using regional distributions from the Blue Brain Cell Atlas (Figure 1.A). To reconstruct connectivity

within the cerebellar cortex, we computed the orientations of ascending axons and parallel fibers (Figure 1.CD), and combined them with axonal length limits and synaptic in- and out-degree ratios reported by Casali et al. (2019). The final scaffold model has 39,376,980 neurons, with 0.51% Purkinje cells, 83.20% Granule cells, 0.12% Golgi cells, 0.03% Lugano cells, 0.80% Unipolar brush cells, 10.23% Stellate cells, 5.11% Basket cells (Figure 1.B). We assigned point-neuron electrical parameters to each of our cells and synaptic parameters to each of our connection types, according to Casali et al. (2019). The resulting scaffold model is about 400 times larger than the original counterpart of Casali et al. (2019) and can be simulated using the Neural Simulation Tool NEST (Gewaltig and Diesmann, 2007). The model will be iteratively refined as more data become available. We present results from simulations at multiple scales and compare them to the results of Casali et al. (2019).



A) Slice of the mouse brain model. Yellow dots represent cells. The granular layer is visible as a dark band due to its density. **B)** Counts and densities of the cerebellum model. **CD)** Orientation field of ascending axons, in coronal and sagittal views. Colors represent orientation vector components.

Acknowledgements

This study was supported by funding to the Blue Brain Project, a research center of the École polytechnique fédérale de Lausanne, from the Swiss government's ETH Board of the Swiss Federal Institutes of Technology. This work would not have been possible without the excellent work of the Allen Brain.

References

- 1 Casali, S., Marenzi, E., Medini, C., Casellato, C., & D'Angelo, E. (2019). Reconstruction and Simulation of a Scaffold Model of the Cerebellar Network. *Frontiers in Neuroinformatics*, 13, 37. [10.3389/fninf.2019.00037](https://doi.org/10.3389/fninf.2019.00037)
- 2 Erő, C., Gewaltig, M.-O., Keller, D., & Markram, H. (2018). A Cell Atlas for the Mouse Brain. *Frontiers in Neuroinformatics*, 12, 84. [10.3389/fninf.2018.00084](https://doi.org/10.3389/fninf.2018.00084)
- 3 Sekerková, G., Watanabe, M., Martina, M., & Mugnaini, E. (2014). Differential distribution of phospholipase C beta isoforms and diacylglycerol kinase-beta in rodents cerebellar corroborates the division of unipolar brush cells into two major subtypes. *Brain Structure and Function*, 219(2), 719–749. [10.1007/s00429-013-0531-9](https://doi.org/10.1007/s00429-013-0531-9)
- 4 Dieudonné, S., & Dumoulin, A. (2000). Serotonin-Driven Long-Range Inhibitory Connections in the Cerebellar Cortex. *The Journal of Neuroscience*, 20(5), 1837–1848. [10.1523/JNEUROSCI.20-05-01837.2000](https://doi.org/10.1523/JNEUROSCI.20-05-01837.2000)
- 5 Gewaltig, M.-O., & Diesmann, M. (2010). NEST (NEural Simulation Tool). *Scholarpedia*, 2(4), 1430. [10.4249/scholarpedia.1430](https://doi.org/10.4249/scholarpedia.1430)

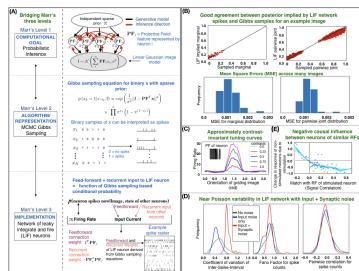
[W 95] A neural-sampling based model of early visual processing based on leaky integrate-and-fire neurons

Ankani Chattoraj¹, Richard Lange¹, Shuchen Wu², Ralf Haefner¹

1. Brain and Cognitive Sciences, University of Rochester, Meliora Hall, University of Rochester, Rochester, NY 14627, United States of America

2. Institute of Neuroinformatics, University of Zurich, Winterthurerstrasse 190 8057 Zürich, Switzerland

Olshausen & Field [1], and a series of studies building on it, have shown that V1 receptive fields emerge from learning in a linear Gaussian model of natural images under a sparse sprior. How V1 neurons might implement inference in such a system is less clear, and prior work has typically assumed that network dynamics serve to find the most probable explanation of the visual inputs rather than the full posterior distribution [1,3, but see 9, 12]. Here, we derive a spiking neural network model using deterministic leaky integrate-and-fire (LIF) neurons and stochastic synapses whose responses represent binary samples from the joint posterior given a retinal input (Fig A, B). Simulating the model we find agreement with classic neurophysiological observations about V1 neurons, from approximately contrast-invariant tuning curves (Fig C) to near Poisson variability to small noise correlations with a mean of close to zero (Fig D) [6], to negative causal influences between neurons of similar receptive fields (Fig E) [7]. Recently, it was also shown that responses from such a model also form a probabilistic population code over orientation [8]. Within the context of this model we can understand the underlying cause for each observation, e.g. why near contrast-invariant orientation tuning is not in contradiction to a sharpening posterior over orientation with increasing contrast, or that the main contribution to near-Poisson variability are stochastic synapses, not feedforward input noise or unreliable neurons – making empirically testable predictions. With our work we build on and extend prior results, key among them are the findings that learning in binary linear Gaussian models yields V1-like RFs [2], a proposal how sampling in discrete time may be implemented by asynchronous spikes in continuous time [10], and the proposal that a synapse's stochasticity may reflect Bayesian uncertainty about its correct value [4, 13]. It complements work showing that networks of deterministic LIF neurons can sample from Boltzmann distributions with Poisson-like variability when in a high conductance regime [5]. More generally, our work bridges Marr's three levels [11], from assuming a computational goal (here, probabilistic inference over visual inputs) to an algorithm (neural sampling) to neural implementation (network of LIF neurons) (Fig A).



Bridging Marr's Three Levels: Probabilistic Inference to Gibbs Sampling to Network of Leaky-Integrate and Fire Neurons

References

- 1 Olshausen, Bruno A., and David J. Field. "Sparse coding with an overcomplete basis set: A strategy employed by V1?" *Vision research* 37.23 (1997): 3311-3325.
- 2 Bornschein, Jörg, Marc Henniges, and Jörg Lücke. "Are V1 simple cells optimized for visual occlusions? A comparative study." *PLoS computational biology* 9.6 (2013): e1003062.
- 3 Rozell, Christopher J., et al. "Sparse coding via thresholding and local competition in neural circuits." *Neural computation* 20.10 (2008): 2526-2563.
- 4 Aitchison, Laurence, and Peter E. Latham. "Synaptic sampling: A connection between PSP variability and uncertainty explains neurophysiological observations." *arXiv preprint arXiv:1505.04544* (2015).
- 5 Petrovici, Mihai A., et al. "The high-conductance state enables neural sampling in networks of LIF neurons." *BMC neuroscience* 16.1 (2015): O2.
- 6 Ecker, Alexander S., et al. "Decorrelated neuronal firing in cortical microcircuits." *science* 327.5965 (2010): 584-587
- 7 Chettih, Selmaan N., and Christopher D. Harvey. "Single-neuron perturbations reveal feature-specific competition in V1." *Nature* (2019): 1.
- 8 Shivkumar, Sabyasachi, et al. "A probabilistic population code based on neural samples." *Advances in Neural Information Processing Systems*. 2018.
- 9 Hoyer, Patrik O., and Aapo Hyvärinen. "A multi-layer sparse coding network learns contour coding from natural images." *Vision research* 42.12 (2002): 1593-1605.
- 10 Buesing, Lars, et al. "Neural dynamics as sampling: a model for stochastic computation in recurrent networks of spiking neurons." *PLoS computational biology* 7.11 (2011): e1002211.
- 11 Marr, David. "Vision: A computational investigation into the human representation and processing of visual information." (1982).
- 12 Orbán, Gergő, et al. "Neural variability and sampling-based probabilistic representations in the visual cortex." *Neuron* 92.2 (2016): 530-543.
- 13 Zhu, Mengchen, and Christopher J. Rozell. "Visual nonclassical receptive field effects emerge from sparse coding in a dynamical system." *PLoS computational biology* 9.8 (2013): e1003191

©(2019) Chattoraj A, Lange R, Wu S, Haefner R

Cite as: Chattoraj A, Lange R, Wu S, Haefner R (2019) A neural-sampling based model of early visual processing based on leaky integrate-and-fire neurons. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0112](https://doi.org/10.12751/nncn.bc2019.0112)

[W 96] A synthetic biology approach to the evolutionary transformation of visual cortex architecture

Julian Vogel^{1,2}, Manuel Schottendorf³, Jonas Franz⁴, Shy Shoham⁵, Walter Stühmer², Fred Wolf^{1,6}

1. Campus Institute for Dynamics of Biological Networks, Georg-August-Universität Göttingen, Hermann-Rein-Str. 3, 37075 Göttingen, Germany

2. Max-Planck Institute for Experimental Medicine, Hermann-Rein-Str. 3, 37075 Göttingen, Germany

3. Princeton Neuroscience Institute, Princeton University, Washington Road, Princeton, NJ 08544, USA

4. University Medical Center Göttingen, Robert-Koch-Straße 40, 37075 Göttingen, Germany

5. New York University Langone Health, 550 First Avenue, New York, NY 10016, USA

6. Max-Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany

The arrangement of orientation selective neurons in the visual cortex into functional domains is a common feature over a wide range of mammalian taxa [1]. This architecture presumably evolved from a primordial rodent-like salt-and-pepper layout. Here, we present a synthetic biology approach to investigate transition scenarios between the two types of functional architecture and assess evolutionary benefits that might have driven the emergence of functional orientation domains. We used a bidirectional neuronal interface to connect a computational model of the retino-thalamic pathway to a living neuronal cell culture serving as a model for cortical input layer. Specifically, the in-silico components were connected to the in-vitro neurons via optogenetic holographic stimulation [2, 3]. Neural activity was registered either by multielectrode array recording or optically using a genetically-encoded calcium indicator [4]. In this system, we implemented the Hubel&Wiesel feed-forward model of orientation tuning

[5] and explored the consequences of scaling orientation domains down to the size of a single neuron. We found that the fraction of orientation selective neurons only weakly decreases with shrinking domain size. Intriguingly, even in the absence of orientation tuned input a considerable level of orientation selectivity was retained. In this limit of infinitesimally small domains, the arrangement of orientation selective cells resembles a sparse salt-and-pepper layout. During scaling, preferred orientation switches from the imposed input orientation to a preference intrinsically generated within the in-vitro network. The level of orientation selectivity substantially increased with larger domains and saturated at the natural scale of orientation columns. Our results demonstrate that neural interface technology can be used to study evolutionary transitions in neuronal computation by a synthetic biology approach.

References

- 1 Kaschube et al., Science 330, 1113-1116 (2010) [10.1126/science.1194869](https://doi.org/10.1126/science.1194869)
- 2 L. Golan et al., Journal of Neural Engineering 6, 066004 (2009) [10.1088/1741-2560/6/6/066004](https://doi.org/10.1088/1741-2560/6/6/066004)
- 3 G. Nagel et al., Current Biology 15, 2279-2284 (2005) [10.1016/j.cub.2005.11.032](https://doi.org/10.1016/j.cub.2005.11.032)
- 4 H. Dana et al., eLife 5, 1-24 (2016) [10.7554/eLife.12727](https://doi.org/10.7554/eLife.12727)
- 5 D.H. Hubel and T.N. Wiesel, The Journal of Physiology 160, 106-154 (1962) [10.1113/jphysiol.1962.sp006837](https://doi.org/10.1113/jphysiol.1962.sp006837)

©(2019) Vogel J, Schottdorf M, Franz J, Shoham S, Stühmer W, Wolf F

Cite as: Vogel J, Schottdorf M, Franz J, Shoham S, Stühmer W, Wolf F (2019) A synthetic biology approach to the evolutionary transformation of visual cortex architecture. Bernstein Conference 2019 Abstract.

doi: [10.12751/nncn.bc2019.0113](https://doi.org/10.12751/nncn.bc2019.0113)

[W 97] A toolbox for fitting neural models to electrophysiological data in Brian 2

Aleksandra Teska¹, Marcel Stimberg²

1. Department of Electrical and Computer Engineering, Technical University Munich, Arcisstraße 21, 80333 München, Germany

2. Sorbonne Université, INSERM, CNRS, Institut de la Vision, 17 Rue Moreau, 75012 Paris, France

Brian 2[1,2] is a neural simulator with code generation facilities, that allows the transformation of a high-level user-specified model into compiled code. Such an approach makes the description of the model not only very flexible but also easy to write and read. This makes the software a perfect tool for data driven optimization of custom models.

Fitting models of neurons to experimental data is a common task in computational neuroscience. To address the demand, we developed a Model Fitting Toolbox for Brian 2, to allow the user to find the best fit of the parameters for recorded traces and spike trains.

The proposed solution is developed using a modular approach, where both the optimization method and metric to be optimized can be easily swapped out. By default, we support a range of global derivative-free optimization methods, that include popular methods for model fitting, such as: Differential Evolution, Particle Swarm Optimization and Covariance Matrix Adaptation (provided by the library Nevergrad[3]) as well as Bayesian Optimization for black box functions (provided by Scikit-Optimize[4]). For metrics, users can select one of the available metrics, eg. the Γ factor[5], or easily plug in a code extension with a custom metric. The feedback provided by the fitting function is designed with the same principle in mind and can also be easily extended to fulfill the individual requirements.

Both Brian and the Model Fitting Toolbox are designed to be easy to use and save time through automatic parallelization of the simulations using code generation. The provided software enables researchers to quickly achieve fitting results for arbitrary models, while at the same time giving them the flexibility and extensibility needed for solving more complex problems.

Acknowledgements

This project has been developed as part of the International Neuroinformatics Coordination Facility's (<https://www.incf.org/>) participation in the Google Summer of Code program 2019 (<https://summerofcode.withgoogle.com/>).

References

- 1 M. Stimberg, D. F. M. Goodman, V. Benichoux, and R. Brette. "Equation-Oriented Specification of Neural Models for Simulations." *Frontiers in Neuroinformatics* 8 (2014) [10.3389/fninf.2014.00006](https://doi.org/10.3389/fninf.2014.00006)
- 2 M. Stimberg, R. Brette, and D. F. M. Goodman. "Brian 2: An Intuitive and Efficient Neural Simulator." *BioRxiv* (2019) [10.1101/595710](https://doi.org/10.1101/595710)
- 3 J. Rapin and O. Teytaud, "Nevergrad - A gradient-free optimization platform", GitHub repository (2018)
- 4 Scikit-optimize
- 5 W. M. Kistler, W. Gerstner, and J. L. van Hemmen. "Reduction of the Hodgkin-Huxley Equations to a Single-Variable Threshold Model." *Neural Computation* 9 (5) (1997) [10.1162/neco.1997.9.5.1015](https://doi.org/10.1162/neco.1997.9.5.1015)

©(2019) Teska A, Stimberg M

Cite as: Teska A, Stimberg M (2019) A toolbox for fitting neural models to electrophysiological data in Brian 2. *Bernstein Conference 2019* Abstract. doi: [10.12751/ncnbc2019.0114](https://doi.org/10.12751/ncnbc2019.0114)

[W 98] Attractor sequences in motor cortex underlie self-initiated behavior

Stefano Recanatesi¹, Ulises Pereira², Masayoshi Murakami³, Zachary Mainen⁴, Luca Mazzucato⁵

1. Computational Neuroscience Center, University of Washington, Seattle, USA

2. Center for Neural Science, New York University, New York, USA

3. Champalimaud Centre for the Unknown, Lisbon, Portugal

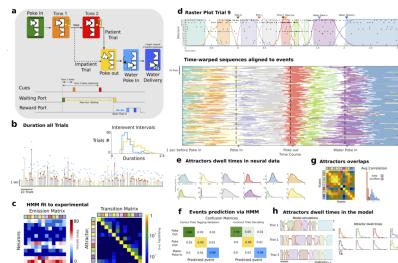
4. Champalimaud Centre for the Unknown, Lisbon, Portugal

5. Departments of Biology and Mathematics, Institute of Neuroscience, University of Oregon, Eugene, USA

When interacting with a complex environment, animals generate naturalistic behavior in the form of action sequences. The decision to choose specific self-initiated actions and execute them at certain times may depend on deterministic factors including the animal's goals and internal state, and external stimuli. Part of the behavioral variability may have a stochastic origin as well. Here we investigated the mechanisms underlying variability in self-initiated actions during a waiting task [1,2], where animals freely decided when to abort waiting for a delayed tone (Fig. 1a). After training, animals performed a specific action sequence leading to a water reward in correct trials. Even though the order of actions in the rewarded sequence was the same across trials, intervals between consecutive actions showed large trial-to-trial variability (Fig. 1b). To elucidate the neural underpinnings of such variability, we recorded neural ensemble activity in secondary motor cortex (M2). We found that M2 activity unfolded through sequences of attractors, each attractor representing a population firing rate vector estimated, using a cross-validated hidden Markov model (Fig. 1c,d). Attractors were long-lived, lasting on average hundreds of milliseconds, with heterogeneous, long-tailed distributions of dwell times (Fig. 1e). Upcoming self-initiated actions were reliably predicted by specific attractor onsets, thus establishing a link between neural and behavioral variability. We

were able to reliably predict erratic actions performed during error trials from neural activity, by using an attractor/action dictionary trained on correct trials only (Fig. 1f). Most M2 neurons participated in sequences, with dense and overlapping neural representations (Fig. 1g).

To elucidate the neural mechanism underlying attractor sequences with long-tailed dwell times yet reliable sequence identity, we modeled the M2 circuit as a recurrent network, with parameters fit to the empirical data [3]. Existing models could produce reliable attractor sequences [4], but failed to generate long-tailed distributions of attractor dwell times (not shown). We found that a novel mechanism was necessary to match the empirical onset time variability, whereby transitions between attractors are driven by low-dimensional synaptic noise (Fig. 1h). The model predicted that spike count correlations conditioned on attractors are confined on a low-dimensional manifold, which was confirmed in the empirical data.



A: The waiting task (A) and behavior (B) in a representative session. C: HMM fit to M2 ensemble activity. D: M2 ensemble activity in one trial (top, colored intervals where $p(\text{attractor}) > 80\%$); detected attractor sequences (bottom). H: Model: Attractor probabilities (left) reveal reliable sequences wi

References

- 1 Murakami, Masayoshi, et al. "Neural antecedents of self-initiated actions in secondary motor cortex." *Nature neuroscience* 17.11 (2014): 1574. [10.1038/nn.3826](https://doi.org/10.1038/nn.3826)
- 2 Murakami, Masayoshi, et al. "Distinct sources of deterministic and stochastic components of action timing decisions in rodent frontal cortex." *Neuron* 94.4 (2017): 908-919. [10.1016/j.neuron.2017.04.040](https://doi.org/10.1016/j.neuron.2017.04.040)
- 3 Lim, Sukbin, et al. "Inferring learning rules from distributions of firing rates in cortical neurons." *Nature neuroscience* 18.12 (2015): 1804. [10.1038/nn.4158](https://doi.org/10.1038/nn.4158)
- 4 Sompolinsky, Haim, and I. Kanter. "Temporal association in asymmetric neural networks." *Physical review letters* 57.22 (1986): 2861. [10.1103/PhysRevLett.57.2861](https://doi.org/10.1103/PhysRevLett.57.2861)

©(2019) Recanatesi S, Pereira U, Murakami M, Mainen Z, Mazzucato L

Cite as: Recanatesi S, Pereira U, Murakami M, Mainen Z, Mazzucato L (2019) Attractor sequences in motor cortex underlie self-initiated behavior. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0115](https://doi.org/10.12751/nncn.bc2019.0115)

[W 99] **Bistable firing patterns and epileptic seizures**

Fernando da Silva Borges¹, Paulo Ricardo Protachevicz², Alexandre Hiroaki Kihara¹

1. Center for Mathematics, Computation, and Cognition, Federal University of ABC, São Bernardo do Campo, Brazil

2. Graduate in Science Program-Physics, State University of Ponta Grossa, Ponta Grossa, Brazil

Excessively high, neural synchronisation has been associated with epileptic seizures, one of the most common brain diseases worldwide. Previous researchers have argued which epileptic and normal neuronal activity are support by the same physiological structure. However, to understand how neuronal systems transit between these regimes is a wide question to be answered. In this work, we study neuronal synchronisation in a random network where nodes are neurons with excitatory and inhibitory synapses, and neural activity for each node is provided by the adaptive exponential integrate-and-fire model. In this framework, we verify that the decrease in the influence of inhibition can generate synchronisation originating from a pattern of desynchronised spikes. The transition from desynchronous spikes to synchronous bursts of activity, induced by varying the synaptic coupling, emerges in a hysteresis loop due to bistability where abnormal (excessively high synchronous) regimes exist. We verify that, for parameters in the bistability regime, a square current pulse can trigger excessively high (abnormal) synchronisation, a process that can reproduce features of epileptic seizures. Then, we show that it is possible to suppress such abnormal synchronisation by applying a small-amplitude external current on less than 10% of the neurons in the network. Our results demonstrate that external electrical stimulation not only can trigger synchronous behaviour, but more importantly, it can be used as a means to reduce abnormal synchronisation and thus, control or treat effectively epileptic seizures.

Acknowledgements

This study was possible by partial financial support from the following Brazilian government agencies: CNPq, CAPES, and FAPESP (2015/50122-0, 2017/18977-1).

References

- 1 Borges, F. S., Protachevicz, P. R., Lameu, E. L., Bonetti, R. C., Iarosz, K. C., Caldas, I. L., et al. (2017). Synchronised firing patterns in a random network of adaptive exponential integrate-and-fire neuron model. *Neural Networks* 90, 1–7. [10.1016/j.neunet.2017.03.005](https://doi.org/10.1016/j.neunet.2017.03.005)
- 2 Protachevicz PR, Borges FS, Lameu EL, Ji P, Iarosz KC, Kihara AH, Caldas IL, Szezech JD Jr, Baptista MS, Macau EEN, Antonopoulos CG, Baptista AM and Kurths J (2019) Bistable Firing Pattern in a Neural Network Model. *Front. Comput. Neurosci.* 13:19. [10.3389/fncom.2019.00019](https://doi.org/10.3389/fncom.2019.00019)
- 3 Protachevicz, P. R., Borges, R. R., Reis, A. S., Borges, F. S., Iarosz, K. C., Caldas, I. L., et al. (2018). Synchronous behaviour in network model based on human cortico-cortical connections. *Physiol. Measur.* 39:074006. [10.1088/1361-6579/aace91](https://doi.org/10.1088/1361-6579/aace91)

©(2019) Borges FdS, Protachevicz PR, Kihara AH

Cite as: Borges FdS, Protachevicz PR, Kihara AH (2019) Bistable firing patterns and epileptic seizures. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0116](https://doi.org/10.12751/nncn.bc2019.0116)

[W 100] Can Spatio-Temporal Spike Patterns Found in Experimental Data be Explained by the Synfire Chain Model?

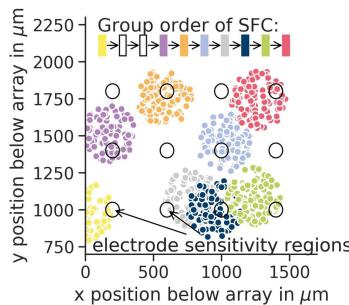
David Berling^{1,2}, Tom Tetzlaff¹, Alexander Kleinjohann^{1,2}, Alessandra Stella^{1,2}, Markus Diesmann^{1,3}, Sonja Grün^{1,2}

1. Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA-Institut Brain Structure-Function Relationships (INM-10), Forschungszentrum Jülich, Jülich, Germany

2. Theoretical Systems Neurobiology, RWTH Aachen University, Aachen, Germany

3. School of Medicine, RWTH Aachen University, Aachen, Germany

To investigate cortical network interactions during a reach-to-grasp task [1], we analyzed spatio-temporal patterns (STPs) in massively parallel spike data. Using the SPADE analysis [2,3], we found significant STPs in about 100 simultaneously recorded single units. For each of the four task types, we observe up to 50 patterns during the movement period. The STPs differ in spatial and temporal arrangement of spikes, and are composed of 2 to 6 units which belong to the same set of maximal 10 units. Here, we investigate if the characteristics of the found STPs can be explained by a simple assembly network model, the synfire chain (SFC) model [4]. In the SFC model, neurons form groups connected in a feedforward, highly convergent-divergent manner. Synchronous stimulation of neurons in the first group results in volleys of spikes reliably propagating through the chain [5]. Spike recordings from a subset of cells in this model would reveal recurring STPs similar to those observed in the data, provided the same SFCs are repeatedly stimulated. We investigate if the observed STP statistics is consistent with a network model where SFCs are spatially distributed in accordance with biologically realistic connection probabilities [6,7]. In the context of this model, we evaluate the probability of observing multiple neurons involved in the same STP by means of a 10x10 Utah electrode array spanning $4 \times 4 \text{ mm}^2$ of cortical space. We explore how model parameters such as the neuron density, the distance dependence of lateral connections between cortical neurons and the spatial reach of extracellular electrodes constrain the spatial arrangement of SFCs (see figure) and the number of observable SFC neurons. In future work, we will equip the current network model with a temporal dynamics [8], and further, embed it into a balanced network [similar to 9] to study the temporal characteristics of STPs.



Spatial distribution of neurons (dots) in a Synfire chain. The extract shows 8/10 groups (colors) embedded in cortical space. Open circles mark the positions and the reach (radius) of the Utah array electrodes.

Acknowledgements

This project has received funding from RTG2416 MultiSenses-MultiScales (Deutsche Forschungsgemeinschaft), EU Grant 785907 (HBP), Helmholtz IVF Grant ZT-I-0003 (HAF) and Internationally Associated Laboratories LIA between CNRS Marseille and INM-6, FZ Jülich.

References

- 1 Riehle, A, Wirtzsohn, S, Grün, S & Brochier, T 2013, 'Mapping the spatio-temporal structure of motor cortical LFP and spiking activities during reach-to-grasp movements', *Frontiers in Neural Circuits*, vol. 7, art. 48 [10.3389/fncir.2013.00048](https://doi.org/10.3389/fncir.2013.00048)
- 2 Torre, E, Picado-Muiño, D, Denker, M, Borgelt, C, Grün, S 2013, 'Statistical evaluation of synchronous spike patterns extracted by frequent item set mining', *Frontiers in Computational Neuroscience*, vol. 7, art. 132 [10.3389/fncom.2013.00132](https://doi.org/10.3389/fncom.2013.00132)
- 3 Quaglio, P, Stella, A, Torre, E, Grün, S, '3d-SPADE: Significance evaluation of spatio-temporal patterns of various temporal extents', under review
- 4 Abeles, M 1991, 'Corticonics: neural circuits of the cerebral cortex', Cambridge University Press
- 5 Diesmann, M, Gewaltig, MO, Aertsen, A 1999, 'Stable propagation of synchronous spiking in cortical neural networks', *Nature*, vol. 402, no. 6761, pp. 529-533 [10.1038/990101](https://doi.org/10.1038/990101)
- 6 Hehl, U 2001, 'Embedding of synchronous spike activity in cortical networks', PhD Thesis
- 7 Hellwig, B 2000, 'A quantitative analysis of the local connectivity between pyramidal neurons in layers 2/3 of the rat visual cortex', *Biological Cybernetics*, vol. 82, no. 2, pp. 111-121 [10.1007/PL00007964](https://doi.org/10.1007/PL00007964)
- 8 Nest, spiking neural network simulator
- 9 Schrader, S, Grün, S, Diesmann, M, Gerstein, GL 2008, 'Detecting synfire chain activity using massively parallel spike train recording' [10.1152/jn.01245.2007](https://doi.org/10.1152/jn.01245.2007)

©(2019) Berling D, Tetzlaff T, Kleinjohann A, Stella A, Diesmann M, Grün S

Cite as: Berling D, Tetzlaff T, Kleinjohann A, Stella A, Diesmann M, Grün S (2019) Can Spatio-Temporal Spike Patterns Found in Experimental Data be Explained by the Synfire Chain Model?. *Bernstein Conference 2019* Abstract.
doi: [10.12751/nncn.bc2019.0117](https://doi.org/10.12751/nncn.bc2019.0117)

[W 101] Comparing filter-based models of ganglion cell responses across cell types

Neda Shahidi^{1,2}, Fernando Rozenblit^{1,2}, Tim Gollisch^{1,2}

1. Department of Ophthalmology, University Medical Center Goettingen, Waldweg 33, 37073 Göttingen, Germany

2. Bernstein Center for Computational Neuroscience, 37073 Göttingen, Germany

Standard classes of functional models for retinal ganglion cells (RGCs) represent the stimulus processing using linear filters and predict the probability of spike generation using non-linear transformations of the filtered stimuli. However, a single stimulus filter is often inadequate to capture the response properties of an RGC. Several models have been proposed with parallel components such as excitatory and suppressive components, spatially segregated sub-units or latent variables of the stimulus features. Some of these models capture the diversity of functional sub-types in salamander or rodent while others represent unique properties of a single sub-type. We asked the question whether standard filter-based models with one or multiple filters capture the diversity of responses from different types of ganglion cells and whether the diversity of the cells is explicitly represented in the components of the model. We stimulated salamander, mouse and marmoset retina using stimuli with rich temporal dynamics, recorded activity of RGCs using multi-electrode arrays and compared different models from the literature by how well they predict responses of recorded cell types. Furthermore, we are exploring the effects of different model components, aiming to relate the structure of the components to the response diversity of RGCs.

Acknowledgements

- This work was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme and by the Deutsche Forschungsgemeinschaft (DFG). We thank the German Primate Center Göttingen for donating the retina samples used in this study.

©(2019) Shahidi N, Rozenblit F, Gollisch T

Cite as: Shahidi N, Rozenblit F, Gollisch T (2019) Comparing filter-based models of ganglion cell responses across cell types. Bernstein Conference 2019 Abstract. doi: 10.12751/nncn.bc2019.0118

[W 102] Comparing spikes and the local field potential (LFP) in V1 between experimental data and a comprehensive biophysical model

Gaute T. Einevoll^{1,2}, Espen Hagen¹, Alexander J. Stasik¹, Yazan N. Billeh³, Joshua H. Siegle³, Kael Dai³, Atle E. Rimehaug⁴, Torbjørn V. Ness², Malin B. Røe⁵, Marianne Fyhn⁵, Torkel Hafting⁶, Christof Koch³, Shawn R. Olsen³, Anton Arkhipov³

1. Department of Physics, University of Oslo, Oslo, Norway

2. Faculty of Science and Technology, Norwegian University of Life Sciences, Ås, Norway

3. Allen Institute for Brain Science, Seattle, USA

4. Norwegian University of Science and Technology, Trondheim, Norway

5. Department of Biosciences, University of Oslo, Oslo, Norway

6. Institute of Basic Medical Sciences, University of Oslo, Oslo, Norway

Several large-scale data-collection efforts have been undertaken to characterize different brain areas in different species, including their underlying neuronal composition and circuitry down to the cellular, synaptic and molecular levels [1,2]. Parallel efforts also aim to develop neuronal circuit models incorporating this vast biological detail, to explain/match various features observed *in vivo* and *in vitro* (e.g., [3,4]). Such data-driven computer models can be used as frameworks for hypothesis testing and experimentation. Traditionally, comparison of experimental activity data and equivalent neuronal network models have been conducted at the level of spiking activity. Here, we aim to substantiate such a model by also comparing the commonly recorded local field potential (LFP), that is, the low frequency part of extracellularly recorded potentials, and the corresponding current source density (CSD).

Here, we use a model of the mouse primary visual cortex (area V1), currently in development at the Allen Institute for Brain Science (that will be made publicly available when it has been validated). The model incorporates 230,000 neurons across each cortical layer, 21 neuronal classes, over 100 unique cell models, and over 200 connection classes. 52,000 of the neurons are morphologically detailed multicompartment models, while remaining neurons are single-compartment models. The neuron model responses were fit to *in vitro* experimental measurements [5]. The use of multicompartment neuron models facilitates LFP predictions using electrostatic forward modeling [6,7]. Visual inputs are mediated by a feed-forward, filter-based model representing the retina and lateral geniculate nucleus (LGN) V1 pathway [8]. The V1 and LGN models are set up with the Brain Modeling ToolKit (BMTK, github.com/AllenInstitute/bmtk) in Python, and simulated using NEURON [9].

The experimental validation datasets are obtained using high-density multi-electrode arrays (Neuropixels [10]) inserted in V1 and LGN, and conventional laminar probes (NeuroNexus) inserted in V1. The awake, head-fixed mice are subjected to various visual stimuli (flashes, drifting gratings etc.).

We systematically compare activity observed in the V1 model with that recorded experimentally, at the level of spikes, LFP and CSD, for different types of visual stimuli. We also explore the use of laminar population analysis (LPA) [11] as a means to decompose laminar recordings of spikes and LFP/CSD into contribut

References

- 1 Koch C, Reid RC. *Nature*. 2012, 483:397–398 DOI:[10.1038/483397a](https://doi.org/10.1038/483397a)
- 2 Kandel ER et al. *Nat Rev Neurosci*. 2013, 14:659–664 DOI:[10.1038/nrn3578](https://doi.org/10.1038/nrn3578)
- 3 Potjans T, Diesmann M. *Cereb Cortex*. 2014, 24:785–806 DOI:[10.1093/cercor/bhs358](https://doi.org/10.1093/cercor/bhs358)
- 4 Markram H, et al. *Cell*. 2015, 163:456–492 DOI:[10.1016/j.cell.2015.09.029](https://doi.org/10.1016/j.cell.2015.09.029)
- 5 Gouwens NW, et al. *Nat Commun*. 2018, 9:710 DOI:[10.1038/s41467-017-02718-3](https://doi.org/10.1038/s41467-017-02718-3)
- 6 Holt G, Koch C. *J Comput Neurosci*. 1999, 6:169–184 DOI:[10.1023/A:100883270](https://doi.org/10.1023/A:100883270)
- 7 Hagen E, et al. *Front Neuroinform*. 2018, 12:92 DOI:[10.3389/fninf.2018.00092](https://doi.org/10.3389/fninf.2018.00092)
- 8 Arkhipov A, et al. *PLoS Comput Biol*. 2018, 14(11): e1006535 DOI:[10.1371/journal.pcbi.1006535](https://doi.org/10.1371/journal.pcbi.1006535)
- 9 Hines ML, Carnevale NT. *Neural Comput*. 1997, 9(6):1179–1209 DOI:[10.1162/neco.1997.9.6.1179](https://doi.org/10.1162/neco.1997.9.6.1179)
- 10 Jun JJ, et al. *Nature*. 2017, 551:232–236 DOI:[10.1038/nature24636](https://doi.org/10.1038/nature24636)
- 11 Einevoll GT, et al. *J Neurophysiol*. 2007, 97:2174–2190 DOI:[10.1152/jn.00845.2006](https://doi.org/10.1152/jn.00845.2006)

©(2019) Einevoll GT, Hagen E, Stasik AJ, Billeh YN, Siegle JH, Dai K, Rimehaug AE, Ness TV, Røe MB, Fyhn M, Hafting T, Koch C, Olsen SR, Arkhipov A

Cite as: Einevoll GT, Hagen E, Stasik AJ, Billeh YN, Siegle JH, Dai K, Rimehaug AE, Ness TV, Røe MB, Fyhn M, Hafting T, Koch C, Olsen SR, Arkhipov A (2019) Comparing spikes and the local field potential (LFP) in V1 between experimental data and a comprehensive biophysical model. *Bernstein Conference 2019 Abstract*. doi: [10.12751/ncnc.b2019.0119](https://doi.org/10.12751/ncnc.b2019.0119)

[W 103] Complementary Compartmental Modeling, Two-Photon Ca²⁺ Imaging and Photolytic Activation: Dendritic Integration in Olfactory Bulb Granule Cells

S. Sara Aghvami^{1,2}, Max Mueller¹, Babak N. Araabi², Veronica Egger¹

1. *Neurophysiology, Institute of Zoology, Universität Regensburg, 93049 Regensburg, Germany*

2. *School of Electrical and Computer Engineering, University of Tehran, 14395-515 Tehran, Iran*

Within the olfactory bulb of mammals, the large excitable spines of the inhibitory axonless granule cells (GC) allow for special reciprocal synaptic interactions with the dendrites of the principal excitatory mitral cells. Since direct measurement of the spines' membrane potential is not yet feasible, we have examined their behavior through models which were tailor-fitted to experimental data with respect to their passive and active properties, e.g. voltage-gated conductances for Ca²⁺ and Na⁺, synaptic receptors, Ca²⁺ dynamics and the GC morphology. The experimental data are based on electrophysiology and two-photon Ca²⁺ imaging, and the compartmental model of GCs is developed in NEURON/Python. To investigate the integration of inputs within the GC dendritic tree, the generation of global action potentials (APs) and their interaction with local excitatory synaptic inputs, two patterns of stimuli were considered, one within the time domain and one along the spatial domain of the dendritic arbor. (1) Within a time frame of ±100 mSec, different sequences of local synaptic inputs and global APs were simulated. At perfect coincidence ($\Delta t=0$), local postsynaptic Ca²⁺ entry summates sublinearly with AP-mediated Ca²⁺ entry. This result is due to the refractoriness of voltage-gated Na⁺ channels in the wake of the local synaptic spine spike that has been demonstrated earlier [1]. For positive and negative Δt , i.e. where the global AP proceeds local synaptic input and vice versa, the summation efficiency rises to linear and supra-linear summation of Ca²⁺, respectively. These results were confirmed by experimental tests [2]. (2) Simultaneous local inputs to sets of spines were simulated, with varying distributions along the dendritic tree. Regardless of the active spines' locations, integration of the local excitatory postsynaptic potential unto initiation of a global AP depends mostly on the number of spines, which is likely due to the small size of GCs. A threshold spine number for AP initiation of approx. 10 is predicted by the model,

in line with experiments based on simultaneous multisite uncaging of transmitter by means of holographic 3D photostimulation [3]. This threshold is substantially lower than expected for passive integration alone. Since APs propagate well within GC dendrites, active dendritic processing in GCs thus facilitates lateral inhibition within the olfactory bulb.

Acknowledgements

This work was supported by German Ministry for Education and Research FKZ 01GQ1502 (V.E.) and I.R. Iran Cognitive Science and Technology Council (S.S.A.).

References

- 1 Bywalez WG, Patirniche D, Rupprecht V, Stemmler M, Herz AVM, Pálfi D, Rózsa B, Egger V (2015) Local Postsynaptic Voltage-Gated Sodium Channel Activation in Dendritic Spines of Olfactory Bulb Granule Cells. *Neuron* 85:590-601
- 2 Aghvami SS, Müller M, Araabi BN, Egger V (2019) Coincidence Detection within the Excitable Rat Olfactory Bulb Granule Cell Spines. *J Neurosci* 39:584–595
- 3 Go MA, Mueller M, Castanares ML, Egger V, Daria VR (2019) A compact holographic projector module for high-resolution 3D multi-site two-photon photostimulation. *PLOS ONE* (2019) [10.1371/journal.pone.0210564](https://doi.org/10.1371/journal.pone.0210564)

©(2019) Aghvami SS, Mueller M, N. Araabi B, Egger V

Cite as: Aghvami SS, Mueller M, N. Araabi B, Egger V (2019) Complementary Compartmental Modeling, Two-Photon Ca^{2+} Imaging and Photolytic Activation: Dendritic Integration in Olfactory Bulb Granule Cells. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0120](https://doi.org/10.12751/nncn.bc2019.0120)

[W 104] Critical Correlation between Memory Engrams in Associative Memory

Chiara Gastaldi¹, Tilo Schwalger², Wulfram Gerstner³

1. *BMI, EPFL, EPFL SV LCN 1015 Lausanne, Switzerland*

2. *Institut für Mathematik, Technische Universität Berlin, Sekretariat MA 7-2 Straße des 17. Juni 136 10623 Berlin, Germany*

3. *Wulfram, Gerstner, EPFL SV LCN 1015 Lausanne, Switzerland*

Experimental evidence [1] suggests that associative memory is stored in the area CA3 of the hippocampus, by cell assemblies that respond selectively to single concepts [2]. Associations between different concepts are encoded in the fraction of shared neurons between the cell assemblies, which spans from 0% up to a maximum of 4-5% of neurons [3-4].

Associative memory is traditionally modeled through attractor neural networks [5-8]. Memory engrams are represented by binary patterns with low mean activity $\langle \xi^\mu \rangle = \gamma: \{\xi_i^\mu\}_{i=1,\dots,N}^P = \{0, 1\}$, where N is the total number of neurons, P is the number of stored patterns ($\alpha = P/N$ is the load of the network). While there is extensive literature on i.i.d. patterns, how correlation between patterns affects their stability is an open question. Correlated patterns share more than the expected γN neurons. We define a network composed of normalized rate neurons [9]: $\tau \frac{dr_i}{dt} = -r_i + \phi(\sum_j J_{ij} r_j + I_i)$, where I_i the external input, the gain function ϕ is a sigmoid and J_{ij} is the weights matrix of connections between neurons, $J_{ij} = \frac{1}{N\gamma(1-\gamma)} \sum_\mu^P (\xi_j^\mu - \gamma)(\xi_i^\mu - \gamma)$.

We allow each pattern to have finite correlation \hat{C} with K others and we monitor the overlaps m^1 and m^2 between the network state and the first two stored patterns. Using mean-field approximation, adapting [10], we find the overlap dynamics:

$$m^1 = \frac{1}{\gamma(1-\gamma)} \langle (\xi_i^1 - \gamma)\phi(h_i) \rangle$$

$$m^2 = \frac{1}{\gamma(1-\gamma)} \langle (\xi_i^2 - \gamma) \phi(h_i) \rangle$$

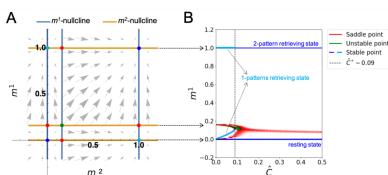
$$q = \langle \phi'(h_i) \rangle$$

$$p = \langle \phi^2(h_i) \rangle$$

$$r = \frac{P_{11} + \gamma - 2\gamma^2}{\gamma(1-\gamma)} \frac{p}{\left((1-q) - (K-1)q \frac{P_{11}-\gamma^2}{\gamma(1-\gamma)} \right)^2}$$

where $h_i = \xi_i^1 - \gamma)m^1 + (\xi_i^2 - \gamma)m^2 + \frac{\alpha q}{1-q}\phi(h_i) + \sqrt{\alpha r}z + I$ and P_{11} is the probability that $\xi_i^1 = \xi_i^2 = 1$.

We find a critical correlation \hat{C}^* (which corresponds to a percentage of shared neurons $n^* = (1-\gamma)\hat{C}^* + \gamma$) above which patterns are not distinguishable (Fig.). In particular, $n^* \sim 9\%$ for small number of stored patters ($\alpha = 0$) and $n^* \sim 7.5\%$ for $\alpha = 0.05$, which can explain why memory engrams share not more than 5% of their neurons.



Phase-plane of the overlap dynamics, for two independent patterns (correlation=0).

B) The m^1 -projection of each fixed point is plotted as a function of the correlation, for gamma=0.001and alpha=0.

Acknowledgements

Special thanks to Valentin Schmutz for the insightful discussions. This research was supported by Swiss National Science Foundation (no. 200020_184615) and by the European Union Horizon 2020 Framework Program under grant agreement no. 785907 (HumanBrain Project, SGA2).

References

- 1 Ison, Matias J., Rodrigo Quián Quiroga, and Itzhak Fried. "Rapid encoding of new memories by individual neurons in the human brain." *Neuron* 87.1 (2015): 220-230. [10.1016/j.neuron.2015.06.016](https://doi.org/10.1016/j.neuron.2015.06.016)
- 2 Quiroga, R. Quián, et al. "Invariant visual representation by single neurons in the human brain." *Nature* 435.7045 (2005): 1102.
- 3 Waydo, Stephen, et al. "Sparse representation in the human medial temporal lobe." *Journal of Neuroscience* 26.40 (2006): 10232-10234.
- 4 De Falco, Emanuela, et al. "Long-term coding of personal and universal associations underlying the memory web in the human brain." *Nature communications* 7 (2016): 13408.
- 5 Amit, Daniel J., Hanoch Gutfreund, and Haim Sompolinsky. "Information storage in neural networks with low levels of activity." *Physical Review A* 35.5 (1987): 2293.
- 6 Romani, Sandro, et al. "Scaling laws of associative memory retrieval." *Neural computation* 25.10 (2013): 2523-2544.
- 7 Pereira, Ulises, and Nicolas Brunel. "Attractor dynamics in networks with learning rules inferred from in vivo data." *Neuron* 99.1 (2018): 227-238.
- 8 Tsodyks, M. V. "Associative memory in neural networks with the hebbian learning rule." *Modern Physics Letters B* 3.07 (1989): 555-560.
- 9 Wilson, Hugh R., and Jack D. Cowan. "Excitatory and inhibitory interactions in localized populations of model neurons." *Biophysical journal* 12.1 (1972): 1-24.
- 10 Shiiro, Masatoshi, and Tomoki Fukai. "Self-consistent signal-to-noise analysis and its application to analogue neural networks with asymmetric connections." *Journal of Physics A: Mathematical and General* 25.7 (1992): L375.

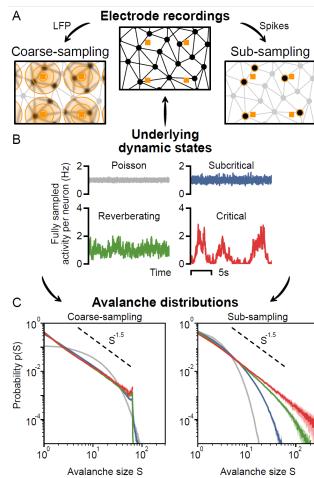
[W 105] Criticality lies in the sampling: explaining the contradiction between neuronal avalanches from LFP and spikes

Joao Pinheiro Neto¹, Franz Paul Spitzner¹, Viola Priesemann^{1,2}

1. Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany

2. Bernstein Center for Computational Neuroscience, Am Faßberg 17, 37077 Göttingen, Germany

The criticality hypothesis suggests that the brain self-organizes to a critical state, which would account for the maximization of many information processing properties [1,2]. While enticing, it remains a controversial hypothesis. In particular, depending on recording technique, experimental results disagree on whether *in vivo* neuronal networks are critical. Our results offer an explanation of the controversy that is rooted in the difference between what we call coarse-sampled recordings – such as LFP or EEG – and spike recordings. In experiments, coarse-sampled recordings usually show apparent signatures of criticality, predominantly power-laws in the avalanche size distributions [3,4]. In contrast, spike recordings *in vivo* do not show the characteristic power-laws, which rather suggests subcritical dynamics [5,6]. To resolve this apparent contradiction, we employ a minimal model of spiking neurons and mimic the two recording types. From the spike recordings of our model, critical and subcritical dynamics are clearly distinguishable. In contrast, we find that under coarse-sampling, the characteristic power-laws are not specific to the critical state: When coarse measures are used, our model produces evidence of criticality for a wide range of underlying dynamic states. Thus, our results strongly suggest that the presence of power-laws under coarse-sampling (LFP, EEG) and the absence of power-laws under sub-sampling (spikes) are perfectly compatible – if one assumes subcritical dynamics for the underlying network.



A. Schematic of the sampling process of neurons (black circles) using electrodes (orange squares). B. Population rate for states with timescales varying in the range of 20–2000 ms (plus Poisson activity). C. Avalanche size distribution for coarse-sampled (left) and sub-sampled (right) activity.

Acknowledgements

JPN received financial support from the Brazilian National Council for Scientific and Technological Development (CNPq) under Grant No. 206891/2014-8. JPN, FPS and VP received financial support from the Max

Planck Society.

References

- 1 Beggs J.M. & Plenz D., *J. Neurosci.* 23 11167–11177 (2003) [10.1523/JNEUROSCI.23-35-11167.2003](https://doi.org/10.1523/JNEUROSCI.23-35-11167.2003)
- 2 Muñoz, M. A., *Rev. Mod. Phys.* 90 (2018). [10.1103/RevModPhys.90.031001](https://doi.org/10.1103/RevModPhys.90.031001)
- 3 Klaus, A. et al, *PLoS ONE*, 6(5) (2011) [10.1371/journal.pone.0019779](https://doi.org/10.1371/journal.pone.0019779)
- 4 Arviv, O. et al, *J. Neurosci.* 35(41), 13927–13942 (2015) [10.1523/JNEUROSCI.0477-15.2015](https://doi.org/10.1523/JNEUROSCI.0477-15.2015)
- 5 Priesemann, V. et al, *Front. Syst. Neurosci.* 8, 108 (2014) [10.3389/fnsys.2014.00108](https://doi.org/10.3389/fnsys.2014.00108)
- 6 Dehghani, N. et al, *Front. Physiol.* 3, 1–18. (2012) [10.3389/fphys.2012.00302](https://doi.org/10.3389/fphys.2012.00302)

©(2019) Pinheiro Neto J, Spitzner FP, Priesemann V

Cite as: Pinheiro Neto J, Spitzner FP, Priesemann V (2019) Criticality lies in the sampling: explaining the contradiction between neuronal avalanches from LFP and spikes. *Bernstein Conference 2019* Abstract.

doi: [10.12751/nncn.bc2019.0122](https://doi.org/10.12751/nncn.bc2019.0122)

[W 106] Different Mechanisms of the Generation of the Gamma Oscillations in Inhibitory Networks

Zeinab Kouhpeimay Jahromi¹, Alireza Valizadeh^{1,2}

1. Physics, Institute for Advanced Studies in Basic Sciences, Zanjan, Iran

2. School of Cognitive Sciences, Institute for Research in Fundamental Sciences, Tehran, Iran

Gamma oscillations are known as a fundamental mechanism for spatial navigation, memory and neural communication in the mammal's brain. The mechanism of the generation of the gamma oscillations has been extensively explored in recent decades through both experimental and theoretical/computational studies [1]. It is well accepted that the inhibitory neurons play a major role in the generation of gamma rhythms and a network of interconnected inter-neurons can produce collective oscillations in the gamma range. Although not explicitly noted in the literature, two different mechanisms can underlie the gamma oscillations in a pure inhibitory network. In the first scenario, the neurons receive a supra-threshold tonic input and hence the single neurons fire almost regularly and most of the neurons contribute in every cycle of the oscillations [2]. In the second, the mean input to the neurons is under the threshold and the neurons fire sparsely and irregularly due to the input fluctuation, while the network shows collective oscillations [3]. In this study, different properties have been explored the simulated networks which produce gamma oscillations by the two above mechanisms. Consistent with the previous results it has been shown that in the first case, the synapses should be fast with small decay time constant, while in the second, short decay times cannot lead to network oscillations. The network frequency in the two cases is determined mainly by the level of tonic input and the synaptic decay time, respectively. In the first case, the response of the network to external stimuli has been characterized by a collective phase response curve (cPRC), while in the second case, the network response is greatly independent of the characteristics of the constituent model neurons. The obtained results are important in determining the routes of information transfer between neural populations based on communication through coherence CTC theory [4,5].

References

- 1 Tiesinga [10.1016/j.neuron.2009.09.009](https://doi.org/10.1016/j.neuron.2009.09.009)
- 2 Bartos [10.1038/nrn2044](https://doi.org/10.1038/nrn2044)
- 3 Wang [10.1152/physrev.00035.2008](https://doi.org/10.1152/physrev.00035.2008)
- 4 Fries [10.1016/j.neuron.2015.09.034](https://doi.org/10.1016/j.neuron.2015.09.034)
- 5 Pariz [10.1016/j.neuroimage.2017.11.014](https://doi.org/10.1016/j.neuroimage.2017.11.014)

©(2019) Kouhpeimay Jahromi Z, Valizadeh A

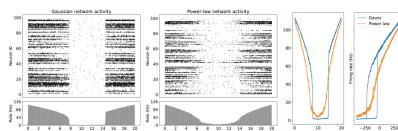
Cite as: Kouhpeimay Jahromi Z, Valizadeh A (2019) Different Mechanisms of the Generation of the Gamma Oscillations in Inhibitory Networks. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0123](https://doi.org/10.12751/nncn.bc2019.0123)

[W 107] Dynamical mean field theory of neural networks with power-law disorder

Łukasz Kuśmierz¹, Shun Ogawa¹, Taro Toyoizumi¹

1. Laboratory for Neural Computation and Adaptation, RIKEN Center for Brain Science, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

Transitions to chaos have been previously extensively studied in different setups of randomly connected networks. The prevailing assumption is that, due to the central limit theorem, synaptic input can be modelled as a Gaussian random variable. In this scenario, a continuous transition has been found in rate models with continuous activation functions [1,2]. However, these models do not take into account that neurons feature thresholds that cut off small inputs. With such thresholds, the transition to chaos in Gaussian networks becomes discontinuous, making it impossible for the network to stay close to the edge of chaos and to reproduce biologically relevant low activity states. Here we introduce a model with biologically motivated, heavy-tailed distribution of synaptic weights and analytically show that it exhibits a continuous transition to chaos. Notably, in this model the edge of chaos is associated with well-known avalanches [3]. We validate our predictions in simulations of networks of binary as well as leaky integrate and fire neurons (see Fig. 1). Our results uncover an important functional role of non-Gaussian distributions of synaptic efficacy and suggest that their heavy tails may form a weak sparsity prior that can be useful in biological and artificial adaptive systems.



Simulation results of two fully connected networks of leaky integrate and fire neurons with a slowly changing, homogeneously injected current. Displayed are exemplary spiking trains and average firing rates as functions of time and the injected current amplitude.

Acknowledgements

We acknowledge useful discussions with Francesco Fumarola. This work was supported by RIKEN Center for Brain Science, Brain/MINDS from AMED under Grant Number JP19dm020700, and JSPS KAKENHI Grant Number JP18H05432.

References

1. H. Sompolinsky, A. Crisanti, and H. J. Sommers. Phys. Rev. Lett. 61, 259 (1988) [10.1103/PhysRevLett.61.259](https://doi.org/10.1103/PhysRevLett.61.259)
2. J. Kadmon and H. Sompolinsky, Phys. Rev. X 5, 041030 (2015) [10.1103/PhysRevX.5.041030](https://doi.org/10.1103/PhysRevX.5.041030)
3. J. M. Beggs, and D. Plenz. Journal of neuroscience 23.35 (2003): 11167-11177. [10.1523/JNEUROSCI.23-35-11167.2003](https://doi.org/10.1523/JNEUROSCI.23-35-11167.2003)

©(2019) Kuśmierz Ł, Ogawa S, Toyoizumi T

Cite as: Kuśmierz Ł, Ogawa S, Toyoizumi T (2019) Dynamical mean field theory of neural networks with power-law disorder. Bernstein Conference 2019 Abstract. doi: [10.12751/mncn.bc2019.0124](https://doi.org/10.12751/mncn.bc2019.0124)

[W 108] Dynamic clamp revisited: artificial capacitance in biological neurons

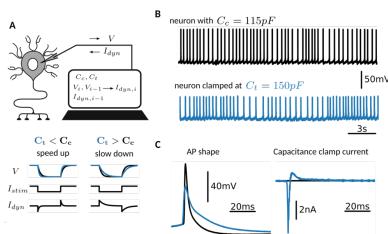
Paul Pfeiffer^{1,2}, Federico José Barreda Tomás^{2,3}, Jiameng Wu^{1,2}, Jan-Hendrik Schleimer^{1,2}, Imre Vida^{2,3}, Susanne Schreiber^{1,2}

1. Institute for Theoretical Biology, Humboldt-Universität zu Berlin, Philippstraße 13, Building 4, 10115 Berlin, Germany

2. Bernstein Center for Computational Neuroscience, Humboldt-Universität zu Berlin, Philippstraße 13, Building 6, 10115 Berlin, Germany

3. Institute for Integrative Neuroanatomy, Charité-Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, Charitéplatz 1, 10117 Berlin, Germany

A basic time scale in neural dynamics from single cells to the network level is the membrane time constant - set by a neuron's input resistance and its capacitance. Interestingly, the membrane capacitance appears to be more dynamic than previously assumed with implications for neural function and pathology. Indeed, altered membrane capacitance has been observed in reaction to physiological changes like neural swelling [1], but also in ageing and Alzheimer's disease [2]. Importantly, according to theory, even small changes of the capacitance can affect neuronal signal processing, e.g. increase network synchronization or facilitate transmission of high frequencies [3]. In experiment, robust methods to modify the capacitance of a neuron have been missing. Here, we present the capacitance clamp - an electrophysiological method for capacitance control based on an unconventional application of the dynamic clamp. In its original form, dynamic clamp mimics additional synaptic or ionic conductances by injecting their respective currents [4]. Whereas a conductance directly governs a current, the membrane capacitance determines how fast the voltage responds to a current. Accordingly, capacitance clamp mimics an altered capacitance by injecting a dynamic current that slows down or speeds up the voltage response (Fig 1 A). For the required dynamic current, the experimenter only has to specify the original cell and the desired target capacitance. In particular, capacitance clamp requires no detailed model of present conductances and thus can be applied in every excitable cell. To validate the capacitance clamp, we performed numerical simulations of the protocol and applied it to modify the capacitance of cultured neurons. First, we simulated capacitance clamp in conductance based neuron models and analysed impedance and firing frequency to verify the altered capacitance. Second, in cultured hippocampal neurons from rats, we could reliably control the capacitance in a range of 75 to 200% of the original capacitance and observed pronounced changes in the shape of the action potentials: increasing the capacitance reduced after-hyperpolarization amplitudes and slowed down repolarization(Fig 1 B, C). To conclude, we present a novel tool for electrophysiology: the capacitance clamp provides reliable control over the capacitance of a neuron and thereby opens a new way to study the temporal dynamics of excitable cells.



The capacitance clamp. A Given the original cell and the target capacitance (C_c and C_t), the dynamic clamp mimics a change of capacitance. B Spike trains of a cultured neuron: original at $C_c=115\text{pF}$ (black) and clamped at $C_t=150\text{pF}$ (blue). C Spike shapes from B (l.) and capacitance clamp currents (r.).

Acknowledgements

The work was supported by BMBF (01GQ0901, 01GQ1403) and DFG (GRK 1589/2). We are grateful to Jan Benda for support with dynamic clamp and to Janina Hesse for valuable advice on the modelling.

References

- 1 Amzica F, Neckelmann D. Membrane Capacitance of Cortical Neurons and Glia During Sleep Oscillations and Spike-Wave Seizures. *J. Neurophysiol.* 2017; 82, 2731–2746. [10.1152/jn.1999.82.5.2731](https://doi.org/10.1152/jn.1999.82.5.2731)
- 2 Brown J. T et al. Altered intrinsic excitability of hippocampal CA1 pyramidal neurons in aged PDAPP mice. *Front. Cell. Neurosci.* 2015; 9, 1–14. [10.3389/fncel.2015.00372](https://doi.org/10.3389/fncel.2015.00372)
- 3 Hesse J, Schleimer J. H, Schreiber S. Qualitative changes in phase-response curve and synchronization at the saddle-node-loop bifurcation. *Phys. Rev. E* 2017; 95. [10.1103/PhysRevE.95.052203](https://doi.org/10.1103/PhysRevE.95.052203)
- 4 Sharp A. A, O’Neil M. B, Abbott L. F, Marder E. The dynamic clamp: artificial conductances in biological neurons. *Trends Neurosci.* 1993; 16, 389–394. [10.1016/0166-2236\(93\)90004-6](https://doi.org/10.1016/0166-2236(93)90004-6)

©(2019) Pfeiffer P, Tomás FJB, Wu J, Schleimer J, Vida I, Schreiber S

Cite as: Pfeiffer P, Tomás FJB, Wu J, Schleimer J, Vida I, Schreiber S (2019) Dynamic clamp revisited: artificial capacitance in biological neurons. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0125](https://doi.org/10.12751/nncn.bc2019.0125)

[W 109] Dynamic gain analysis of an idealized model of axo-somatic membrane potential dynamics

Chenfei Zhang^{1,2}, Andreas Neef^{1,2}, David Hofmann³, Fred Wolf^{1,2}

1. Department of Physics, University of Göttingen, Göttingen, Germany

2. Campus Institute for Dynamics of Biological Networks, Göttingen, Germany

3. Department of Physics, Emory University, Atlanta, USA

Populations of cortical neurons in the fluctuation-driven regime exhibit an ultrafast population response, by which the population firing rate can increase within a millisecond after mean input is changed. In the frequency domain, this corresponds to a high bandwidth of the dynamic gain function [1, 2]. While the ultrafast population response has important implications for information encoding, its biophysical basis remains unresolved. Some studies argue that passive, morphological features of the axon and dendrites determine the population response [3, 4, 5, 6], while others emphasize the importance of ion channel properties at the axon initial segment (AIS), the action potential (AP) initiation site [7, 8]. Based on a simplified multi-compartment model, we here analyze the impact of morphological and biophysical parameters on AP initiation dynamics and population encoding. To compare the dynamic gain functions of different model variants, the neuron models are tuned to emit spikes at a fixed operating point, i.e. with spiking statistics matched by adjusting the mean and the std of injected currents.

We find: 1) The morphological and biophysical properties of neuron models influence the transformation of the injected current to the voltage at the AP initiation site. For the simplest passive model, high frequency components of the stimulus are slightly damped when transmitted to the AP initiation site. More generally, adding ion currents to the neuron model further impacts the frequency components of the axonal voltage fluctuations. 2) The bandwidth of the dynamic gain is closely related to the voltage waveform at the AP initiation site, near the time of AP onset. In contrast, the voltage waveform at the soma is less predictive, in particular at times when lateral currents dominate the depolarization. 3) Electrotonic separation between the soma and the AIS does affect the somatic AP waveform while the AP waveform at the AP initiation site is less affected. Consequently, electrotonic separation by itself, does not guarantee high bandwidth encoding and ultrafast population response. Our methodology can be generalized to more sophisticated scenarios.

Acknowledgements

We thank Barbara Feulner, Rainer Engelken and Ricardo Martins Merino for fruitful discussions.

References

- 1 Kondgen H, Geisler C, Fusi S, Wang XJ, Lüscher HR, Giugliano M. The dynamical response properties of neocortical neurons to temporally modulated noisy inputs *in vitro*. *Cereb Cortex*. 2008;18(September):2086–2097 [10.1093/cercor/bhm235](https://doi.org/10.1093/cercor/bhm235)
- 2 Tchumatchenko T, Malyshov A, Wolf F, Volgushev M. Ultrafast population encoding by cortical neurons. *J Neurosci*. 2011;31(34):12171–12179 [10.1523/JNEUROSCI.2182-11.2011](https://doi.org/10.1523/JNEUROSCI.2182-11.2011)
- 3 Brette R. Sharpness of spike initiation in neurons explained by compartmentalization. *PLoS Comput Biol*. 2013;9(12):e1003338 [10.1371/journal.pcbi.1003338](https://doi.org/10.1371/journal.pcbi.1003338)
- 4 Eyal G, Mansvelder HD, de Kock CPJ, Segev I. Dendrites impact the encoding capabilities of the axon. *J Neurosci*. 2014;34(24):8063–71 [10.1523/JNEUROSCI.5431-13.2014](https://doi.org/10.1523/JNEUROSCI.5431-13.2014)
- 5 Ostojic S, Szapiro G, Schwartz E, Barbour B, Brunel N, Hakim V. Neuronal morphology generates high-frequency firing resonance. *J Neurosci*. 2015;35(18):7056–706 [10.1523/JNEUROSCI.3924-14.2015](https://doi.org/10.1523/JNEUROSCI.3924-14.2015)
- 6 Doose J, Doron G, Brecht M, Lindner B. Noisy juxtacellular stimulation *in vivo* leads to reliable spiking and reveals high-frequency coding in single neurons. *J Neurosci*. 2016;36(43):11120–1113 [10.1523/JNEUROSCI.0787-16.2016](https://doi.org/10.1523/JNEUROSCI.0787-16.2016)
- 7 Iljin V, Malyshov A, Wolf F, Volgushev M. Fast computations in cortical ensembles require rapid initiation of action potentials. *J Neurosci*. 2013;33(6):2281–229 [10.1523/JNEUROSCI.0771-12.2013](https://doi.org/10.1523/JNEUROSCI.0771-12.2013)
- 8 Lazarov E, Dannemeyer M, Feulner B, Enderlein J, Gutnick MJ, Wolf F, et al. An axon initial segment is required for temporal precision in action potential encoding by neuronal populations. *Science Advances*. 2018;4(11) [10.1126/sciadv.aau8621](https://doi.org/10.1126/sciadv.aau8621)

©(2019) Zhang C, Neef A, Hofmann D, Wolf F

Cite as: Zhang C, Neef A, Hofmann D, Wolf F (2019) Dynamic gain analysis of an idealized model of axo-somatic membrane potential dynamics. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0126](https://doi.org/10.12751/nncn.bc2019.0126)

[W 110] Streamlined microcircuits for cortical simulations

Henri Hokkanen^{1,2}, Vafa Andalibi³, Simo Vanni^{1,2}

1. Faculty of Medicine, University of Helsinki, Finland

2. HUS Neurocenter, Helsinki University Hospital, Finland

3. School of Informatics, Computing and Engineering, Indiana University Bloomington, USA

Recently, Markram et al. (1) presented a model of the rat somatosensory cortical microcircuit (Markram model). Their model is highly detailed in terms of anatomy and physiology and its simulation requires supercomputers. Both lack of neuroinformatics and computing power are obstacles for using a similar approach to build models of other cortical areas or larger cortical systems. Simplified neuron models offer an attractive alternative to high-fidelity Hodgkin-Huxley type neuron models, but their validity in modeling cortical circuits is unclear. We simplified the Markram model to a network of exponential integrate-and-fire (EIF) neurons with linear synapses while preserving the number of neurons and synapses. We analyzed the electrophysiology and the morphology of the Markram model neurons with the eFel and NeuroM software, provided by the Blue Brain Project. We then constructed neurons with few compartments and average parameters from the reference model. We used the CxSystem simulation toolkit (2) to explore the role of short-term plasticity and GABA-B and NMDA synaptic conductances in replicating oscillatory phenomena in the Markram model. We show that while the dynamics of neurons are much simpler, having a long-acting inhibitory synaptic conductance (GABA-B) allows replication of global oscillations at the network level. Furthermore, we show that qualitatively similar dynamics are seen even with a reduced number of cell types (from 55 to 17 types). This reduction halved the computation time. Our results suggest that streamlined microcircuits facilitate experimentation with cortical networks. The simplification procedure can easily be adapted to studying other microcircuits for which extensive electrophysiological and morphological data is available.

References

- 1 Markram et al. (2015). Reconstruction and Simulation of Neocortical Microcircuitry. *Cell*, 163(2), 456–492 [10.1016/j.cell.2015.09.029](https://doi.org/10.1016/j.cell.2015.09.029)
- 2 Andalibi et al. (2019). Controlling Complexity of Cerebral Cortex Simulations—I: CxSystem, a Flexible Cortical Simulation Framework. *Neural Computation* 31, 1048–65 [10.1162/neco_a_01120](https://doi.org/10.1162/neco_a_01120)

©(2019) Hokkanen H, Andalibi V, Vanni S

Cite as: Hokkanen H, Andalibi V, Vanni S (2019) Streamlined microcircuits for cortical simulations. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0127](https://doi.org/10.12751/nncn.bc2019.0127)

[W 111] Evaluating Data Adaptive Harmonic Decomposition/Multi-Layer Stuart Landau Modelling for characterising brain electrical activity in Alzheimer's disease

Tanja Zerenner^{1,2}, Peter Ashwin^{1,2}, Marc Goodfellow^{1,2,3,4}

1. EPSRC Centre for Predictive Modelling in Healthcare, University of Exeter, Exeter, UK

2. College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, UK

3. Living Systems Institute, University of Exeter, Exeter, UK

4. Centre for Biomedical Modelling and Analysis, University of Exeter, Exeter, UK

Alzheimer's disease appears to be associated with a slowing (shift of power spectral peak to lower frequencies) and decreased synchronization in resting state EEG recordings. Numerous data analysis approaches have been used to quantify these changes, aiming at providing biomarkers for improved diagnosis and objective monitoring of disease progression (Cassani et al., 2018). Combined with such data analysis, inverse modelling can serve as a tool to disentangle the mechanisms underlying the observed changes in brain electrical activity. Even models of comparably low complexity, such as set of coupled Stuart Landau oscillators fitted to fMRI or EEG recordings as in Dermitas et al. (2017) or Tait et al. (2019), have provided insightful results suggesting, for example, a reduction of effective connectivity of the temporal lobe to be contributing to the observed changes in brain activity in Alzheimer's. A recent study by Chekroun and Kondrashov (2017) proposes an inverse stochastic modeling framework that combines a spatiotemporal data decomposition (Data Adaptive Harmonic Decomposition, DAHD) with a modelling framework (Multi-Layer Stuart Landau, MLSL). For a large number of systems transforming the data in the space spanned by the spatiotemporal DAH modes one obtains sets of paired oscillatory time series with a specific dominant frequency in approximate phase quadrature, which may thus be well-described by a set of coupled Stuart Landau Oscillators. This DAHD/MLSL technique has been applied to geophysical data such as arctic sea ice extent (Kondrashov et al., 2018 a) or wind-driven ocean gyres (Kondrashov et al., 2018 b). We study the applicability of this framework for inverse modelling of brain activity as recorded by EEG. We have applied DAHD to test data (e.g., traveling waves) and illustrate how the spatial component of the DAH modes might relate to phase locking between EEG sources. Comparing DAH modes from actual EEG recordings from a group of subjects diagnosed with Alzheimer's disease and a control group of healthy older adults, we find changes in the mode shapes, presumably related to altered synchronization in brain activity in Alzheimer's disease.

References

- 1 Cassani, R., Estarellas, M., San-Martin, R., Fraga, F.J. and Falk, T.H., 2018. Systematic review on resting-state EEG for Alzheimer's disease diagnosis and progression assessment. *Disease markers*.
- 2 Chekroun, M.D. and Kondrashov, D., 2017. Data-adaptive harmonic spectra and multilayer Stuart-Landau models. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 27(9), p.093110.
- 3 Demirtaş, M., Falcon, C., Tucholka, A., Gispert, J.D., Molinuvejo, J.L. and Deco, G., 2017. A whole-brain computational modeling approach to explain the alterations in resting-state functional connectivity during progression of Alzheimer's disease. *NeuroImage: Clinical*, 16, pp.343-354.
- 4 Kondrashov, D., Chekroun, M. and Berloff, P., 2018 a. Multiscale Stuart-Landau emulators: Application to wind-driven ocean gyres. *Fluids*, 3(1), p.21.
- 5 Kondrashov, D., Chekroun, M.D. and Ghil, M., 2018 b. Data-adaptive harmonic decomposition and prediction of Arctic sea ice extent. *Dynamics and Statistics of the Climate System*, 3(1), p.dzv001
- 6 Tait, L., Stothart, G., Coulthard, E., Brown, J.T., Kazanina, N., Goodfellow, M., 2019. Network Substrates of Cognitive Impairment in Alzheimer's Disease. *Clinical Neurophysiology*.

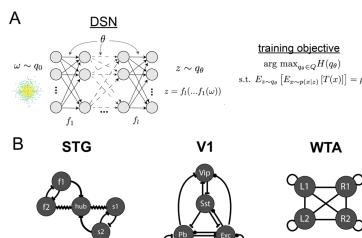
[W 112] Examining models in theoretical neuroscience with DSNs

Sean R Bittner¹, John P Cunningham²¹. Neuroscience Department, Columbia University². Statistics Department, Columbia University

Theoretical neuroscientists often design circuit models of neural activity with the hopes of producing some emergent property observed in data. However, the standard inference toolkit is designed to condition on data points collected in an experiment, rather than the abstract notion of an emergent property. We introduce a novel machine learning methodology called degenerate solution networks (DSNs), which learn a distribution of generative model parameterizations that produces the emergent property of interest, and is otherwise as random as possible. As models continue to increase in complexity and become less tractable in terms of conventional analytic and theoretical approaches, DSNs will be a useful tool for theorists to interrogate their models.

DSNs combine ideas from likelihood-free variational inference (Tran et al. 2017) and maximum entropy flow networks (Loaiza-Ganem et al. 2017). A maximum entropy flow network is used as a deep generative model for the parameter distribution, while these samples are passed through a differentiable model/dynamics simulator, which can lack a tractable likelihood function.

With DSNs, we use deep networks to learn the maximally random distribution of parameterizations, z , of a generative model, $p(x | z)$, that produces some emergent property of interest (Fig. 1, top). For example, consider the stomatogastric ganglion (STG) circuit in the crustacean, which generates tri-phasic rhythms and has a well-studied biophysical model. Rather than examining the parameter space of this model though extensive simulation (Prinz et al. 2004) as is common practice, we could directly learn the maximally random distribution of channel conductances and synaptic efficacies that yield tri-phasic rhythms with a DSN (Fig. 1, bottom, STG). Not only can we identify distributions of parameters of our theoretical models conditioned on an emergent property, but we can also use DSNs for exploratory analyses of models. With DSNs, we show novel insights about two 4-D nonlinear dynamical system models (V1 and WTA), which are not amenable to theoretical approaches that have been effective in 2-D.



A. DSNs are deep generative models of theoretical model parameterizations. They learn the maximally random distribution of model parameterizations that yield an emergent property of interest. B. Models examined: Stomatogastric ganglion (STG), primary visual cortex (V1), and winner-take-all (WTA).

References

- 1 Prinz, Astrid A., Dirk Bucher, and Eve Marder. "Similar network activity from disparate circuit parameters." *Nature neuroscience* 7.12 (2004): 1345.
- 2 Loaiza-Ganem, Gabriel, Yuanjun Gao, and John P. Cunningham. "Maximum entropy flow networks." arXiv preprint arXiv:1701.03504 (2017).
- 3 Tran, Dustin, Rajesh Ranganath, and David Blei. "Hierarchical implicit models and likelihood-free variational inference." *Advances in Neural Information Processing Systems*. 2017.

©(2019) Bittner SR, Cunningham JP

Cite as: Bittner SR, Cunningham JP (2019) Examining models in theoretical neuroscience with DSNs. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0129](https://doi.org/10.12751/nncn.bc2019.0129)

[W 113] Exploring the parameter space of spiking neural networks for winner-take-all dynamics

Marin Ozaki¹, Alpha Renner¹, Yulia Sandamirskaya¹

1. Institute of Neuroinformatics, University of Zurich and ETH Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

Winner-take-all (WTA) networks – circuits composed of recurrently connected populations of excitatory and inhibitory neurons – have been shown to model crucial aspects of cortical processing [1] and provide a powerful framework for a vast range of computations [2]. WTA dynamics have been studied extensively using both rate-based and spiking neuron models. Using a strategy similar to the mean-field approach that allows obtaining rate-based population dynamics from spiking neuron equations [3], we here explore the parameter space of spiking neural networks that results in winner-take-all dynamics with different dynamical properties.

Based on Rutishauser et al. [4], we first derived equations to find parameter ranges for a rate-based neuron model that results in stable soft and hard WTA behavior. We thereby extended the approach to allow stability analysis in networks with an arbitrary number of excitatory units. Furthermore, we derived new conditions that separate hysteresis and self-sustained behavior of the WTA network.

To relate the parameter ranges in which the network shows the desired behavior to parameters in a spiking model, we derived a function describing the relationship between the input and output firing rate for a single leaky-integrate-and-fire neuron under regular spiking input. Using this function and a strategy resembling the mean-field approach [5], we constructed a spiking neural network consisting of groups of excitatory or inhibitory neurons and mapped its parameters to the rate-based ones. In particular, we mapped the borders between parameter ranges that separate some of the different dynamical winner-take-all behaviors that we explored in the previous step. Further, based on the input-output relationship, the system's phase planes, and numerical approximations of fixed points on those phase planes, we provided a firing rate prediction and compared it to spiking network simulations. Our results show that this prediction is accurate when neurons of the spiking model are weakly connected. For strong connectivity, however, neurons start to synchronize, and the self-excitation effect gets weakened, leading to lower activity of the spiking neuron than predicted, confirming previously discussed limitations of mean-field approaches.

The pipeline presented here could prove useful in assisting the tuning of spiking neural network parameters to achieve desired behaviors in the WTA-framework, in particular on neuromorphic hardware.

Acknowledgements

This work is supported by the Swiss National Science Foundation (SNSF Ambizione grant PZOOP2_168183).

References

- 1 Douglas, R. J., Martin, K. A., & Whitteridge, D. (1989). A canonical microcircuit for neocortex. *Neural computation*, 1(4), 480-488. [10.1162/neco.1989.1.4.480](https://doi.org/10.1162/neco.1989.1.4.480)
- 2 Maass, W. (2000). On the computational power of winner-take-all. *Neural computation*, 12(11), 2519-2535. [10.1162/089976600300014827](https://doi.org/10.1162/089976600300014827)
- 3 Schwalger, T., Deger, M., & Gerstner, W. (2017). Towards a theory of cortical columns: From spiking neurons to interacting neural populations of finite size. *PLoS computational biology*, 13(4), e1005507. [10.1371/journal.pcbi.1005507](https://doi.org/10.1371/journal.pcbi.1005507)
- 4 Rutishauser, U., Douglas, R. J., & Slotine, J. J. (2011). Collective stability of networks of winner-take-all circuits. *Neural computation*, 23(3), 735-773. [10.1162/NECO_a_00091](https://doi.org/10.1162/NECO_a_00091)
- 5 Renart, A., Brunel, N., & Wang, X. J. (2004). Mean-field theory of irregularly spiking neuronal populations and working memory in recurrent cortical networks. *Computational neuroscience: A comprehensive approach*, 431-490. [10.1201/9780203494462](https://doi.org/10.1201/9780203494462)

©(2019) Ozaki M, Renner A, Sandamirskaya Y

Cite as: Ozaki M, Renner A, Sandamirskaya Y (2019) Exploring the parameter space of spiking neural networks for winner-take-all dynamics. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0130](https://doi.org/10.12751/nncn.bc2019.0130)

[W 114] Feature-binding in working memory through neuronal synchronization

Joao Barbosa¹, Ainsley Temudo², Vahan Babushkin², Kartik Sreenivasan², Albert Compte¹

1. *Systems Neuroscience, IDIBAPS, Barcelona, Spain*

2. *Psychology, NYU, Abu Dhabi, United Arab Emirates*

Swap-errors occur in working memory (WM) tasks when a wrong response is in fact accurate relative to a non-target stimulus. These errors reflect the failure to bind in memory the conjunction of features that define one object, and the mechanisms implicated remain unknown. Here, we tested the mechanism of synchrony across feature-specific neural assemblies. We built a biophysical neural network model for WM composed of two 1D attractor networks for WM, one representing colors and the other one locations. Within each network, gamma-oscillations were induced during bump-attractor activity through the interplay of fast recurrent excitation and slower feedback inhibition. These two networks are then connected via weak excitation, accomplishing color-location binding through the selective synchronization of pairs of bumps across the networks. Association-encoding was accomplished by stimulating simultaneously the corresponding bumps in each network, and feature-decoding by stimulating the cued location with a .5s pulse, which impacted strongly the corresponding phase-locked bump. In some simulations, "color bumps" abruptly changed their phase relationship with "location bumps" from which we derived a neural prediction: swap-errors are associated with a lower phase consistency of oscillatory activity in the delay period. Finally, we tested this prediction in MEG recorded from n=30 humans.

©(2019) Barbosa J, Temudo A, Babushkin V, Sreenivasan K, Compte A

Cite as: Barbosa J, Temudo A, Babushkin V, Sreenivasan K, Compte A (2019) Feature-binding in working memory through neuronal synchronization. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0131](https://doi.org/10.12751/nncn.bc2019.0131)

[W 115] **Functional spiking network model of the monkey motor cortex with inhibitory clustering and cellular adaptation**

Vahid rostami¹, Thomas Rost¹, Alexa Riehle^{2,3}, Sacha j. Van Albada², Martin P. Nawrot¹

1. *Computational Systems Neuroscience, Institute of Zoology, Cologne, Germany*

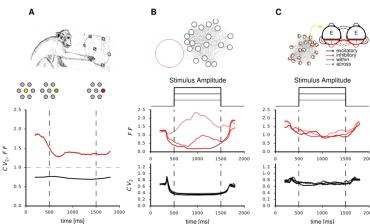
2. *Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6), Jülich, Germany*

3. *UMR7289 Institut de Neurosciences de la Timone (INT), Centre National de la Recherche Scientifique (CNRS), Marseille, France*

Recent studies [1-3] have extended the balanced random network model to incorporate clusters of strongly interconnected excitatory neurons. This network topology can exhibit a functionally desired multistable attractor dynamics [3-5]. In the multistable regime repeated attractor stimulation results in a temporal reduction of an initially increased trial-to-trial spike count variability [1-3] that qualitatively matches the experimentally observed variability dynamics [6-8] (Fig. 1A). However, it has been shown that in the multistable regime the firing rate of inactivated clusters tends quickly towards firing rate saturation [9], which is inconsistent with experimental observations and strongly limits the dynamic working range. Moreover, the multistable regime is highly sensitive even to small changes in network parameters, which strongly limits robustness. Moreover, when the stimulus is weak the spiking network model fails to capture the reduction of trial-to-trial variability during stimulation (Fig. 1B).

To improve on these aspects we incorporated two biologically plausible mechanisms in our cortical network models. We first implemented clustering of inhibitory neuron pools (Fig. 1C) as motivated by an increasing number of anatomical and physiological studies that suggest stimulus and choice selectivity of inhibitory neurons [10-11].

We find that the network model with inhibitory clustering achieves biologically realistic spiking activity with respect to the firing rate regime, spiking regularity and trial-to-trial spike count variability. As shown in Fig. 1C the temporal dynamics of the Fano factor (FF) shows a realistic reduction even for weak stimulation (light colors) while spike train regularity remains constant, in line with the experimental observation. We further added the cellular mechanisms of spike frequency adaptation (SFA) to all neurons in the network consistent with its importance in accounting for cortical network dynamics as described theoretically [12-13] and evidenced in large-scale recordings [14]. Including the cellular mechanism of SFA adds a second early transient temporal component to variability dynamics that is also observed *in vivo* and enhances the robustness of attractor dynamics against variation in network parameters. We propose that both mechanisms - inhibitory clustering at the network level and spike frequency adaptation at the cellular level - are crucial features of functional processing units in neocortex.



Variability dynamics in A) experimental data, B) network model with purely excitatory clusters and global inhibition, and C) network model with excitatory and inhibitory clusters. In all three panels, Fano factor (FF) and coefficient of variation (CV2) are computed in a 400 ms sliding window.

Acknowledgements

This work is supported by the German Science Foundation under the Institutional Strategy of the University of Cologne within the German Excellence Initiative (DFG-ZUK 81/1).

References

- 1 Litwin-Kumar, Doiron (2012) *Nat. Neurosci.*, 15(11), 1498–1505
- 2 Mazzucato et al. (2019) *Nat. Neurosci.* 22(5):1546-1726
- 3 Deco, Hugues (2012) *PLOS Comput. Biol.*, 8(3): e1002395
- 4 Wang, X.-J. (2002) *Neuron* 36, 955–968
- 5 Roudi and Latham (2007) *PLoS Comput Biol* 3(9): e141
- 6 Rickert et al. *J Neurosci* (2009) 29(44):13,870–82
- 7 Churchland et al. (2010) *Nat. Neurosci.* 13(3):369–78
- 8 Riehle et al. (2018) *Front. Neural Circuits* 12:52
- 9 Rost et al. (2018) *Biol. Cybern.*, doi: 10.1007/s00422-017-0737-7
- 10 Khan et al. (2018) *Nat. Neurosci.* 21 851–859
- 11 Najafi et al. (2018) *bioRxiv* 354340
- 12 Farkhooi et al. (2013) *PLoS Comput Biol* 9(10): e1003251
- 13 Farkhooi et al., (2011) *PRE* 83, 050905
- 14 Stringer et al. (2016) *eLife*. 5: e19695

©(2019) rostami V, Rost T, Riehle A, Van Albada Sj, Nawrot MP

Cite as: rostami V, Rost T, Riehle A, Van Albada Sj, Nawrot MP (2019) Functional spiking network model of the monkey motor cortex with inhibitory clustering and cellular adaptation. *Bernstein Conference 2019 Abstract*.

doi: [10.12751/nncn.bc2019.0132](https://doi.org/10.12751/nncn.bc2019.0132)

[W 116] How to self-organize a neuronal network towards the balanced state?

Osame Kinouchi¹, Ludmila Brochini², Ariadne de Andrade Costa³, Tawan Tayron Andrade de Carvalho⁴, Maurício Girardi-Schappo¹

1. Departamento de Física, Universidade de São Paulo, Ribeirão Preto -SP, Brazil

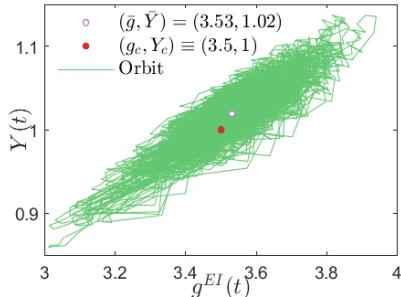
2. Instituto de Matemática e Estatística, Universidade de São Paulo, São Paulo - SP, Brazil

3. Unidade Acadêmica Especial de Ciências Exatas, Universidade Federal de Goiás - Regional Jataí, Jataí - GO, Brazil

4. Departamento de Física, Universidade Federal de Pernambuco, Recife - PE, Brazil

We study a mean field discrete time version of Brunel (2000) model with stochastic neurons. We show that the balanced point can be achieved in a self-organized way by using two homeostatic mechanisms: a Levina-Herrmann-Geisel dynamics for the inhibitory synapses and an adaptive threshold dynamics (that implements firing rate adaptation). The system presents self-organized quasi-criticality (SOqC) as defined by Bonachela et al. (2010), that is, it hovers around the critical region, producing both power laws avalanches and large synchronized events ('dragon-kings'), see Kinouchi et

al. (2019). So, our system is a self-organized critical balanced network, unifying the SOC paradigm with the balanced networks paradigm in a single framework.



Self-organization trajectories in the g vs Y plane. The system hovers around the critical balanced point of the static model, $g_c=3.5$ and $Y_c=1$, where neuronal avalanches occur. The time-series average (red dot) is $\langle g \rangle^{IT/EI} = 3.53(2)$, $\langle Y \rangle = 1.02(2)$.

Acknowledgements

This article was produced as part of the activities of FAPESP Research, Innovation and Dissemination Center for Neuromathematics (Grant No. 2013/07699-0, S. Paulo Research Foundation). We acknowledge financial support from CNPq, FACEPE, and CNAIPS-USP. M.G.-S. thanks FAPESP (Grant No. 2018/09150-9)

References

- 1 Brunel, N. (2000). Dynamics of sparsely connected networks of excitatory and inhibitory spiking neurons. *Journal of computational neuroscience*, 8(3), 183-208. [10.1023/A:1008925309027](https://doi.org/10.1023/A:1008925309027)
- 2 Bonachela, J. A., De Franciscis, S., Torres, J. J., & Munoz, M. A. (2010). Self-organization without conservation: are neuronal avalanches generically critical?. *Journal of Statistical Mechanics: Theory and Experiment*, 2010(02), P02015. [10.1088/1742-5468/2010/02/P02015](https://doi.org/10.1088/1742-5468/2010/02/P02015)
- 3 Kinouchi, O., Brochini, L., Costa, A. A., Campos, J. G. F., & Copelli, M. (2019). Stochastic oscillations and dragon king avalanches in self-organized quasi-critical systems. *Scientific reports*, 9(1), 3874. [10.1038/s41598-019-40473-1](https://doi.org/10.1038/s41598-019-40473-1)

©(2019) Kinouchi O, Brochini L, Costa AdA, Andrade de Carvalho TT, Girardi-Schappo M

Cite as: Kinouchi O, Brochini L, Costa AdA, Andrade de Carvalho TT, Girardi-Schappo M (2019) How to self-organize a neuronal network towards the balanced state?. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0133](https://doi.org/10.12751/nncn.bc2019.0133)

[W 117] Impact of functional synapse clusters on neuronal response selectivity

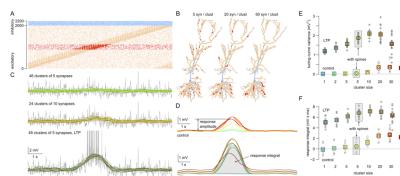
Balázs B Ujfalussy¹, Judit K Makara¹

1. Laboratory of Neuronal Signaling, , Institute of Experimental Medicine, 1083 Budapest, Szigony utca 43., Hungary

Clustering of functionally similar synapses in dendrites is thought to affect input-output transformation by inducing dendritic nonlinearities. However, neither the *in vivo* impact of synaptic clusters on somatic membrane potential (*sVm*), nor the rules of cluster formation are elucidated.

We developed a computational technique to measure the impact of functional synaptic clusters by decomposing the variability of the somatic voltage response of biophysical model neurons to behaviorally relevant *in vivo*-like inputs into three components: dendritic factors (including clustering), synaptic factors, and trial-to-trial variability. We then applied this technique to CA1 pyramidal neurons with inputs matched to hippocampal population activity in rodents during spatial exploration in the theta state. We found that large-scale dendritic spatial inhomogeneities in synaptic tuning properties did influence *sVm*, but small synaptic clusters appearing randomly with unstructured connectivity did not. We then demonstrate that without nonlinear amplification of the effect of random clusters, action potential-based, global plasticity rules can not generate functional clustering. Next we systematically varied the size of the functional synaptic clusters we found that 10-20 synapses per cluster was optimal to achieve a robust, clustering-based tuning, as larger cluster sizes caused local saturation of the synaptic driving force. However, substantially larger response selectivity was achieved by 2-fold potentiation of the same synapses with or without clustering. We obtained similar results in a L2/3 pyramidal cell model with inputs tuned to visual cortical activity during drifting grating stimulation. Finally, we found that during hippocampal sharp-wave activity the elevated network synchrony paradoxically decreases the effect of functional clustering on the response selectivity by both increasing the NMDA contribution in the absence of clustering and reducing the neuronal gain.

Our findings indicate that 1) the selective responses of cortical neurons are primarily the consequence of the tuning of their synaptic inputs, 2) functional synaptic clustering matched to local dendritic properties can have additional role in refining those responses, 3) plasticity of functional synapse clusters such as those observed *in vivo* requires local rather than global mechanisms, and 4) in turn, local plasticity by small synaptic clusters may lead to powerful tuning of somatic responses.



A) Clustered excitatory inputs (red). B) Location of the synaptic clusters. C) *sVm* response of the CA1 neuron (grey), filtered responses (dark) and tuning curve (light). D) Tuning curve (TC) with (bottom) and without (top) LTP. E-F) TC variance and integral as a function of synaptic clustering.

Acknowledgements

This work was supported by an MTA and an NKFIIH fellowship (PD-020/2015 and PD-125386, FK-125324; B.B.U.), the Howard Hughes Medical Institute (55008740; J.K.M.), and the ERC (CoG 771849; J.K.M.).

©(2019) Ujfalussy BB, Makara JK

Cite as: Ujfalussy BB, Makara JK (2019) Impact of functional synapse clusters on neuronal response selectivity. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0134](https://doi.org/10.12751/nncn.bc2019.0134)

[W 118] **Improving coding fidelity in spiking neural networks by harnessing noise and chaos**

Jonathan Kadmon¹, Jonathan Paul Timcheck², Surya Ganguli^{1,3}, Kwabena Boahen⁴

1. Applied Physics, Stanford University, Stanford, CA

2. Physics, Stanford University, Stanford, CA

3. Google, Mountain View, CA

4. Bioengineering, Stanford University, Stanford, CA

Both neural noise and disordered connectivity are prominent features of cortical circuitry. However, it is unclear whether such heterogeneity is biologically unavoidable or whether it benefits computation. In classical models of neural circuitry, weakly correlated noise induces decoding errors that decrease as the square-root of network size. In contrast, a recent efficient coding framework has shown that spiking networks can achieve superclassical scaling, in which decoding error decreases linearly with network size. A key property enabling this improved coding is asynchronous neural dynamics, maintained by fast and strong lateral inhibition. However, transmission delays in realistic networks are unavoidable due to the underlying biophysical processes. Indeed, numerical simulations show that the decoding performance of large networks significantly decreases in the presence of delays.

We derive an analytic theory for efficient coding that considers spike latency, synchronization, and noise. In a fully deterministic system, transmission delays synchronize the neural activity, thereby destroying the high coding fidelity. Counterintuitively, added noise can recover superclassical coding. Furthermore, there exists an optimal noise level that minimizes the error. Importantly, finite spike-latencies limit the performance of large networks, and the optimal error scales as a power-law of the delay time. We show that synaptic heterogeneity is sufficient to regain superclassical coding even in deterministic systems, reminiscent of the emergence of deterministic chaos in neural networks. Finally, we derive a theory for efficient coding in high dimensional dynamical systems and show that the readout error scales with the maximum firing rate of individual neurons.

Acknowledgements

JK thanks the Swartz Foundation for funding

References

- Boerlin, Martin, Christian K. Machens, and Sophie Denève. 2013. "Predictive Coding of Dynamical Variables in Balanced Spiking Networks." *PLoS Computational Biology* 9 (11): e1003258.
- Chalk, Matthew, Boris Gutkin, and Sophie Denève. 2016. "Neural Oscillations as a Signature of Efficient Coding in the Presence of Synaptic Delays." *eLife* 5 (July). <https://doi.org/10.7554/eLife.13824>.
- Schwemmer, Michael A., Adrienne L. Fairhall, Sophie Denève, and Eric T. Shea-Brown. 2015. "Constructing Precisely Computing Networks with Biophysical Spiking Neurons." *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience* 35 (28): 10112–34.

©(2019) Kadmon J, Timcheck JP, Ganguli S, Boahen K

Cite as: Kadmon J, Timcheck JP, Ganguli S, Boahen K (2019) Improving coding fidelity in spiking neural networks by harnessing noise and chaos. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0135](https://doi.org/10.12751/nncn.bc2019.0135)

[W 119] Insights into the dynamics of finite recurrent networks

Pierre Ekelmans¹, Nataliya Kraynyukova¹, Tatjana Tchumatchenko¹

1. Theory of Neural Dynamics, Max Planck Institute for Brain Research, Max Von Laue stra e 4, Germany

The activity of a neural network depends on the network size, its external input and the strength of its recurrent connections. A common framework used to predict the activity regime in a network is the balanced state framework, which assumes that the recurrent input exactly compensates the feedforward input (van Vreeswijk and Sompolinsky, 1996). The balanced state hypothesis has two limitations. First, it assumes that the network is very large ($N \rightarrow \infty$). This limit can be difficult to achieve in biological networks such as a cortical column because these often contain $10^3 - 10^4$ neurons (Krueger et al, 2008), and LIF networks of this size do not meet the balanced state limit in simulations. Furthermore, the convergence to balanced state is relatively slow, and scales as $\frac{1}{\sqrt{N}}$. Second, if the N to infinity limit was precisely achieved the balanced state would lead to a linear input-output response at the network level. However, experimental data have shown that network activity can be a nonlinear function of the external input. While plasticity can make the balanced state non-linear (Mongillo et al, 2012), we wondered whether deviations from the balanced state are already enough to generate significant non-linearities. The stabilized supralinear network (SSN), is a network model which can predict nonlinear network activity (Ahmadian et al, 2013). It is based on the observation that the input-output response of individual neurons follows a power law. The SSN model can predict nonlinear network activity regimes, such as bistability or supersaturation, even in the absence of synaptic plasticity (Kraynyukova and Tchumatchenko, 2018). The SSN provides a mathematically tractable framework in which the network activity can be studied analytically. Here, we explore the hypothesis that networks of finite size can be understood using the SSN model. Specifically, we show that multiple non-linear regimes predicted in the SSN can be recovered in spiking network simulations. Via the analysis of the SSN, we characterize the range of nonlinear activity regimes that spiking networks can have at their disposal to perform complex computation.

Acknowledgements

Max Planck Society and DFG (CRC 1080)

References

- 1 Ahmadian et al. *Neural Computation*, 2013 [10.1162/NECO_a_00472](https://doi.org/10.1162/NECO_a_00472)
- 2 Krueger et al. *Nature Reviews Neuroscience*, 2008 [10.1038/nrn2521](https://doi.org/10.1038/nrn2521)
- 3 van Vreeswijk and Sompolinsky. *Science*, 1996 [10.1126/science.274.5293.1724](https://doi.org/10.1126/science.274.5293.1724)
- 4 Mongillo et al. *Physical Review letters*, 2012 [10.1103/PhysRevLett.108.158101](https://doi.org/10.1103/PhysRevLett.108.158101)
- 5 Kraynyukova and Tchumatchenko. *PNAS*, 2018 [10.1073/pnas.1700080115](https://doi.org/10.1073/pnas.1700080115)

 (2019) Ekelmans P, Kraynyukova N, Tchumatchenko T

Cite as: Ekelmans P, Kraynyukova N, Tchumatchenko T (2019) Insights into the dynamics of finite recurrent networks. *Bernstein Conference 2019 Abstract*. doi: [10.12751/ncnbc2019.0136](https://doi.org/10.12751/ncnbc2019.0136)

[W 120] **Intrinsic timescales define a cortical hierarchy and suggest network-tuning to task requirements.**

Jonas Dehning¹, Nicholas M. Dotson², Steven J. Hoffman³, Charles M. Gray³, Viola Priesemann^{1,4}

1. MPI for Dynamics and Self-organization, Am Fassberg 17, 37077 Göttingen, Germany

2. Department of Bioengineering, University of California, Berkeley, Berkeley, CA 94708, USA

3. Department of Cell Biology and Neuroscience, Montana State University, Bozeman, MT 59717, USA

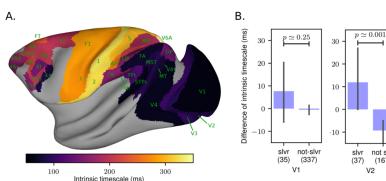
4. Bernstein Center for Computational Neuroscience, Am Fassberg 17, 37077 Göttingen

In cortex, information processing is likely to be organized hierarchically. Recently, a functional hierarchy was identified across five visual areas and two somatosensory areas in different macaques, based on estimates of an intrinsic timescale for each area [1]. The intrinsic timescale is defined as the decay constant of the autocorrelation function of the spiking activity [1,2]. This intrinsic timescale implies that information can be maintained in ongoing activity without the need for synaptic changes, and can thereby be used for processing across an extended time window of the order of this timescale.

We present results from whole hemisphere spiking recordings, realized by up to 107 movable electrodes in two macaques [3]. We could assess the intrinsic timescales of 42 areas in the first macaque and of 16 areas in the second. We find in both monkeys the same hierarchical organization: Visual cortex exhibits the shortest intrinsic timescales (80 ms), prefrontal and posterior parietal intermediate ones (200 ms) and motor and somatosensory cortex the highest (300 ms).

More importantly, we found indications of a dependence of the intrinsic timescales on the type of task performed: Neurons that are presumably inside the visual receptive field of the relevant stimuli tend to increase their timescales when confronted with a task, whereas the ones that are outside decrease theirs. Such a decrease (increase) of the intrinsic timescale is related to a direct decrease (increase) in computational properties like the sensitivity, dynamic range and amplification strength of the network [4].

Therefore, we interpret the increase of timescales of neurons in the visual field as a tuning-in to task requirements (higher sensitivity) and the decrease as a tuning-out (reduced sensitivity). Thereby we did not only expand on earlier insights about a hierarchy of information processing but also showed that changes of the intrinsic timescales may be explained by changing task requirements. This advances our understanding of the relation between the function of cortical networks and their temporal dynamics.



A. A surface plot of the intrinsic timescales of monkey 1. B. Preliminary results of the task dependency of the timescales. By "slvr" we designate neurons where the visual stimulus is presumably inside their receptive field.

References

- 1 Murray et al., Nat. Neurosci., 2014 [10.1038/nn.3862](https://doi.org/10.1038/nn.3862)
- 2 J. Wilting and V. Priesemann, Nat. Commun., 2018 [10.1038/s41467-018-04725-4](https://doi.org/10.1038/s41467-018-04725-4)
- 3 N. M. Dotson et al., Neuron, 2017 [10.1016/j.neuron.2017.09.050](https://doi.org/10.1016/j.neuron.2017.09.050)
- 4 J. Wilting et al., Front. Syst. Neurosci., 2018 [10.3389/fnsys.2018.00055](https://doi.org/10.3389/fnsys.2018.00055)

©(2019) Dehning J, Dotson NM, Hoffman SJ, Gray CM, Priesemann V

Cite as: Dehning J, Dotson NM, Hoffman SJ, Gray CM, Priesemann V (2019) Intrinsic timescales define a cortical hierarchy and suggest network-tuning to task requirements.. Bernstein Conference 2019 Abstract.
doi: [10.12751/mncn.bc2019.0137](https://doi.org/10.12751/mncn.bc2019.0137)

[W 121] Introducing conductance-based dynamics in spike-coding networks preserves efficient and accurate network representation.

Amber M. Brands¹, Sander W. Keemink¹, Christian K. Machens¹

1. Champalimaud Research, Champalimaud Centre for the Unknown, Av. Brasília, 1400-038, Lisbon, Portugal

A central question in neuroscience remains how neural networks encode information in their spikes. A recent theory for spike-based neuronal processing is given by (predictive) spike coding networks (SCNs) (Boerlin et al., 2013; Deneve & Machens, 2016). These are networks of leaky integrate-and-fire neurons whose dynamics and connectivity are derived by assuming linear decoding of information and by assuming that each neuron spikes only if that improves the decoded information. While this framework naturally reproduces several experimental observations, including trial-to-trial variability, irregular and Poisson-like spiking patterns, balance between excitation and inhibition, and robustness to perturbations (Denève & Machens, 2016), it also deviates from the known biology in several ways. One of those differences is that the network is based on current-based neuron-models rather than conductance-based models. Previously, Schwemmer et al. (2015) investigated this question in a simulation study by making several biology-inspired adjustments to SCNs, and showing that the core features of SCNs remain preserved. However, these adjustments were not derived from first principles and it therefore remains unclear to what extent moving into such a biologically more plausible regime changes or worsens the information representation in SCNs. Here, we explored the SCN with conductance-based integrate-and-fire neurons using a normative approach. In the original, current-based SCN framework, the voltage of individual neurons represents the projection of the coding error between input and output signals. We show that by implementing conductance-based neurons, the voltages can be re-interpreted as a normalized projection of the coding errors. In terms of signal representation, our results initially reveal that this normalisation introduces a bias in the coding error. However, further examination shows that this bias can be corrected for with a simple adjustment of the decoder. Altogether, our work shows that conductance-based dynamics can be derived from core principles, improving the biophysical plausibility of SCNs without deteriorating the information representation.

Acknowledgements

Amber Brands thanks Sander Keemink and Christian Machens for supervision and the general Champalimaud community for discussions.

References

- 1 Boerlin, M., Machens, C. K., & Denève, S. (2013). Predictive coding of dynamical variables in balanced spiking networks. PLoS computational biology, 9(11), e1003258. [10.1371/journal.pcbi.1003258](https://doi.org/10.1371/journal.pcbi.1003258)
- 2 Denève, S. and Machens, C. K. (2016). Efficient codes and balanced networks. Nature neuroscience, 19(3):375. [10.1038/nn.4243](https://doi.org/10.1038/nn.4243)

- 3 Schuemmer, M. A., Fairhall, A. L., Denéve, S., & Shea-Brown, E. T. (2015). Constructing precisely computing networks with biophysical spiking neurons. *Journal of Neuroscience*, 35(28), 10112-10134. [10.1523/JNEUROSCI.4951-14.2015](https://doi.org/10.1523/JNEUROSCI.4951-14.2015)

©(2019) Brands AM, Keemink SW, Machens CK

Cite as: Brands AM, Keemink SW, Machens CK (2019) Introducing conductance-based dynamics in spike-coding networks preserves efficient and accurate network representation.. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0138](https://doi.org/10.12751/nncn.bc2019.0138)

[W 122] Judging between Excitation and Inhibition: Identifying Local Network Architecture by an Analytic Pre-Post Relation

Safura Rashid Shomali¹, Majid Nili Ahmadabadi², Seyyed Nader Rasuli^{3,4}, Hideaki Shimazaki^{5,6}

1. School of Cognitive Sciences, Institute for Research in Fundamental Sciences (IPM), Tehran 19395-5746, Iran

2. School of Electrical and Computer Engineering, University of Tehran, Tehran 14395-515, Iran

3. Department of Physics, University of Guilan, Rasht 41335-1914, Iran

4. School of Physics, Institute for Research in Fundamental Sciences (IPM), Tehran 19395-5531, Iran

5. Graduate School of Informatics, Kyoto University, Kyoto 606-8501, Japan

6. Honda Research Institute Japan, Wako-shi 351-0188, Japan

Recognizing network architecture exploiting the recorded activity of neurons only, is a challenge in neuroscience. In general, this is a hard task; but an analytic tool can help us to narrow down possible scenarios and approach the architecture behind the activity. Recently, researchers have found a statistical pre-post relation for a Leaky-Integrate-and-Fire (LIF) neuron when the neuron receives signaling input on top of noisy background inputs near the threshold regime [1]. We use this analytic relation in mixture models to investigate the effect of shared inputs on network architecture. It connects synaptic inputs and statistics of population activity (pairwise and higher-order correlations) to network architecture in basic symmetric and asymmetric motifs; this lets us identify the underlying network architecture. We use it to address the architecture behind sparse population activity, reported for monkey's V1 neurons [2]. Comparing the theoretical graphs with the experimental data [2,3], we determine whether the underlying architecture is symmetric or asymmetric, whether synapses are excitatory or inhibitory, and more. We also consider the possibility of recurrent activities among neurons; which we categorize in 16 main motifs. The study on shared inputs and recurrent connections shows the main structure in which one excitatory common input gives synapses to a pair of neurons is responsible for the observed strong negative triple-wise correlations. This is in contrast with the intuitive expectation that shared inhibition causes the observed sparse activity. Finally, we ask why excitatory to pairs, and not inhibitory based architectures, induce such strong correlations in the aforementioned experiment. We attribute it to the sparseness of neuronal activity: When neurons are predominantly silent; an excitatory input causes a more significant change compared to any inhibitory one.

References

- Shomali, S.R., Ahmadabadi, M.N., Shimazaki, H. et al. J Comput Neurosci (2018) 44: 147 [10.1007/s10827-017-0664-6](https://doi.org/10.1007/s10827-017-0664-6)
- Ohiorhenuan, I. E., Mechler, F., Purpura, K. P. et al. . Nature (2010). 466(7306): 617. [10.1038/nature09178](https://doi.org/10.1038/nature09178)
- Ohiorhenuan, I.E. & Victor, J.D. J Comput Neurosci (2011) 30: 125 [10.1007/s10827-010-0257-0](https://doi.org/10.1007/s10827-010-0257-0)

©(2019) Rashid Shomali S, Nili Ahmadabadi M, Rasuli SN, Shimazaki H

Cite as: Rashid Shomali S, Nili Ahmadabadi M, Rasuli SN, Shimazaki H (2019) Judging between Excitation and Inhibition: Identifying Local Network Architecture by an Analytic Pre-Post Relation. *Bernstein Conference 2019 Abstract*. doi: 10.12751/nncn.bc2019.0139

[W 123] Learning low-dimensional inputs for brain-machine interface control

Jorge Aurelio Menendez^{1,2}, Peter E. Latham¹

1. Gatsby Computational Neuroscience Unit, University College London, 25 Howland Street, London, W1T 4JG, United Kingdom

2. CoMPLEX, University College London, Engineering Building, Malet Place WC1E 7JG, United Kingdom

Mammalian motor systems adapt well to new environments. A remarkable demonstration of this is primates' acquisition of proficient control with a brain-machine interface (BMI). The short timescales at which this can happen (100s of trials [1,2,3]) is surprising when one considers that, because the BMI decoder is unknown to the animal, learning must be accomplished using gradient-free optimization. Gradient-free algorithms scale badly with the number of parameters learnt [4], suggesting that learning the millions of synaptic parameters in the local circuit [5,6] is implausible. Here we propose that the animal instead uses a re-aiming strategy, and learns the right motor commands for the BMI task at hand. We model these as upstream inputs to the local motor cortical circuit. We assume that any changes over learning modify these inputs within a low-dimensional space, thus reducing the dimensionality of the learning problem. However, this assumption has the consequence that the resulting network activity is likewise constrained to a low-dimensional "activity manifold". This means that if the BMI decoder happens to be mis-aligned with this manifold – i.e. large activity patterns on it map to small BMI readouts – then very large inputs will be needed to control the BMI. A common BMI learning task is to perturb a BMI decoder and ask how well an animal can re-learn to control it. In the case of linear dynamics, we show analytically that, under our model, optimal performance depends on the alignment between the network "activity manifold" and the perturbed BMI decoder: better alignment requires less input strength to reach good performance. We corroborate this with simulations in fig 1, which shows the minimum achievable reaching error with a given input strength for fully (blue), strongly (orange) and weakly (green) aligned decoders. Nonlinear ReLU networks show similar behavior (fig 2). Our model thus implies that this low-dimensional learning strategy is only feasible for aligned decoder perturbations, offering an explanation for why fast learning is observed only for those [1]. Moreover, we find that if we constrain the dimensionality of the learned input to two, our model predicts that the population activity during BMI control will conserve its correlation structure through learning (fig 3), which has been observed experimentally [7,8,9]. When the inputs are allowed to vary over higher dimensions, however, the population activity changes drastically (fig 3).

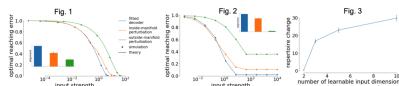


Fig 1,2 insets show alignment of each decoder with "activity manifold". See ref 1 for algorithm used to construct these perturbations. See ref 7 for definition of "repertoire change" metric used in fig 3. Shown are means +/- SEM over 100 sampled perturbations.

References

- 1 Sadtler, P. T., Quick, K. M., Golub, M. D., Chase, S. M., Ryu, S. I., Tyler-Kabara, E. C., ... & Batista, A. P. (2014). Neural constraints on learning. *Nature*, 512(7515), 423. [10.1038/nature13665](https://doi.org/10.1038/nature13665)
- 2 Jarosiewicz, B., Chase, S. M., Fraser, G. W., Velliste, M., Kass, R. E., & Schwartz, A. B. (2008). Functional network reorganization during learning in a brain-computer interface paradigm. *Proceedings of the National Academy of Sciences*, 105(49), 19486-19491. [10.1073/pnas.0808113105](https://doi.org/10.1073/pnas.0808113105)
- 3 Chase, S. M., Kass, R. E., & Schwartz, A. B. (2012). Behavioral and neural correlates of visuomotor adaptation observed through a brain-computer interface in primary motor cortex. *Journal of neurophysiology*, 108(2), 624-644. [10.1152/jn.00371.2011](https://doi.org/10.1152/jn.00371.2011)
- 4 Werfel, J., Xie, X., & Seung, H. S. (2004). Learning curves for stochastic gradient descent in linear feedforward networks. In *Advances in neural information processing systems* (pp. 1197-1204). [10.1162/089976605774320539](https://doi.org/10.1162/089976605774320539)
- 5 Legenstein, R., Chase, S. M., Schwartz, A. B., & Maass, W. (2010). A reward-modulated hebbian learning rule can explain experimentally observed network reorganization in a brain control task. *Journal of Neuroscience*, 30(25), 8400-8410. [10.1523/JNEUROSCI.4284-09.2010](https://doi.org/10.1523/JNEUROSCI.4284-09.2010)
- 6 Wärnberg, E., & Kumar, A. (2019). Perturbing low dimensional activity manifolds in spiking neuronal networks. *PLoS computational biology*, 15(5), e1007074. [10.1371/journal.pcbi.1007074](https://doi.org/10.1371/journal.pcbi.1007074)
- 7 Golub, M. D., Sadtler, P. T., Oby, E. R., Quick, K. M., Ryu, S. I., Tyler-Kabara, E. C., ... & Yu, B. M. (2018). Learning by neural reassociation. *Nature neuroscience*, 21(4), 607-616. [10.1038/s41593-018-0095-3](https://doi.org/10.1038/s41593-018-0095-3)
- 8 Hennig, J. A., Golub, M. D., Lund, P. J., Sadtler, P. T., Oby, E. R., Quick, K. M., ... & Chase, S. M. (2018). Constraints on neural redundancy. *eLife*, 7, e36774. [10.7554/eLife.36774](https://doi.org/10.7554/eLife.36774)
- 9 Hwang, E. J., Bailey, P. M., & Andersen, R. A. (2013). Volitional control of neural activity relies on the natural motor repertoire. *Current Biology*, 23(5), 353-361. [10.1016/j.cub.2013.01.027](https://doi.org/10.1016/j.cub.2013.01.027)

©(2019) Menendez JA, Latham PE

Cite as: Menendez JA, Latham PE (2019) Learning low-dimensional inputs for brain-machine interface control. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncc.bc2019.0140](https://doi.org/10.12751/nncc.bc2019.0140)

Brain disease, network dysfunction and intervention

[W 124] Can bursts with a low load of epileptic spikes reduce seizure susceptibility?

Katharina Heining^{1,2,3}, Antje Kiliias^{1,2,3}, Philipp Janz^{3,4}, Ute Häussler^{4,5}, Arvind Kumar^{2,6}, Carola Anneliese Haas^{2,4,5}, Ulrich Egert^{1,2,5}

1. Biomicrotechnology, Department of Microsystems Engineering, Faculty of Engineering, University of Freiburg, 79110 Freiburg, Germany

2. Bernstein Center Freiburg, University of Freiburg, 79104 Freiburg, Germany

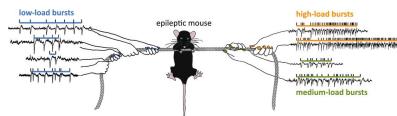
3. Faculty of Biology, University of Freiburg, 79104 Freiburg, Germany

4. Experimental Epilepsy Research, Department of Neurosurgery, Medical Center – University of Freiburg, 79106 Freiburg, Germany

5. BrainLinks-BrainTools Cluster of Excellence, University of Freiburg, 79110 Freiburg, Germany

6. Computational Science and Technology, School of Electrical Engineering and Computer Science, KTH Royal Institute of Technology, 11428 Stockholm, Sweden

Hypersynchronous network activity is the defining hallmark of epilepsy and manifests in a wide spectrum of phenomena of which electrographic activity during seizures is only one extreme. We developed a framework to differentiate between types of epileptiform activity patterns and investigated their temporal succession and interactions. In local field potentials of freely behaving epileptic mice, epileptiform spikes occur in distinct bursts. Using machine learning, we derived a scale reflecting the spike load of bursts and three main burst categories: high-load, medium-load and low-load bursts. These different burst types were non-randomly distributed in time: High-load bursts formed clusters and were typically surrounded by transition phases with increased rates of medium-load and low-load bursts. In apparent contradiction to this, increased rates of low-load bursts were positively correlated with the duration of phases lacking high-load dynamics. These findings are consistent with the hypothesis that low-level epileptiform activity can promote network stability in epilepsy, but that its impact ultimately depends on the current state of the network.



Acknowledgements

This work was supported by the German Research Foundation as part of the Cluster of Excellence 'BrainLinks-BrainTools' within the framework of the German Excellence Initiative (EXC 1086), by the state of Baden-Württemberg through bwHPC, and by the Federal Ministry of Education and Research (BMBF).

©(2019) Heining K, Kiliias A, Janz P, Häussler U, Kumar A, Haas CA, Egert U

Cite as: Heining K, Kiliias A, Janz P, Häussler U, Kumar A, Haas CA, Egert U (2019) Can bursts with a low load of epileptic spikes reduce seizure susceptibility?. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0141](https://doi.org/10.12751/nncn.bc2019.0141)

[W 125] Collective neural dynamics in epilepsy: Can epileptic seizures be described by a transition to supercritical dynamics?

Annika Hagemann¹, Bita Samimizad², Florian Mormann², Viola Priesemann¹

1. Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

2. Department of Epileptology, University of Bonn Medical Centre, Bonn, Germany

A prevalent hypothesis in the field of neuroscience is that the collective neural dynamics self-organizes to a state close to the critical point of a phase transition, separating stable, subcritical dynamics from unstable, supercritical dynamics. Although such a critical point can provide advantages for information processing, recent experimental evidence suggests that the brain operates in a slightly subcritical regime instead, maintaining a safety margin from instability.[1] In epilepsy patients, the brain repeatedly fails to regulate activity, resulting in excessive neural activity that is observed during an epileptic seizure. Epileptic seizures have been hypothesized to be related to a transition to supercritical dynamics but quantitative evidence for this hypothesis is limited. Based on spike recordings from epilepsy patients, we are investigating whether collective neural dynamics in epilepsy patients show signatures of a failure to stay within the stable, subcritical regime. We use a branching process to model activity propagation in the brain. In this model, the distance to the critical point is described by a single order parameter, defined as the average number of spikes that is triggered by a single additional spike in the system. Applying a novel subsampling-invariant estimator [2], we estimate the distance to criticality for the medial temporal lobe of patients with focal epilepsy. In particular, we are analyzing whether there are (i) general differences in the distance to criticality in brain regions that are known to trigger seizures and (ii) changes in the distance to criticality before seizure onset. Our results suggest that human spiking activity is in a slightly subcritical regime during seizure-free periods. Furthermore, preliminary results indicate a difference between the hemisphere containing the epileptic focus and the contra-lateral hemisphere. To analyze changes in the distance to criticality before seizure onset, we are currently working on a time-dependent estimation method that we will apply to pre-ictal spike recordings.

References

- 1 Priesemann, V., Wibral, M., Valderrama, M., Pröpper, R., Le Van Quyen, M., Geisel, T., ... & Munk, M. H. (2014). Spike avalanches *in vivo* suggest a driven, slightly subcritical brain state. *Frontiers in systems neuroscience*, 8, 108. [10.3389/fnsys.2014.00108](https://doi.org/10.3389/fnsys.2014.00108)
- 2 Wilting, J., & Priesemann, V. (2018). Inferring collective dynamical states from widely unobserved systems. *Nature communications*, 9(1), 2325. [10.1038/s41467-018-04725-4](https://doi.org/10.1038/s41467-018-04725-4)

©(2019) Hagemann A, Samimizad B, Mormann F, Priesemann V

Cite as: Hagemann A, Samimizad B, Mormann F, Priesemann V (2019) Collective neural dynamics in epilepsy: Can epileptic seizures be described by a transition to supercritical dynamics?. Bernstein Conference 2019 Abstract.
doi: [10.12751/hncn.bc2019.0142](https://doi.org/10.12751/hncn.bc2019.0142)

[W 126] Computational modeling of neuroimmune interactions in epileptogenesis

Danylo Batulin^{1,2}, Fereshteh Lagzi¹, Peter Jedlicka^{1,3,4}, Jochen Triesch^{1,5,6}

1. Frankfurt Institute for Advanced Studies, Ruth-Moufang-Straße 1, 60438 Frankfurt, Germany

2. The International Max Planck Research School for Neural Circuits, Max Planck Institute for Brain Research, Max-von-Laue-Straße 4, 60438 Frankfurt, Germany

3. Interdisciplinary Centre for 3Rs in Animal Research, Faculty of Medicine, Justus-Liebig-University, Rudolf-Buchheim-Straße 6, 35392 Giessen, Germany

4. Institute of Clinical Neuroanatomy, Neuroscience Center, Goethe University, Heinrich-Hoffmann-Straße 7, Building 89, 60528 Frankfurt, Germany

5. Department of Physics, Goethe University, Max-von-Laue-Straße 1, 60438 Frankfurt, Germany

6. Department of Computer Science and Mathematics, Goethe University, Robert-Mayer-Straße 11-15, 60629 Frankfurt, Germany

Epileptogenesis is often triggered by a brain injury. Such injuries can differ in origin (e.g. traumatic, infectious), but most of them cause neuronal loss and inflammation, which is mediated by glial cells in the central nervous system. Despite intensive research, an understanding of the causality of events in epilepsy development (epileptogenesis) remains elusive. Interestingly, there is evidence that neuroinflammation in the central nervous system is both a consequence and a cause of seizures [1, 2]. This suggests a vicious circle of misdirected neuroimmune interactions as a possible cause of epilepsy. To better understand these complex interactions, we study the interplay between brain injury, inflammation, neuronal loss and epileptogenesis using mathematical modeling. Our goal is to identify key processes and time scales that are crucial for disease development and to suggest novel therapeutic interventions to stop disease progression. Building on human and animal data, we have designed a minimalistic phenomenological model of epileptogenesis. The model accounts for inflammatory reaction to injury, sensitization of microglia upon recurrent activation, neurotoxicity, glial reaction to neuronal activity during epileptic seizures, and circuit remodeling due to neuronal loss. The interaction between these processes is modeled in the form of a nonlinear dynamical system based on coarse-grained variables. Modeling results suggest prominent targets for medical treatment, which have been found to play a central role in epileptogenesis. One of these processes is sensitization of microglia caused by recurrent activation, which results in an amplified inflammatory reaction to subsequent proinflammatory stimuli. In the case of epilepsy, recurrent activation may be caused by an initial injury, which kicks off a pathological process, and following inflammatory reactions in response to excessive neuronal activity during seizures. Our results provide a phenomenological framework for understanding epileptogenesis and suggesting targets for further experimental and clinical research in order to develop novel therapies.

Acknowledgements

All authors thank Center for Personalized Translational Epilepsy Research (CePTER). Danylo Batulin thanks German Academic Exchange Service (DAAD), Max Planck Society (MPG) and Frankfurt Institute for Advanced Studies (FIAS) for financial support of studies and research.

References

- 1 Vezzani, A., French, J., Bartfai, T. and Baram, T.Z., 2011. The role of inflammation in epilepsy. *Nature reviews neurology*, 7(1), p.31. [10.1038/nrneurol.2010.178](https://doi.org/10.1038/nrneurol.2010.178)
- 2 Li, G., Bauer, S., Nowak, M., Norwood, B., Tackenberg, B., Rosenow, F., Knake, S., Oertel, W.H. and Hamer, H.M., 2011. Cytokines and epilepsy. *Seizure*, 20(3), pp.249-256. [10.1016/j.seizure.2010.12.005](https://doi.org/10.1016/j.seizure.2010.12.005)

[W 127] Gender dependent pharmacotherapy for blocking transition to chronic back pain: a proof of concept randomized trial

Diane Reckziegel^{1,2}, Pascal Tetreault¹, Mariam Ghantous¹, Kenta Wakaizumi³, Bogdan Petre¹, Lejian Huang¹, Rami Jabakhanji^{1,2,3}, Taha Abdullah¹, Etienne Vachon-Pessau¹, Sara E Berger¹, Alexis Baria¹, James Griffith⁴, Marwan N Baliki^{2,3}, Thomas J Schnitzer^{2,5}, A Vania Apkarian^{1,2}

1. Physiology, Northwestern University, Chicago, United States

2. Center for Chronic Pain and Drug Abuse, Northwestern University, Chicago, United States

3. Shirley Ryan AbilityLab, Chicago, United States

4. Medical Social Sciences, Northwestern University, Chicago, United States

5. Physical Medicine and Rehabilitation, Northwestern, Chicago, United States

Preventing transition to chronic back pain (CBP) is an ideal strategy that would rescue patients from years to a lifetime of suffering with pain. Recent studies suggest involvement of sexually-dimorphic dopaminergic-motivational circuits in the transition to chronic pain (tCBP), and hints the combination of carbidopa/levodopa and naproxen (LDP+NPX) may block tCBP. We tested these concepts in early onset BP, who were stratified by risk for tCBP using brain properties. Those identified as low-risk entered a no-treatment arm. The rest were randomized into a double-blind, placebo and naproxen (PLC+NPX) controlled trial of oral LDP+NPX for 12 weeks, and a post-treatment 12-weeks follow-up. 59 participants completed the study. Both treatments resulted in 50% pain relief for 75%, sustained post-treatment. LDP+NPX was highly effective in females (>80% pain relief), it modified BP personality, and was related to objective brain functional changes. Although performed in a small group of early onset BP, multiple subjective and objective measures consistently suggest that these long-duration treatments persistently, and gender-dependently, block tCBP.

Acknowledgements

The study was funded by National Institute of Dental and Craniofacial Research (Blue Print grant number R01DE022746) and in part by National Institute on Drug Abuse (P50 DA044121).

References

- 1 Baliki, M.N., et al. Corticostriatal functional connectivity predicts transition to chronic back pain. *Nat Neurosci* 15, 1117-1119 (2012) [10.1038/nn.3153](https://doi.org/10.1038/nn.3153)
- 2 Mansour, A.R., et al. Brain white matter structural properties predict transition to chronic pain. *Pain* 154, 2160-2168 (2013) [10.1016/j.pain.2013.06.044](https://doi.org/10.1016/j.pain.2013.06.044)
- 3 Ren, W., et al. The indirect pathway of the nucleus accumbens shell amplifies neuropathic pain. *Nat Neurosci* 19, 220-222 (2016) [10.1038/nn.4199](https://doi.org/10.1038/nn.4199)
- 4 Reckziegel, Diane, et al. Deconstructing biomarkers for chronic pain: context-and hypothesis-dependent biomarker types in relation to chronic pain. *Pain* 160, S37-S48 (2019) [10.1097/j.pain.0000000000001529](https://doi.org/10.1097/j.pain.0000000000001529)

©(2019) Reckziegel D, Tetreault P, Ghantous M, Wakaizumi K, Petre B, Huang L, Jabakhanji R, Abdullah T, Vachon-Pessau E, Berger SE, Baria A, Griffith J, Baliki MN, Schnitzer TJ, Apkarian AV

Cite as: Reckziegel D, Tetreault P, Ghantous M, Wakaizumi K, Petre B, Huang L, Jabakhanji R, Abdullah T, Vachon-Pessau E, Berger SE, Baria A, Griffith J, Baliki MN, Schnitzer TJ, Apkarian AV (2019) Gender dependent pharmacotherapy for blocking transition to chronic back pain: a proof of concept randomized trial. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0144](https://doi.org/10.12751/nncn.bc2019.0144)

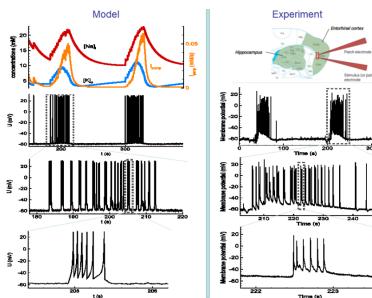
[W 128] **Interictal and ictal discharge generation and propagation: modeling and experiments**

Anton V Chizhov^{1,2}, Dmitry V Amakhin², Aleksey V Zaitsev²

1. Computational Physics Laboratory, Ioffe Institute, Polytekhnicheskaya str. 26, 194021, Saint-Petersburg, Russia

2. Laboratory of Molecular Mechanisms of Neuronal Interactions, Institute of Evolutionary Physiology and Biochemistry of RAS, Torez pr. 44, 194223, Saint-Petersburg, Russia

Generation of interictal (IID) and ictal discharges (ID) is determined by neuronal interactions and ionic dynamics. With our full and reduced mathematical models we have reproduced a spontaneous activity observed in on a certain experimental model of epilepsy (combined hippocampal-entorhinal cortex slices of rat in high potassium, low magnesium solution containing 4-AP). Separate AMPA, NMDA and GABA_A conductances were evaluated for different types of IIDs, using an original experimental technique [1]. The conductances has shown that the first type of the discharges (IID1) is determined by activity of only GABA_A channels with a depolarized reversal potential. The second type (IID2) is determined by the early GABA_A followed by AMPA and NMDA components. Our biophysically detailed mathematical model of interacting neuronal populations reproduces the recorded synaptic currents and conductances [2]. The main role in the generation of IID1 and IID2 is played by the synchronization of interneurons, and the main factor that determines the duration of the discharges is the synaptic depression. IIDs occur spontaneously and propagate as waves with a speed of about a few tens of mm/s [3]. IDs are clusters of IID-like discharges. Dynamics of IDs is determined by the dynamics of ionic concentrations. A reduced, minimal mathematical model "Epileptor-2" has been proposed, which reproduces both IDs and IIDs [4] and is formulated in terms of physically meaningful variables: extracellular potassium and intracellular sodium concentrations, a mean membrane potential and a short-term depressing synaptic resource. In silico an in vitro, IIDs are bursts of spikes, whereas IDs represent clusters of spike bursts (Fig. 1). Potassium accumulation governs the transition from the silent state to IDs. The sodium accumulates during an ID and activates the sodium-potassium pump, which terminates the ID by restoring the potassium gradient and thus repolarizing the neurons. Mathematical analysis reveals that IID-like bursts are spontaneous large-amplitude oscillations, which may cluster in an ID after a saddle-node-on-invariant-circle-like bifurcation in our non-smooth dynamical system. The clustering is controlled by slow oscillations of ionic concentrations. Consistency of the proposed models with experiments confirms the correctness of the revealed mechanisms of generation of epileptic discharges.



Minimal model Epileptor-2 reproduces ictal events observed in slices. Intracellular sodium and extracellular potassium concentrations and membrane potential of a representative neuron are shown.

Acknowledgements

This work was supported by the Russian Science Foundation (project 16-15-10201).

References

- Amakhan DV, Ergina JL, Chizhov AV, Zaitsev AV. Synaptic conductances during interictal discharges in pyramidal neurons of rat entorhinal cortex. *Front. In Cell. Neurosci.* 10:233, 2016 DOI: [10.3389/fncel.2016.00233](https://doi.org/10.3389/fncel.2016.00233)
- Chizhov A, Amakhan D, Zaitsev A. Computational model of interictal discharges triggered by interneurons. *PLoS ONE* 12(10):e0185752, 2017 [10.1371/journal.pone.0185752](https://doi.org/10.1371/journal.pone.0185752)
- Chizhov AV, Amakhan DV, Zaitsev AV. Spatial propagation of interictal discharges along the cortex. *Biochem Biophys Res Commun.* 508(4):1245-1251, 2019 [10.1016/j.bbrc.2018.12.070](https://doi.org/10.1016/j.bbrc.2018.12.070)
- Chizhov AV, Zefirov AV, Amakhan DV, Smirnova EV, Zaitsev AV. Minimal model of interictal and ictal discharges "Epileptor-2". *PLoS Comp. Biol.* 14(5): e1006186, 2018 [10.1371/journal.pcbi.1006186](https://doi.org/10.1371/journal.pcbi.1006186)

©(2019) Chizhov AV, Amakhan DV, Zaitsev AV

Cite as: Chizhov AV, Amakhan DV, Zaitsev AV (2019) Interictal and ictal discharge generation and propagation: modeling and experiments. *Bernstein Conference 2019 Abstract.* doi: [10.12751/nncn.bc2019.0145](https://doi.org/10.12751/nncn.bc2019.0145)

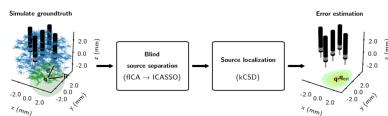
[W 129] Localization of coherent activity based on multi-electrode local field potentials

Robin Pauli¹, Abigail Morrison^{1,2,3}, Tom Tetzlaff¹

- Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA Institute Brain Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany*
- Simulation Laboratory Neuroscience – Bernstein Facility Simulation and Database Technology, Institute for Advanced Simulation, Jülich Research Centre, Jülich, Germany*
- Institute of Cognitive Neuroscience, Faculty of Psychology, Ruhr University Bochum, Bochum, Germany*

Deep brain stimulation (DBS) of the subthalamic nucleus (STN) is an established method for the suppression of motor deficits in Parkinson's disease. The efficacy and the extent of side effects of DBS depend critically on the positioning of the stimulation electrode. In particular with the increased use of directional DBS, it is becoming more difficult to find optimal stimulation parameters. A major challenge during the positioning of DBS electrodes is the detection of hotspots associated with the generation of pathological coherent activity. Here, we develop and test a method aiming at localizing confined regions of coherent activity based on the local field potential (LFP) recorded with multiple electrodes (see figure). Our approach involves two steps, the

identification of coherent sources by independent-component analysis of the multi-channel recordings in Fourier space, and the localization of identified sources by means of current-source-density analysis. We benchmark this technique for a range of source sizes and source-electrode distances based on synthetic ground-truth data generated by multicompartment models of STN neurons with realistic morphology. In this framework, we show that the spatio-temporal structure of the LFP recorded with multiple electrodes can be exploited to achieve a localization precision exceeding the spatial resolution of the electrode configuration. The proposed method permits a continuous tracking of source positions and may therefore provide a tool to study the spatio-temporal organization of pathological activity in STN. Moreover, it could serve as an intra-operative guide for the positioning of DBS electrodes and thereby improve and speed up the implantation process and the adjustment of stimulus parameters.



Sketch of setup and method chain.

Acknowledgements

Funded by the Initiative and Networking Fund of the Helmholtz Association, the German Research Foundation (DFG; grants DI 1721/3-1 [KFO219-TP09]) and the European Union's Horizon 2020 Framework Programme for Research and Innovation under Specific Grant Agreement No. 720270, 785907 (Human Brain Projec

©(2019) Pauli R, Morrison A, Tetzlaff T

Cite as: Pauli R, Morrison A, Tetzlaff T (2019) Localization of coherent activity based on multi-electrode local field potentials. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0146](https://doi.org/10.12751/nncn.bc2019.0146)

[W 130] Modular organisation of individual cortical morphological networks in dementia

Philipp Loske¹, Alison Murray¹, Claude Wischik^{2,3}, Vesna Vuksanovic¹

1. *1Aberdeen Biomedical Imaging Centre, University of Aberdeen, Aberdeen, UK*

2. *School of Medicine and Dentistry, University of Aberdeen, Aberdeen, UK*

3. *TauRx, Therapeutics, Aberdeen, UK*

Introduction: We present a study on a novel method for the extraction of individual cortical morphological networks in two types of dementia, Alzheimer's disease (AD) and behavioural variant FrontoTemporal Dementia (bvFTD). Morphological networks extracted from structural Magnetic Resonance Images (MRIs) have been useful in investigating patterns of co-atrophy in patients with dementia. However, these networks were analysed only at the group level. The aim of this study was to (i) extract individual morphological network from structural MRIs, (ii) analyse the modular structure of these networks and (iii) compare the results with group-level analysis.

Methodology: We used the baseline (at the study entry) MRI data from a large population of patients with AD ($N = 1614$) and bvFTD ($N = 215$) available from clinical trials (TRx-237-005, TRx-237-007 and TRx-237-015). The networks were constructed on pair-wise correlations of morphological properties (Cortical Volume, Surface Area, Mean and Standard Deviation of Cortical Thickness, Gaussian, Mean and Intrinsic Curvature

and Folded Index) on 68 cortical regions of the Desikan-Killiany Atlas, implemented in FreeSurfer v5.3.0.

Findings and Conclusion: This study is first to show individual morphometric-similarity networks in patients with dementia. We have shown that the individual networks have an underlying modular organisation, i.e., constitute of sub-unites with a higher correlation strength within than between the units. Our results confirm previous findings on morphometric similarity networks at group level analysis. These sub-units may provide a basis for assisting in the monitoring of progression of neurodegeneration in dementia and differentiation between the two types of dementia.

Acknowledgements

We would like to acknowledge the support of the Maxwell compute cluster funded by University of Aberdeen. We gratefully acknowledge study investigators and the generosity of study participants. P. Loskes PhD studentship is founded by Medical Research Scotland and TauRx joint grant (RG14565/RG14884).

References

1. Vuksanović, RT Staff, T. Ahearn, AD Murray and CM Wischik, Cortical thickness and surface area networks in healthy aging, Alzheimer's disease and behavioural variant frontotemporal dementia, International Journal of Neural Systems, 2018 [10.1142/S0129065718500557](https://doi.org/10.1142/S0129065718500557)
2. W. Li, C. Yang, F. Shi, S. Wu, Q. Wang, Y. Nie, and X. Zhang, Construction of individual morphological brain networks with multiple morphometric features, Frontiers in Neuroanatomy, 2017 [10.3389/fnana.2017.00034](https://doi.org/10.3389/fnana.2017.00034)
3. J. Seidlitz, F. Váša, M. Shinn, R. Romero-Garcia, K. J. Whitaker, P. E. Vértes, K. Wagstyl, P. K. Reardon, et al., Morphometric similarity networks detect microscale cortical organization and predict inter-individual cognitive variation, Neuron, 2018 [10.1016/j.neuron.2017.11.039](https://doi.org/10.1016/j.neuron.2017.11.039)
4. M. Rubinov, O. Sporns, Weight-conserving characterization of complex functional brain networks, NeuroImage, 2011 [10.1016/j.neuroimage.2011.03.069](https://doi.org/10.1016/j.neuroimage.2011.03.069)

©(2019) Loske P, Murray A, Wischik C, Vuksanovic V

Cite as: Loske P, Murray A, Wischik C, Vuksanovic V (2019) Modular organisation of individual cortical morphological networks in dementia. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0147](https://doi.org/10.12751/nncn.bc2019.0147)

[W 131] NMDA-Receptor Dysfunction Disrupts Serial Biases in Spatial Working Memory

Heike Stein¹, Joao Barbosa¹, Josep Dalmau², Albert Compte¹

1. Theoretical Neurobiology, IDIBAPS, Carrer Rosselló 149-151, Spain

2. Neuroimmunology, IDIBAPS, Carrer Rosselló 149-151, Spain

In working memory (WM) tasks, attractive biases to previous items are evidence for continuous temporal integration of memories. These serial biases have been modeled as a product of synaptic short-term plasticity, allowing WM representations to endure in a synaptic trace and interfere with the next trial even when neural activity returns to baseline values. We hypothesized that the NMDAR, a key component of both short-term potentiation (STP) and stable WM delay activity, would be of central importance to serial biases in a visuospatial WM task. Confirming this hypothesis, we found drastically reduced biases in patients with anti-NMDAR encephalitis and schizophrenia, both diseases that have been related to NMDAR hypofunction. We simulated serial biases in a spiking neural network supported by a Hebbian STP mechanism that builds up during persistent delay-activity. We found a close correspondence between patient and model behavior when gradually lowering levels of STP, suggesting a disruption of short-term plasticity in associative cortices of schizophrenic and anti-NMDAR encephalitis patients. Further, we explored the capability of the model to explain reduced biases in light of the disinhibition theory of schizophrenia.

Acknowledgements

Institute Carlos III (PIE 16/00014), Cellex Foundation, Spanish Ministry of Science (BFU 2015-65318-R, RTI2018-094190-B-100), European Regional Development Fund, Generalitat de Catalunya (AGAUR 2017 SGR 1565), "la Caixa" (LCF/BQ/IN17/11620008), EU Horizon 2020 Marie Skłodowska-Curie grant (713673)

©(2019) Stein H, Barbosa J, Dalmau J, Compte A

Cite as: Stein H, Barbosa J, Dalmau J, Compte A (2019) NMDA-Receptor Dysfunction Disrupts Serial Biases in Spatial Working Memory. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0148](https://doi.org/10.12751/nncn.bc2019.0148)

[W 132] Prediction of Psychotic Delusions using Multisite Resting State Functional Connectivity Data from BSNIP1 Study

Victoria T Okuneye¹, Brett Clementz², Matcheri S Keshavan³, Carol A Tamminga⁴, John A Sweeney⁵, Elliot S Gershon¹, Godfrey D Pearlson⁶, Sarah K Keedy¹

1. The University of Chicago, Chicago, IL, U.S.A.

2. University of Georgia, Athens, GA, U.S.A.

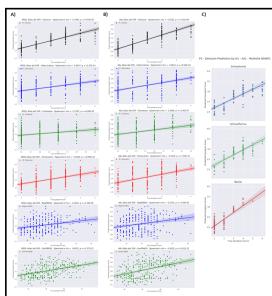
3. Harvard University, Boston, MA, U.S.A.

4. University of Texas Southwestern Medical Center, Dallas, TX, U.S.A.

5. University of Cincinnati, Cincinnati, OH, U.S.A.

6. Yale University, New Haven, CT, U.S.A.

Delusions, false beliefs held despite disconfirming evidence, are a highly distressing and common feature of psychotic disorders. Currently, there exists no robust biomarker for delusions and its neurobiology remains poorly understood. Recent smaller fMRI studies have identified neurocorrelates of delusions such as brain function in regions involved in prediction error processing and hubs of the salience and default mode networks^{3,6,7}. These functional brain networks could therefore be useful biomarkers of delusion severity⁵. Here, we use multivariate machine learning to test this using resting state (rs)fMRI connectivity in a large multisite-sample of psychotic subjects. RS-fMRI data was obtained from 94 schizophrenic, 94 schizoaffective, and 94 bipolar with psychosis subjects recruited as part of the multisite Bipolar & Schizophrenia Network on Intermediate Phenotypes (BSNIP1) study¹¹. Preprocessed¹² resting state brains were parcellated with either the AAL 116 regions neuroanatomical atlas¹⁰ or MSDL brain network atlas¹⁴. Support Vector Regression (SVR) algorithms were parameter optimized and trained on rs-fMRI partial correlation matrices^{2,8}. Delusion severity (relevant PANSS⁴ items) was predicted using 5-fold cross validation⁹. Relative prediction performance was examined in other PANSS symptom domains. Highest delusion prediction performance (spearman's rho=0.82, p<.001) was obtained with the AAL atlas using a non-linear SVR classifier. Important trends can be observed in the relative performance of classifiers. Cross prediction to other PANSS domain were significant but reduced for other positive/general symptoms and weaker for negative symptoms. Similar performance was seen between diagnostic groups, with slight increased performance for bipolar subjects. Prediction performance was also similar between functional and structural brain atlases. These results provide tentative support for brain connectivity dependent association with delusion symptoms shared across diagnoses, which may be shared further in specific psychosis symptoms. Future work should seek to further validate these results and examine the relative importance and multivariate interactions of various brain networks to delusion prediction. Furthermore, alternative factors should be explored such as preprocessing, brain parcellation and additional features which may play significant roles to further increase classifier performance¹³.



- a) MSDL atlas based SVR Prediction Performance for PANSS delusions, hallucinations, grandiosity, persecution, negative total, and general total. b) AAL atlas SVR Prediction Performance in same PANSS symptom domains c) Delusion SVR Prediction Performance across Diagnoses for AAL atlas

Acknowledgements

This work is supported by the NIH/NIMH grants MH077851, MH077945, MH078113, MH077852, MH0778623, MH103368-03S2 , the University of Chicago MSTP NIH/NIGMS T32 GM007281, and the work of the tireless BSNIP team.

References

- 1 Abraham, A., Milham, M. P., Di Martino, A., Craddock, R. C., Samaras, D., Thirion, B., & Varoquaux, G. (2017). Deriving reproducible biomarkers from multi-site resting-state data: An Autism-based example. *NeuroImage*, 147, 736-745.
- 2 Abraham, A., Milham, M. P., Di Martino, A., Craddock, R. C., Samaras, D., Thirion, B., & Varoquaux, G. (2017). Deriving reproducible biomarkers from multi-site resting-state data: An Autism-based example. *NeuroImage*, 147, 736-745.
- 3 Corlett, P. R., & Fletcher, P. C. (2012). The neurobiology of schizophrenia: fronto-striatal prediction error signal correlates with delusion-like beliefs in healthy people. *Neuropsychologia*, 50(14), 3612-3620.
- 4 Kay, S. R., Fiszbein, A., & Opfer, L. A. (1987). The positive and negative syndrome scale (PANSS) for schizophrenia. *Schizophrenia bulletin*, 13(2), 261.
- 5 Kambeitz, J., Kambeitz-Ilankovic, L., Leucht, S., Wood, S., Davatzikos, C., Malchow, B., ... & Koutsouleris, N. (2015). Detecting neuroimaging biomarkers for schizophrenia: a meta-analysis of multivariate pattern recognition studies. *Neuropsychopharmacology*, 40(7), 1742.
- 6 Li, T., Wang, Q., Zhang, J., Rolls, E. T., Yang, W., Palaniyappan, L., ... & Gong, X. (2017). Brain-wide analysis of functional connectivity in first-episode and chronic stages of schizophrenia. *Schizophrenia bulletin*, 43(2), 436-448.
- 7 Orlac, F., Naveau, M., Joliot, M., Delcroix, N., Razafimandimbry, A., Braze, P., ... & Delamillieure, P. (2013). Links among resting-state default-mode network, salience network, and symptomatology in schizophrenia. *Schizophrenia research*, 148(1-3), 74-80.
- 8 Orru, G., Pettersson-Yeo, W., Marquand, A. F., Sartori, G., & Mechelli, A. (2012). Using support vector machine to identify imaging biomarkers of neurological and psychiatric disease: a critical review. *Neuroscience & Biobehavioral Reviews*, 36(4), 1140-1152.
- 9 Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., ... & Vanderplas, J. (2011). Scikit-learn: Machine learning in Python. *Journal of machine learning research*, 12(Oct), 2825-2830.
- 10 Rolls, E. T., Joliot, M., & Tzourio-Mazoyer, N. (2015). Implementation of a new parcellation of the orbitofrontal cortex in the automated anatomical labeling atlas. *NeuroImage*, 122, 1-5.
- 11 Tamminga, C. A., Pearson, G., Keshavan, M., Sweeney, J., Clementz, B., & Thaker, G. (2014). Bipolar and schizophrenia network for intermediate phenotypes: outcomes across the psychosis continuum. *Schizophrenia bulletin*, 40(Suppl_2), S131-S137.
- 12 Whitfield-Gabrieli, S., & Nieto-Castanon, A. (2012). Conn: a functional connectivity toolbox for correlated and anticorrelated brain networks. *Brain connectivity*, 2(3), 125-141.
- 13 Varoquaux, G., & Craddock, R. C. (2013). Learning and comparing functional connectomes across subjects. *NeuroImage*, 80, 405-415.
- 14 Varoquaux, G., Gramfort, A., Pedregosa, F., Michel, V., & Thirion, B. (2011, July). Multi-subject dictionary learning to segment an atlas of brain spontaneous activity. In *Biennial International Conference on Information Processing in Medical Imaging* (pp. 562-573). Springer, Berlin, Heidelberg.

©(2019) Okuneye VT, Clementz B, Keshavan MS, Tamminga CA, Sweeney JA, Gershon ES, Pearson GD, Keedy SK

Cite as: Okuneye VT, Clementz B, Keshavan MS, Tamminga CA, Sweeney JA, Gershon ES, Pearson GD, Keedy SK (2019) Prediction of Psychotic Delusions using Multisite Resting State Functional Connectivity Data from BSNIP1 Study. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0149](https://doi.org/10.12751/nncn.bc2019.0149)

Posters Thursday

Learning, plasticity and memory

[T 1] A biophysical network model of the CA3 region of the hippocampus: from *in vitro* calcium imaging to learning in silico.

Ruth Betterton¹, Wyngaard Aurelien², Christophe Mulle¹

1. Institute Interdisciplinaire de Neurosciences, Universite de Bordeaux, France

2. Universite de Toulouse, France

The CA3 region of the hippocampus is involved in the rapid encoding of spatial, episodic and contextual memory (Rebola et al., 2017). A unique feature of the CA3 network is the presence of recurrent excitatory cell connectivity. It is thought that this auto-associative circuitry allows the CA3 to act as an attractor network for the storage of memories. *In vivo* and *ex vivo* studies in rodents have suggested that the presence of rapidly potentiated micro-networks of neurons or 'ensembles' are key to the encoding of new information (Leutgeb et al., 2007). Studies using electrophysiological methods to map connectivity have added great detail to our knowledge of the network structure but are extremely labour intensive and therefore low throughput (Guzman et al., 2016).

To circumvent the limitations of a purely electrophysiological investigation of the CA3 network structure and function, we have combined computational modelling with *in vitro* imaging. Inspired by an existing model of CA1 (Cutsuridis et al., 2010) we have built a biophysical network model of CA3 with inputs from entorhinal cortex, dentate gyrus (DG) and medial septum and outputs to CA1. The model replicates many properties of the network seen *in vivo* and *in vitro* such as action potential firing of both pyramidal cells and interneurons, sparse and bursting inputs from DG, high frequency interneuron activity, and lower frequency CA3 pyramidal cell activity. To inform the structure of the network in addition to using pre-existing literature, we have carried out 2-photon calcium imaging in acute hippocampal slices to assess the population activity of CA3 pyramidal cells (up to 38 spontaneously active cells in single slice). We find that a proportion of the cells are co-active and could therefore be considered as an ensemble. Finally, we investigate the effects of a variety of learning rules on the network and ensemble activity such as a symmetrical STDP rule (Mishra et al., 2016) and DG to CA3 short-term facilitation.

References

- 1 Rebola, Carta and Mulle. Nat Rev: Neurosci. 17(4):208-220 (2017) [10.1038/nrn.2017.10](https://doi.org/10.1038/nrn.2017.10)
- 2 Leutgeb, Leutgeb, Treves, Moser and Moser. Science. 305:1295-1298 (2004) [10.1126/science.1100265](https://doi.org/10.1126/science.1100265)
- 3 Guzman, Schloegl, Jonas. Science 353(6304):1117-1123 (2016) [10.1126/science.aaf1836](https://doi.org/10.1126/science.aaf1836)
- 4 Cutsuridis, Cobb and Graham. Hippocampus 230:423-446 (2010) [10.1002/hipo.20661](https://doi.org/10.1002/hipo.20661)
- 5 Mishra, Kim, Guzman, Jonas. Nature comms. 7(11552):1-11 (2016) [10.1038/ncomms11552](https://doi.org/10.1038/ncomms11552)

©(2019) Betterton R, Aurelien W, Mulle C

Cite as: Betterton R, Aurelien W, Mulle C (2019) A biophysical network model of the CA3 region of the hippocampus: from *in vitro* calcium imaging to learning in silico.. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0150](https://doi.org/10.12751/nncn.bc2019.0150)

[T 2] Abrupt transitions of response patterns emerging from gradual changes in connectivity

Bastian Eppler¹, Dominik Aschauer², Simon Rumpel², Matthias Kaschube¹

1. Frankfurt Institute for Advanced Studies, Goethe University, Frankfurt, Germany

2. Focus Program Translational Neurosciences, Gutenberg University, Mainz, Germany

Recent experimental studies show substantial synaptic volatility in mammalian neocortex even in the absence of an explicit learning paradigm (e.g. [1]). Currently, it is unclear to what extent such ongoing synaptic changes affect neuronal representations of sensory stimuli. Here, we study a generic firing rate model consisting of randomly connected excitatory and inhibitory neurons and compare its predictions to chronic recordings of neural population activity in mouse auditory cortex. The model is tuned to reproduce key characteristics of neuronal activity patterns in auditory cortex, including, sparse activity with a broad distribution of firing rates and a clustering of stimulus responses into a near discrete set of response modes [2]. We use this model to assess the effects of ongoing gradual synaptic changes, which we assume follows a random multiplicative stochastic process previously fitted to experimental data [1]. We find that gradual changes in synaptic strength result in periods of stable responses interrupted by abrupt transitions towards new response patterns, often affecting a large fraction of stimuli simultaneously. Moreover, intermittent, transient phases of almost complete recovery of the initial response state occur. The rate of change of correlation to the initial response state is broadly distributed both for increases and decreases in correlation. We conclude that synaptic volatility can affect sensory representations in a highly nonlinear fashion, with abrupt transitions broadly distributed in magnitude.

References

1 Loewenstein et al., J. Neurosci. 2011; 31(26):9481-9488

2 Bathellier et al., Neuron 2012; 76, 435-449

©(2019) Eppler B, Aschauer D, Rumpel S, Kaschube M

Cite as: Eppler B, Aschauer D, Rumpel S, Kaschube M (2019) Abrupt transitions of response patterns emerging from gradual changes in connectivity. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0151](https://doi.org/10.12751/nncn.bc2019.0151)

[T 3] A computational model to reproduce memory processing and update in *Drosophila melanogaster*

Magdalena Anna Springer¹, Johannes Felsenberg², Martin Paul Nawrot¹

1. Computational Systems Neuroscience, Institute of Zoology, University of Cologne, Cologne, Germany

2. Friedrich Miescher Institute for Biomedical Research, Basel, Switzerland

D. melanogaster, commonly known as the fruit fly, can learn to associate a stimulus with a positive or negative reinforcement to steer its future behavior [1]. However, when learned information turns out to be incorrect, the underlying memory needs to be updated. Many animals, including *D. melanogaster*, have the ability to collect and integrate contradictory information in a process called extinction learning [2,3,4,5]. Examination of the underlying mechanisms has clinical relevance with regard to the treatment of anxiety disorders [6].

Insight from experimental research on *D. melanogaster* suggests that after memory extinction two parallel but opposing memory traces coexist at different sites within the mushroom body (MB) [4]. To validate this hypothesis, we designed and investigated a simple connectionist model (based on [7]) integrating the fly's olfactory and reinforcement pathway. The multi-layered model employs plastic synaptic connections in separate appetitive and aversive learning pathways [8]. We subjected our model to a learning protocol, in which an odor (CS+) was paired with a punishment or a reward. In the following test phase this odor was presented alone to measure the conditioned response (CR). In the extinction protocol, a second training phase, in which the previously conditioned odor was presented without reinforcement, was included.

After initial absolute conditioning the model showed an CR for the CS+ odor test. However, reactivation during the second training phase resulted in a significant suppression of this memory. To test whether two separate memory traces are formed in the model, we compared the total synaptic drive received by specific MB neurons in response to stimulation with CS+ and CS- odors during different experimental phases. There was a significant decrease in the CS+ evoked activation in the approach or avoidance directing MB neurons relative to the CS- evoked activation after the initial aversive or appetitive training, respectively. However, after the extinction training, there was an additional decrease in the CS+ response in the opposing MB neuron.

Thus our model is suitable to qualitatively and quantitatively reproduce recent behavioral and *in vivo* neurophysiological results in *D. melanogaster* [3,4]. The results support the hypothesis of a parallel memory trace that is counteracting the initial memory formed during extinction learning.

Acknowledgements

Supported by the German Research Foundation (grant no. 403329959) within the Research Unit DFG-FOR 2705, <https://www.uni-goettingen.de/de/601524.html>

References

- 1 Tully T, & Quinn WG (1985). Classical conditioning and retention in normal and mutant *Drosophila melanogaster*. *J Comp Physiol A Neuroethol Sens Neural Behav Physiol* 157, 263–277 [10.1007/BF01350033](https://doi.org/10.1007/BF01350033)
- 2 Bouton ME (2004) Context and behavioral processes in extinction. *Learn Mem* 11:485–494 [10.1101/lm.78804](https://doi.org/10.1101/lm.78804)
- 3 Felsenberg J, Barnstedt O, Cognigni P, Lin S, Waddell S (2017) Re-evaluation of learned information in *Drosophila*. *Nature* 544:240–244 [10.1038/nature21716](https://doi.org/10.1038/nature21716)
- 4 Felsenberg J, Jacob PF, Walker T, Barnstedt O, Edmondson-Stait AJ, Pleijzier MW, Otto N, Schlegel P, Sharifi N, Perisse E, Smith CS, Lauritzen JS, Costa M, Jeffries GSXE, Bock DD, Waddell S (2018) Integration of Parallel Opposing Memories Underlies Memory Extinction. *Cell* 175(3):709-722 [10.1016/j.cell.2018.08.021](https://doi.org/10.1016/j.cell.2018.08.021)
- 5 Felsenberg J & Owald D (2018) Making memories. *Neuroforum* 24:1–8 [10.1515/nf-2017-A048](https://doi.org/10.1515/nf-2017-A048)

- 6 Craske MG, Hermans D, Vervliet B (2018) State-of-the-art and future directions for extinction as a translational model for fear and anxiety. *Phil Trans R Soc B*, 373: 20170025 [10.1098/rstb.2017.0025](https://doi.org/10.1098/rstb.2017.0025).
- 7 Peng F & Chittka L (2017) A Simple Computational Model of the Bee Mushroom Body Can Explain Seemingly Complex Forms of Olfactory Learning and Memory. *Curr Biol* 27:224–230 [10.1016/j.cub.2016.10.054](https://doi.org/10.1016/j.cub.2016.10.054)
- 8 Owald D & Waddell S (2015). Olfactory learning skews mushroom body output pathways to steer behavioral choice in *Drosophila*. *Curr Opin Neurobiol* 35, 178–184 [10.1016/j.conb.2015.10.002](https://doi.org/10.1016/j.conb.2015.10.002)

©(2019) Springer MA, Felsenberg J, Nawrot MP

Cite as: Springer MA, Felsenberg J, Nawrot MP (2019) A computational model to reproduce memory processing and update in *Drosophila melanogaster*. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0152](https://doi.org/10.12751/nncn.bc2019.0152)

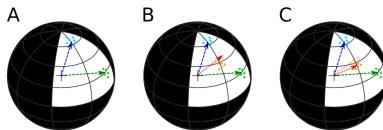
[T 4] Adult dentate gyrus neurogenesis: From cellular properties to pattern separation

Olivia Gozel¹, Wulfram Gerstner^{1,2}

1. Life Sciences, EPFL, EPFL-LCN; AAB 135 (Bâtiment AAB); Station 15; CH-1015 Lausanne, Switzerland

2. Computer and Communication Sciences, EPFL, EPFL-LCN; AAB 135 (Bâtiment AAB); Station 15; CH-1015 Lausanne, Switzerland

Adult neurogenesis of dentate granule cells (DGcs) only concerns a small percentage of the dentate gyrus (DG) principal cells population, and yet it has been shown to strikingly promote behavioral pattern separation of similar stimuli in a variety of tasks. The properties of newborn DGcs evolve as a function of maturation. Ultimately, only the ones that are well integrated into the DG survive, a process which has been observed to critically depend on GABAergic input. In the early maturation phase of newborn DGcs, the GABAergic input they receive has an excitatory effect, and it becomes inhibitory in the late phase of their maturation. It is still unknown, however, why the switch from excitation to inhibition in adult DG neurogenesis is crucial for proper integration. The main input to DG comes from the entorhinal cortex (EC), and mature DGcs receive recurrent inhibitory connections. We thus model the EC-to-DGcs circuit as an input layer (EC) fully feedforwardly connected to a winner-take-all (WTA) network that represents DG. The feedforward connections from EC to DGcs are plastic, and follow a biologically plausible learning rule with heterosynaptic plasticity to avoid runaway dynamics of the weights. We consider normalized stimuli organized in several clusters. Initially, we pretrain a few clusters in the WTA network (the blue and green clusters, see Fig. 1A). Then, we introduce newborn DGcs which have zero-weight connections with EC and mature in two phases. Stimuli coming from a novel cluster (red) are presented intermingled with stimuli from previously stored clusters (blue and green) as newborn DGcs learn their feedforward weights. We suggest that adult DG neurogenesis provides a biological solution to the problem of dead units, which is a common issue in competitive unsupervised learning. Indeed, in the early phase of maturation, GABAergic input is excitatory. Hence, cooperativity makes the EC connections towards newborn DGcs (red arrow) grow in the direction of the subspace of previously presented stimuli (Fig. 1B). When GABAergic input switches to inhibitory in the late phase of maturation, the DG network becomes competitive. Thus the feedforward weights towards newborn DGcs are driven away from previously stored clusters and towards the novel cluster (Fig. 1C). To our knowledge, we present the first model that can explain both how adult newborn DGcs integrate into the preexisting network and why they promote pattern separation of similar stimuli.



Schematics of the hypersphere surface that contains the clusters of patterns (colored dots) and the feedforward weight vectors towards the output units (colored arrows, pointing slightly below the surface).

Acknowledgements

Supported by EU-H2020 nr. 720270 and 785907 [HBP SGA 1 and SGA 2]

References

- 1 J Hertz, A Krogh, and R G Palmer. Introduction to the Theory of Neural Computation. Addison- Wesley, 1991 [10.1063/1.2810360](https://doi.org/10.1063/1.2810360)
- 2 Shaoyu Ge, Eyleen LK Goh, Kurt A Sailor, Yasuji Kitabatake, Guo-li Ming, and Hongjun Song. Gaba regulates synaptic integration of newly generated neurons in the adult brain. *Nature*, 439(7076):589–593, 2006 [10.1038/nature04404](https://doi.org/10.1038/nature04404)

©(2019) Gozel O, Gerstner W

Cite as: Gozel O, Gerstner W (2019) Adult dentate gyrus neurogenesis: From cellular properties to pattern separation. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0153](https://doi.org/10.12751/nncn.bc2019.0153)

[T 5] A model of AMPA-receptor dynamics to describe the different phases of early-phase synaptic plasticity

Moritz Becker¹, Christian Tetzlaff^{1,2}

1. *Computational Neuroscience, III. Institute of Physics – Biophysics, Georg-August University, Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany*
2. *Bernstein Center for Computational Neuroscience, Göttingen, Germany*

AMPA-receptors (AMPAR) in the postsynaptic density (PSD) mediate most of the excitatory synaptic transmission. Long-term potentiation and depression as well as synaptic scaling are linked to changes in their number, composition and properties [1]. Therefore, AMPAR dynamics play an important role for memory and learning. The exact mechanisms and dynamics underlying activity-dependent AMPAR-trafficking are however still largely unknown. In the current work, based on previous studies [2, 3], we developed and analyzed a theoretical multi-compartment model of AMPAR-trafficking in the synapse. We describe the receptor dynamics in each compartment as the PSD or extrasynaptic membrane by a specific set of differential equations. Furthermore, we included mechanisms such as receptor aggregation into nanodomains [4] and signaling pathway models to describe the activity dependence of specific model parameters. Our model is able to reproduce experimental findings [5] that relate potentiation and depression to AMPAR-trafficking and enables us to disentangle the different roles of AMPAR exocytosis [6], diffusion [7] and scaffold binding [8] at different points of time. Thus, our study indicates that AMPAR-trafficking is involved in different phases of synaptic plasticity, where several trafficking mechanisms act on different time scales. In summary, we have developed a compact theoretical model that enables to understand the relationships between processes of synaptic plasticity such as LTP and the underlying AMPAR-dynamics. Based on these results, next, we are able to investigate the link between AMPAR-trafficking and further complex synaptic plasticity processes as homeostatic plasticity [9].

References

- 1 J. M. Henley, E. A. Barker and O. O. Glebov, "Routes, destinations and delays recent advances in AMPA receptor trafficking", Trends in Neurosciences, vol. 34 , pp. 258–268, 2011 [10.1016/j.tins.2011.02.004](https://doi.org/10.1016/j.tins.2011.02.004)
- 2 B. A. Earnshaw and P. C. Bressloff, "Biophysical Model of AMPA Receptor Trafficking and Its Regulation during Long-Term Potentiation/Long-Term Depression", Journal of Neuroscience, vol. 26 , pp. 12362–12373, 2006 [10.1523/JNEUROSCI.3601-06.2006](https://doi.org/10.1523/JNEUROSCI.3601-06.2006)
- 3 K. Czöndör et al., "Unified quantitative model of AMPA receptor trafficking at synapses", Proceedings of the National Academy of Sciences, vol. 109 , pp. 3522–3527, 2012 [10.1073/pnas.1109818109](https://doi.org/10.1073/pnas.1109818109)
- 4 D. Nair et al., "Super-Resolution Imaging Reveals That AMPA Receptors Inside Synapses Are Dynamically Organized in Nanodomains Regulated by PSD95", Journal of Neuroscience, vol. 33 , pp. 13204–13224, 2013 [10.1523/JNEUROSCI.2381-12.2013](https://doi.org/10.1523/JNEUROSCI.2381-12.2013)
- 5 A. C. Penn et al., "Hippocampal LTP and contextual learning require surface diffusion of AMPA receptors", Nature, vol. 549 , pp. 384–388, 2017 [10.1038/nature23658](https://doi.org/10.1038/nature23658)
- 6 M. A. Patterson, E. M. Szatmari and R. Yasuda, "AMPA receptors are exocytosed in stimulated spines and adjacent dendrites in a Ras-ERK-dependent manner during long-term potentiation", Proc. of the National Ac. of Sciences, vol. 107 , pp. 15951–15956, 2010 [10.1073/pnas.0913875107](https://doi.org/10.1073/pnas.0913875107)
- 7 C. Tardin, L. Cognet, C Bats, B. Lounis, D. Choquet, "Direct imaging of lateral movements of AMPA receptors inside synapses", The EMBO Journal, vol. 22 , pp. 4656–4665, 2003 [10.1093/emboj/cdg463](https://doi.org/10.1093/emboj/cdg463)
- 8 P. Opazo and M. Sainlos and D. Choquet, "Regulation of AMPA receptor surface diffusion by PSD-95 slots", Current Opinion in Neurobiology, vol. 22 , pp. 453–460, 2012 [10.1016/j.conb.2011.10.010](https://doi.org/10.1016/j.conb.2011.10.010)
- 9 G. G. Turrigiano and S. B. Nelson, "Homeostatic plasticity in the developing nervous system", Nature Reviews Neuroscience, vol. 5 , pp. 97–107, 2004 [10.1038/nrn1327](https://doi.org/10.1038/nrn1327)

©(2019) Becker M, Tetzlaff C

Cite as: Becker M, Tetzlaff C (2019) A model of AMPA-receptor dynamics to describe the different phases of early-phase synaptic plasticity. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0154](https://doi.org/10.12751/nncn.bc2019.0154)

[T 6] Amplification of grid-cell activity in a recurrent network

Tiziano D'Albis¹, Richard Kempter^{1,2,3}

1. Biology, Humboldt-Universität zu Berlin, Berlin, Germany

2. Einstein Center for Neurosciences, Berlin, Germany

3. Bernstein Center for Computational Neuroscience, Berlin, Germany

Grid cells are neurons of the medial entorhinal cortex (MEC) that are tuned to the animal's position in space and whose firing fields form a periodic triangular pattern [1]. Since their discovery, grid cells are believed to support high-level cognitive processes, such as navigation and spatial memory. Yet it remains unclear how grid-cell activity is formed and how it is processed within the cortex [2].

Recent *in vitro* [3,4] and *in vivo* [5,6] studies suggests that MEC principal cells are embedded in recurrent excitatory circuits and that grid cells with similar properties (grid scale, orientation, and phase) are functionally coupled. Attractor models posit that such a recurrent connectivity generates grid patterns via path integration [7,8], but they fall short in explaining how grids are affected by sensory inputs and how the circuit develops in the first place.

Here, we propose a different view. We suggest that noisy grid patterns initially emerge in a feed-forward circuit via synaptic plasticity and sensory experience [9,10]. After rough grids are formed, cells with similar properties develop recurrent connections locally via a Hebbian mechanism. This recurrent connectivity could serve two purposes: amplify grid patterns when the sensory input is weak, and support path integration when the sensory input is absent.

To explore this hypothesis, we simulate the development of recurrent excitatory connections in a network of noisy grid cells. We then study how different input properties affect both the circuit development and the amplification of the output patterns. Finally,

we propose a minimal mathematical model where the recurrent amplification of grid-cell activity is analytically understood.

References

- 1 Hafting, T. et al. (2005). *Nature*, 436(7052), 801-806
- 2 Rowland, D. C. et al. (2016). *Annu. Rev. Neurosci.*, 39, 19-40
- 3 Fuchs, E. C. et al. (2016). *Neuron*, 89(1), 194-208
- 4 Winterer, J. et al. (2017). *Cell reports*, 19(6), 1110-1116
- 5 Trettel, S. G. et al. (2019). *Nat. Neurosci.*, 22(4), 609
- 6 Gardner, R. J. et al. (2019). *Nat. Neurosci.*, 22(4), 598
- 7 McNaughton, B. L. et al. (2006). *Nat. Rev. Neurosci.*, 7(8), 663
- 8 Burak, Y., & Fiete, I. R. (2009). *PLoS Comp. Bio.*, 5(2), e1000291
- 9 Kropff, E., & Treves, A. (2008). *Hippocampus*, 18(12), 1256-1269
- 10 D'Albis, T. & Kempter, R. (2017). *Plos Comp. Bio.*, e1005782

©(2019) D'Albis T, Kempter R

Cite as: D'Albis T, Kempter R (2019) Amplification of grid-cell activity in a recurrent network. *Bernstein Conference 2019*
Abstract. doi: [10.12751/nncn.bc2019.0155](https://doi.org/10.12751/nncn.bc2019.0155)

[T 7] An energy-based model of folded autoencoders for unsupervised learning in cortical hierarchies

Dominik Dold^{1,2}, João Sacramento³, Akos F. Kung^{1,2}, Walter Senn², Mihai A. Petrovici^{1,2}

1. Kirchhoff Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

2. Department of Physiology, University of Bern, Bühlpark 5, 3012 Bern, Switzerland

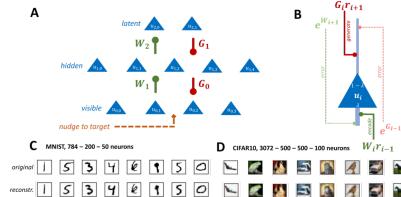
3. Institute of Neuroinformatics, University of Zurich / ETH Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

Recently, the problem of credit assignment in cortical networks has been addressed by several models suggesting a biologically plausible implementation of backprop [1], e.g., by drawing parallels to predictive coding [2] or proposing a circuit-level implementation using interneurons [3-5]. However, these models have so far been restricted to supervised learning.

Here, we propose an extension of these models to unsupervised learning by using a layer-wise recurrent network architecture with convex gating of the forward and backward information flow, controlled by λ . Similar to [2,4], the neurosynaptic dynamics are derived as gradient descent on an energy function composed of two squared error terms and a cost function, $E = \frac{\lambda}{2} \sum_i ||u_i - W_i r_{i-1}||^2 + \frac{1-\lambda}{2} \sum_i ||u_i - G_i r_{i+1}||^2 + \beta C$, where u_i and r_i are the membrane potentials and rates of neurons in layer i , W_i the discriminative weights (DW) projecting from layer $i-1$ to i , G_i the generative weights (GW) from layer $i+1$ to i and βC the cost function weighted by a scalar $\beta \geq 0$ (Fig. 1A). This way, we obtain standard leaky dynamics where forward and backward inputs are convexly combined at the soma (Fig. 1B). The resulting synaptic plasticity for W_i and G_i is driven by the dendritic prediction of somatic activity [6]. For small gating λ the plasticity rules for GW and DW, even though they are formally identical, perform different optimization tasks: the GW minimize a reconstruction error in the visible layer, whereas the DW learn to match the generative input entering the same layer.

Different from previous models [7-12], this network allows the simultaneous training of encoding (DW) and decoding (GW) weights in a deep folded autoencoder with a bottleneck in the highest layer (Fig. 1C,D). Both the encoding, decoding as well as

the error propagation for the plasticity of the generative weights is done via the same neurons simultaneously. In addition, the visible layer is not clamped during training but only nudged towards the correct activity. The model can be directly connected to the microcircuits proposed in [3,4] by having the generative weights and errors project to apical compartments, and forward ones to basal compartments of pyramidal neurons (Fig. 1B). Thus, the presented model proposes a biologically plausible implementation of efficient simultaneous discriminative and generative learning in cortical hierarchies.



(A) Sketch of network architecture. (B) Physiological implementation of derived dynamics. (C) Encoding and decoding of MNIST images. We first encode the image with gating 0.9 and decode with gating 0.1. During training, the gating is kept constant at 0.1. (D) Same as (C) but for CIFAR10.

Acknowledgements

This work has received funding from the Manfred Stärk Foundation and the European Union Horizon 2020 Framework Programme (grant agreement 720270,785907). Calculations were performed on UBELIX (University of Bern HPC) and bwHPC (state BaWü HPC, funded by the DFG through grant no INST 39/963-1 FUGG).

References

- Whittington, J. C., & Bogacz, R. (2019). Theories of error back-propagation in the brain. *Trends in cognitive sciences*.
- Whittington, J. C., & Bogacz, R. (2017). An approximation of the error backpropagation algorithm in a predictive coding network with local Hebbian synaptic plasticity. *Neural computation*, 29(5), 1229-1262.
- Sacramento, J., Costa, R. P., Bengio, Y., & Senn, W. (2018). Dendritic cortical microcircuits approximate the backpropagation algorithm. In *Advances in Neural Information Processing Systems* (pp. 8721-8732).
- Dold, D., Kungl, A. F., Sacramento, J., Petrovici, M. A., Schindler, K., Binas, J., Bengio, Y., & Senn, W. (2019). Lagrangian dynamics of dendritic microcircuits enables real-time backpropagation of errors. *Cosyne Abstracts 2019*, Lisbon, PT.
- Guerguiev, J., Lillicrap, T. P., & Richards, B. A. (2017). Towards deep learning with segregated dendrites. *ELife*, 6, e22901.
- Urbanczik, R., & Senn, W. (2014). Learning by the dendritic prediction of somatic spiking. *Neuron*, 81(3), 521-528.
- Oh, J. H., & Seung, H. S. (1998). Learning generative models with the up propagation algorithm. In *Advances in Neural Information Processing Systems* (pp. 605-611).
- Rao, R. P., & Ballard, D. H. (1999). Predictive coding in the visual cortex: a functional interpretation of some extra-classical receptive-field effects. *Nature neuroscience*, 2(1), 79.
- Seung, H. S. (1998). Learning continuous attractors in recurrent networks. In *Advances in neural information processing systems* (pp. 654-660).
- Wang, J., He, H., & Prokhorov, D. V. (2012). A folded neural network autoencoder for dimensionality reduction. *Procedia Computer Science*, 13, 120-127.
- Burbank, K. S. (2015). Mirrored STDP implements autoencoder learning in a network of spiking neurons. *PLoS computational biology*, 11(12), e1004566.
- Pontes-Filho, S., & Liwicki, M. (2018). Bidirectional Learning for Robust Neural Networks. *arXiv preprint arXiv:1805.08006*.

©(2019) Dold D, Sacramento J, Kungl AF, Senn W, Petrovici MA

Cite as: Dold D, Sacramento J, Kungl AF, Senn W, Petrovici MA (2019) An energy-based model of folded autoencoders for unsupervised learning in cortical hierarchies. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0156](https://doi.org/10.12751/nncn.bc2019.0156)

[T 8] A neural correlate for the precedence of entities in working memory: an MEG study

Yaghoob Khezri¹, Moein Esghaei²

1. Electrical engineering, K.N.Toosi University of Technology, Tehran, Iran

2. Cognitive Neurosciences Laboratory, German Primate Center, Göttingen, Germany

Working memory (WM) enables species to maintain task-relevant information at the absence of sensory stimuli. Persistent neuronal oscillations have been suggested to play a key role in WM, especially in how a specific sequence of entities is internally maintained. Nevertheless, the exact neural mechanism underlying sequence maintenance is not yet unveiled. We analyzed Magnetoencephalography (MEG) data recorded from 35 human subjects while they performed a 2-back WM task (Van Essen et al., 2012). Subjects were presented with consecutive images of tools and faces, where they were asked to report if each image matched the one shown two pictures before. Each picture was shown for an interval of 2 seconds, followed by a 500 ms blank period, during which the subjects had to report if the image was a match or non-match by pressing two different buttons. We focused on pairs of consecutive blank periods with both following requirements: 1. the two pictures maintained in WM were the same across the two blank periods 2. the sequence of the two pictures was the opposite between the two blank periods (named as B1 and B2 here). We first z-scored the LFPs within each pair of B1 and B2 by statistics of B1 and subtracted them point by point. Next, we averaged the resultant time series across pairs of blank periods in a given session. A dominant alpha (8-12 Hz) component was observed across recording channels for individual subjects. Mapping the power of this frequency component across different brain sites, showed localized patches of this frequency component peaking at the medial parietal cortex (around electrode A29, BTI248). This effect was statistically significant across subjects ($z\text{-score} > 2$) and could not be associated to a steady increase/decrease of alpha power through time in a session ($p > 0.05$, Pearson Correlation). Given that the only difference between B1 and B2 was the sequence of pictures (rather than their content), our results suggest that the alpha component of LFPs represents the exact precedence of objects in WM. Whether it is the power or the phase of alpha oscillations that encodes this precedence, remains a question for future studies. Consequently, given the well-established role of the prefrontal cortex in maintaining entities in WM, these results are consistent with the account that processes contributing to the maintenance of WM items are independent from processes determining the precedence of these items.

References

- 1 Van Essen, David C., et al. "The Human Connectome Project: a data acquisition perspective." *Neuroimage* 62.4 (2012): 2222-2231. [10.1016/j.neuroimage.2012.02.018](https://doi.org/10.1016/j.neuroimage.2012.02.018)

©(2019) Khezri Y, Esghaei M

Cite as: Khezri Y, Esghaei M (2019) A neural correlate for the precedence of entities in working memory: an MEG study. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0157](https://doi.org/10.12751/nncn.bc2019.0157)

[T 9] Artificial astrocyte networks.

Erik J Peterson¹, Tim Verstynen¹

1. Dept. of Psychology, Carnegie Mellon, Pittsburgh, PA, USA

Using a simple mixture of sigmoid tuning curves, Barron (1993) proved artificial neural networks are universal function approximators. Here we show that Barron's theoretical work extends to astrocyte networks, if we replace firing rate with calcium concentration. This is because 1) astrocytes release neurotransmitters based on the calcium level and 2) the calcium response to neurotransmitter detection is approximately sigmoidal. In practice, artificial astrocyte networks—with only nearest-neighbor connections—achieve good performance on a range of machine learning tasks, including classic MNIST visual digit recognition. Our practical success using artificial astrocytes suggests the diffuse, non-synaptic, connectivity and slow calcium dynamics of biological glia don't necessarily limit their computational capacity.

References

- 1 A. R. Barron, "Universal approximation bounds for superpositions of a sigmoidal function," in IEEE Transactions on Information Theory, vol. 39, no. 3, pp. 930-945, May 1993. [10.1109/18.256500](https://doi.org/10.1109/18.256500)

©(2019) Peterson EJ, Verstynen T

Cite as: Peterson EJ, Verstynen T (2019) Artificial astrocyte networks.. Bernstein Conference 2019 Abstract.

doi: [10.12751/nncn.bc2019.0158](https://doi.org/10.12751/nncn.bc2019.0158)

[T 10] Associative properties of structural plasticity based on firing rate homeostasis in recurrent neuronal networks

Júlia V Gallinaro¹, Stefan Rotter¹

1. Bernstein Center Freiburg, Faculty of Biology, University of Freiburg, Freiburg, Germany

The interaction between Hebbian and homeostatic plasticity in neuronal networks has recently received a lot of attention. Hebbian synaptic plasticity like STDP, known for its associative properties, tends to lead to instabilities in recurrent networks, and different homeostatic mechanisms have been proposed to stabilize the learning process. While slow homeostatic plasticity has been observed in experiments, a mechanism fast enough to compensate instabilities on short time scales remains to be found [1]. The goal of this work is to contribute another aspect to the understanding of this interaction and show that associative properties can also emerge from a rule solely based on homeostatic principles, and that is not explicitly dependent on correlations between the activity of pairs of neurons. By simulating neural networks of spiking neurons and a computational model of structural plasticity based on homeostasis of firing rate [3,4], we have shown that cell assemblies of strongly connected neurons can be formed upon neuronal stimulation [2]. Moreover, we could demonstrate that this effect is larger for repetitive stimulation [5] and it is long-lasting, i.e. the emerging structure decays only slowly when the specific external stimulation is turned off. While the existence of an assembly has only a small effect on the spontaneous activity of the network it is part of, the evoked activity is larger upon stimulation of the cell assembly, allowing for a simple readout of the memory.

Acknowledgements

Supported by Erasmus Mundus/EuroSPIN, BMBF (grant BFNT 01GQ0830) and DFG (grant EXC 1086).

The HPC facilities are funded by the state of Baden-Württemberg through bwHPC and DFG grant INST 39/963-1 FUGG.

References

- 1 Zenke F, Gerstner W, Ganguli S. The temporal paradox of Hebbian learning and homeostatic plasticity. *Current Opinion in Neurobiology* 43: 166-176, 2017 [10.1016/j.conb.2017.03.015](https://doi.org/10.1016/j.conb.2017.03.015)
- 2 Gallinaro JV, Rotter S. Associative properties of structural plasticity based on firing rate homeostasis in recurrent neuronal networks. *Scientific Reports*: 8: 3754, 2018 [10.1038/s41598-018-22077-3](https://doi.org/10.1038/s41598-018-22077-3)
- 3 Butz M, van Ooyen A. A simple rule for dendritic spine and axonal bouton formation can account for cortical reorganization after focal retinal lesions. *PLOS Computational Biology* 9: e1003259, 2013 [10.1371/journal.pcbi.1003259](https://doi.org/10.1371/journal.pcbi.1003259)
- 4 Diaz-Pier S, Naveau M, Butz-Ostendorf M, Morrison A. Automatic generation of connectivity for large-scale neuronal network models through structural plasticity. *Frontiers in Neuroanatomy* 10: 57, 2016 [10.3389/fnana.2016.00057](https://doi.org/10.3389/fnana.2016.00057)
- 5 Lu H, Gallinaro JV, Rotter S. Network remodeling induced by transcranial brain stimulation: A computational model of tDCS-triggered cell assembly formation. *Network Neuroscience*, accepted, 2019

©(2019) Gallinaro JV, Rotter S

Cite as: Gallinaro JV, Rotter S (2019) Associative properties of structural plasticity based on firing rate homeostasis in recurrent neuronal networks. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0159](https://doi.org/10.12751/nncn.bc2019.0159)

[T 11] **Auditory closed-loop stimulation during an afternoon nap enhanced slow oscillation and spindle activity**

Ping Chai Koo-Poeggel¹, Matthias Mölle², Lisa Marshall¹

1. Institute for experimental and clinical Pharmacology and Toxicology, University of Lübeck, Ratzeburger Allee 160, Germany

2. Centre for Brain, Behaviour and Metabolism, University of Lübeck, Ratzeburger Allee 160, Germany

Auditory closed-loop stimulation during sleep has been shown to increase slow oscillation (SO) amplitude, spindle power, and enhance retention on declarative memory tasks as compared to sham stimulation in humans [1-4]. Furthermore, studies revealed that sleep is essential for subsequent learning [5, 6], which is likely due to the synaptic depotentiation during slow wave sleep [7]. Thus, in the present study closed-loop stimulation was applied during an afternoon nap. It is expected that this stimulation will increase sleep SO and spindle activity, and enhance learning performance. Also, the influence of non-rapid eye movement (NREM) sleep depth on the electrophysiological response to stimulation is to be investigated. A single-blind crossed-over design was employed in this study. Subjects participated in two experimental sessions, preceded by an adaptation, and followed by a session for assessment of IQ performance. Conditions were counter-balanced where half of the participants received stimulation (two 50 ms pink noise bursts were delivered, 'clicks') and the other half sham (no clicks were delivered) during the first session. Participants were given 90-120 minutes to sleep and EEG was recorded throughout this period. After sleep, four learning tasks (word-paired associate, figural-paired associate, verbal learning memory and mirror tracing tasks) were given. During the stimulation session, SO detection was initiated 4 minutes after online detection of stable stage 2 sleep. On detection of a negative SO surpassing the amplitude threshold (-80µV), two clicks separated by an interval of 1075 ms were delivered via in-ear headphones. The procedure was identical in the sham session, with only triggers delivered, but no clicks. Preliminary findings reveal that auditory closed-loop stimulation increased SO amplitude and fast spindle (13-16 Hz) root mean square (RMS) as compared to sham. SO peak amplitude at 564 ms after the first click

was $-21.52 \pm 8.70 \mu\text{V}$ (Mean \pm SEM, n=9) more negative than in sham, and maximum spindle RMS at 930 ms after the first click was $1.39 \pm 0.26 \mu\text{V}^2$ higher after stimulation than in sham ($p < 0.05$, for each). Stimulation during deeper stage N3 sleep was associated with much stronger modulation of both SO and sleep spindle activity (e.g. SO, $-37.53 \pm 15.18 \mu\text{V}$, $p < 0.05$ as compared to sham). Results did not reveal an effect of stimulation on learning, which may be associated with the small sample of subjects.

Acknowledgements

This work was supported by the US-German Collaboration in Computational Neuroscience (BMBF grant 01GQ1706).

References

- 1 Leminen MM, Virkkala J, Saure E, Paajanen T, Zee PC, Santostasi G, et al. Enhanced memory consolidation via automatic sound stimulation during non-REM sleep. *Sleep* 2017;40(3):zsx003. [10.1093/sleep/zsx003](https://doi.org/10.1093/sleep/zsx003)
- 2 Ngo H-VV, Martinetz T, Born J, Mölle M. Auditory closed-loop stimulation of the sleep slow oscillation enhances memory. *Neuron* 2013;78(3):545-53. [10.1016/j.neuron.2013.03.006](https://doi.org/10.1016/j.neuron.2013.03.006)
- 3 Ngo H-VV, Miedema A, Faude I, Martinetz T, Mölle M, Born J. Driving sleep slow oscillations by auditory closed-loop stimulation—a self-limiting process. *Journal of Neuroscience* 2015;35(17):6630-8. [10.1523/JNEUROSCI.3133-14.2015](https://doi.org/10.1523/JNEUROSCI.3133-14.2015)
- 4 Ong JL, Lo JC, Chee NI, Santostasi G, Paller KA, Zee PC, et al. Effects of phase-locked acoustic stimulation during a nap on EEG spectra and declarative memory consolidation. *Sleep medicine* 2016;20:88-97. [10.1016/j.sleep.2015.10.016](https://doi.org/10.1016/j.sleep.2015.10.016)
- 5 Van Der Werf YD, Altena E, Schoonheim MM, Sanz-Arigita EJ, Vis JC, De Rijke W, et al. Sleep benefits subsequent hippocampal functioning. *Nature neuroscience* 2009;12(2):122. [10.1038/nn.2253](https://doi.org/10.1038/nn.2253)
- 6 Yoo S-S, Hu PT, Gujar N, Jolesz FA, Walker MP. A deficit in the ability to form new human memories without sleep. *Nature neuroscience* 2007;10(3):385. [10.1038/nn1851](https://doi.org/10.1038/nn1851)
- 7 Tononi G, Cirelli C. Sleep function and synaptic homeostasis. *Sleep medicine reviews* 2006;10(1):49-62. [10.1016/j.smrv.2005.05.002](https://doi.org/10.1016/j.smrv.2005.05.002)

©(2019) Koo-Poeggel PC, Mölle M, Marshall L

Cite as: Koo-Poeggel PC, Mölle M, Marshall L (2019) Auditory closed-loop stimulation during an afternoon nap enhanced slow oscillation and spindle activity. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0160](https://doi.org/10.12751/nncn.bc2019.0160)

[T 12] Auditory closed-loop stimulation during sleep in mice modulates hippocampal sharp wave ripples and thalamo-cortical activity

Sonat Aksamaz¹, Sonja Binder¹, Maximilian Schumann¹, Matthias Mölle², Lisa Marshall¹

1. Institute for Experimental and Clinical Pharmacology and Toxicology, University of Lübeck, Ratzeburger Allee 160, 23562, Germany

2. Center of Brain, Behavior and Metabolism, University of Lübeck, Ratzeburger Allee 160, 23562, Germany

Learning and memory present a way for the organism to adapt to its environment. According to the active systems consolidation hypothesis neuronal representations of a newly encoded memory which are temporarily stored in the hippocampus, are reactivated during slow-wave sleep (SWS) and thereby integrated into long term representations in the neocortex [1,2]. During SWS brain electric activity is characterized by the sleep slow oscillation (SO) and its grouping of thalamo-cortical sleep spindles and hippocampal sharp-wave ripples (SPWR). Temporal coordination of SPWRs and cortical activity has proven relevant for memory consolidation during sleep [3]. Recent calcium imaging studies revealing enhanced calcium activity when spindles are nested in the slow oscillation up state, support the phase-dependence of processes for brain plasticity [4]. In humans auditory closed-loop stimulation was shown to enhance SOs, sleep spindles and increase memory retention (e.g. [5, 6], but see [7]). This study aimed to

investigate the underlying mechanisms by presenting auditory closed-loop stimulation in mice during SWS, and simultaneously measuring cortical EEG and hippocampal local field potentials (LFPs). Auditory stimulation was presented time-locked to the negative-peak of the SO at two delays relative to the SO negative peak in the surface EEG (60 ms and 12 ms, corresponding to the beginning and end of the SO down-to-up transition). Preliminary results reveal that auditory stimulation in addition to eliciting an evoked potential, induced hippocampal ripples and spindle activity time-locked to the stimulation onset for both delays, 60/120ms (SPWR density: 7.67/6.36 1/min and SPWR RMS: 0.0228/0.0225 mV; spindle density: 2.581/2.388 1/min and spindle RMS: 0.079/0.0783 mV). Only the events within individually determined threshold values were analyzed. In sum, results will contribute to understanding the neural mechanisms of improved sleep-associated memory consolidation with closed-loop auditory stimulation.

Acknowledgements

This research was funded by US-German Collaboration in Computational Neuroscience (NSF/BMBF grant 01GQ1706) to L. M., and the Deutsche Forschungsgemeinschaft (DFG SPP1665 (MA2053/4-2)).

References

1. Diekelmann, S., Born, J., 2010. The memory function of sleep. *Nat. Rev. Neurosci.* 11, 114–126 [10.1038/nrn2762](https://doi.org/10.1038/nrn2762)
2. Rasch, B., Born, J., 2013. About sleep's role in memory. *Physiol. Rev.* 93, 681–766 [10.1152/physrev.00032.2012](https://doi.org/10.1152/physrev.00032.2012)
3. Maingret, M., Girardeau G., Todorova, R., Goutierre, M., Zugaro, M., 2016. Hippocampo-cortical coupling mediates memory consolidation during sleep. *Nat Neurosci.* 19(7):959-64 [10.1038/nn.4304](https://doi.org/10.1038/nn.4304)
4. Niethard N., Ngo H-VV., Ehrlich I., Born J., 2018. Cortical circuit activity underlying sleep slow oscillations and spindles. *PNAS* 115 (39) E9220-E9229 [10.1073/pnas.1805517115](https://doi.org/10.1073/pnas.1805517115)
5. Ngo, H.V., Martinetz, T., Born, J., Molle, M., 2013b. Auditory closed-loop stimulation of the sleep slow oscillation enhances memory. *Neuron* 78, 545–553 [10.1016/j.neuron.2013.03.006](https://doi.org/10.1016/j.neuron.2013.03.006)
6. Papalambros, N.A., Santostasi, G., Malkani, R.G., Braun, R., Weintraub, S., Paller, K.A., Zee, P.C., 2017. Acoustic enhancement of sleep slow oscillations and concomitant memory improvement in older adults. *Front. Hum. Neurosci.* 11, 109 [10.3389/fnhum.2017.00109](https://doi.org/10.3389/fnhum.2017.00109)
7. Ong, J.L., Lo, J.C., Chee, N.I., Santostasi, G., Paller, K.A., Zee, P.C., Chee, M.W., 2016. Effects of phase locked acoustic stimulation during a nap on EEG spectra and declarative memory consolidation. *Sleep Med.* 20, 88–97 [10.1016/j.sleep.2015.10.016](https://doi.org/10.1016/j.sleep.2015.10.016)

©(2019) Aksamaz S, Binder S, Schumann M, Mölle M, Marshall L

Cite as: Aksamaz S, Binder S, Schumann M, Mölle M, Marshall L (2019) Auditory closed-loop stimulation during sleep in mice modulates hippocampal sharp wave ripples and thalamo-cortical activity. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0161](https://doi.org/10.12751/nncn.bc2019.0161)

[T 13] Balance and opposition in the forebrain

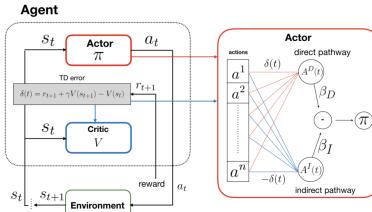
Gonçalo Guiomar¹, Asma Motiwala¹, Bruno Cruz¹, Christian Machens¹, Joseph Paton¹

1. Champalimaud Neuroscience Programme, Champalimaud Centre for the Unknown, Avenida Brasília, Lisbon, Portugal

The execution of motor actions is one of the most fundamental ways in which animals interact with their environment. This interaction entails a process of selecting the appropriate set of actions that allows the achievement of a goal that is relevant for the animal. Recent work has demonstrated that the direct and indirect pathways in the basal ganglia play a crucial role in both the learning, execution and inhibition of action sequences [1,2]. However, there's conflicting evidence in these results as to the actual mechanisms being employed in these pathways.

Most of the neuronal population in the Striatum consist of Medium Spiny Neurons (MSNs) that form a feedforward connection between cortex and thalamus. Neurons that express D1 receptors and form the direct pathway become more excitable with higher tonic levels of dopamine, dealing with positive Reward Prediction Errors (RPEs) and their optogenetic excitation leads to more movement in mice whilst D2 expressing MSNs, which form the indirect pathway, become more excitable with lower tonic levels of dopamine (negative RPEs) inhibiting movement [2]. One of the current hypotheses regarding striatal function lies in these two populations representing Go and No Go signals for particular motor patterns [3]. This same hypothesis lies in contradiction with another set of results that show that both populations are active upon action onset [1]. This leads us to the question; how are these two populations active simultaneously with seemingly opposite functions?

Our aim is thus to reach at a mechanistic description of how the dynamics in these two pathways lead to action selection/suppression, reconciling these seemingly disparate set of results. Inspired by the work in [3] we built a Reinforcement Learning (RL) agent that learns a temporal discrimination task [4] where mice are trained not to move for a certain period. Together with photometry calcium data from D1 and D2 neurons recorded during behaviour [5] we built a model that maps the reward structure of the task into abstract representations of these D1 and D2 neuronal populations. We show that if the RPEs are split into two value streams representing D1 and D2 neurons, both pathways are activated upon action execution while still allowing the agent to perform the task. Our preliminary results thus pave a possible alternative description of the function of these pathways allowing for a simultaneous description of neural activity and behaviour.



Structure of the Reinforcement Learning model: For each action we defined two pathways that are differentially tuned to receive either positive and negative rewards. The combination of the action weights then allows for the learning of an optimal policy that solves a temporal discrimination task.

References

- 1 Cui et. al., Nature 2010 [0.1038/nature11846](#)
- 2 Kravitz et. al. Nature 2012 [10.1038/nature09159](#)
- 3 Collins, Frank - Psych. Rev 2014 [10.1037/a0037015](#)
- 4 Gouvea et al - Frontiers 2014 [10.3389/fnbot.2014.00010](#)
- 5 Cruz et al - In prep

©(2019) Guiomar G, Motiwala A, Cruz B, Machens C, Paton J

Cite as: Guiomar G, Motiwala A, Cruz B, Machens C, Paton J (2019) Balance and opposition in the forebrain. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0162](#)

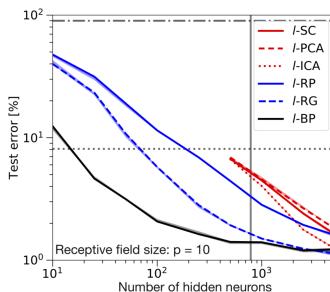
[T 14] Biologically plausible deep learning – but how far can we go with shallow networks?

Bernd Illing¹, Wulfram Gerstner¹, Johanni Brea¹

1. SV/IC, EPFL, 1015 Lausanne, Switzerland

Training deep neural networks with the error backpropagation algorithm is considered implausible from a biological perspective [1,2,3]. Numerous recent publications ([4,5,6] and many others) suggest elaborate models for biologically plausible variants of deep learning, typically defining success as reaching around 98% test accuracy on the MNIST data set. Here, we investigate how far we can go on digit (MNIST) and object (CIFAR10) classification with biologically plausible, local learning rules in a network with one hidden layer and a single readout layer. The hidden layer weights are either fixed (random or random Gabor filters) or trained with unsupervised methods (Principal/Independent Component Analysis or Sparse Coding) that can be implemented by local learning rules. The readout layer is trained with a supervised, local learning rule. We first implement these models with rate neurons. This comparison reveals, first, that unsupervised learning does not lead to better performance than fixed random projections or Gabor filters for large hidden layers. Second, networks with localized receptive fields perform significantly better than networks with all-to-all connectivity. They can reach backpropagation performance on MNIST and the performance of current bio-plausible models of deep learning on CIFAR10 [6]. We then implement two of the networks - fixed, localized, random & random Gabor filters in the hidden layer - with spiking leaky integrate-and-fire

(LIF) neurons and spike timing dependent plasticity (STDP) to train the readout layer. These spiking models achieve > 98.2% test accuracy on MNIST, which is close to the performance of rate networks with one hidden layer trained with backpropagation. The performance of our shallow network models is comparable to most current biologically plausible models of deep learning. Furthermore, our results with a shallow spiking network provide an important reference and suggest the use of datasets other than MNIST for testing the performance of future models of biologically plausible deep learning. For this project, we created a custom framework for simulating networks with spiking LIF neurons which features both exact, event-based and Euler-forward integration. The package is written in the julia programming language for flexible yet fast prototyping and includes features like escape noise and synaptic plasticity. Various applications of our framework and comparisons to other LIF simulation tools will be presented.



MNIST performance using localized receptive fields: Principal/Independent Component Analysis (I-PCA/I-ICA), Sparse Coding (I-SC), Random Projections (I-RP) or Gabor filters (I-RG) & Backpropagation (I-BP). dash-dotted: chance level, dotted: Simple Perceptron (SP), vertical line: input dimension.

Acknowledgements

This research was supported by the Swiss National Science Foundation (no. 200020_165538 and 200020_184615) and by the European Union Horizon 2020 Framework Program under grant agreement no. 785907 (Human-BrainProject, SGA2).

References

1. A. Marblestone et al., Towards an integration of deep learning and neuroscience, *bioRxiv*, 2016
2. F. Crick. The recent excitement about neural networks. *Nature*, 337 (6203):129–32, 1989
3. J. Whittington and R. Bogacz. Theories of Error Back-Propagation in the Brain. *Trends Cogn. Sci.*, 1–16, 2019
4. T. Lillicrap et al., Random synaptic feedback weights support error backpropagation for deep learning. *Nat. Commun.*, 7:13276, 2016
5. J. Sacramento et al., Dendritic error backpropagation in deep cortical microcircuits. *arXiv prepr.*, 2017
6. D. Krotov and J. Hopfield. Unsupervised Learning by Competing Hidden Units. *arXiv prepr.*, 2018

[T 15] Colour clustering in visual working memory

Benjamin Cuthbert¹, Dominic Standage², Martin Paré³, Gunnar Blohm¹

1. Centre for Neuroscience Studies, Queen's University, 18 Stuart St, Kingston, ON, K7L 3N6, Canada

2. School of Psychology, University of Birmingham, Birmingham, United Kingdom

3. Biomedical and Molecular Sciences, Queen's University, 18 Stuart St, Kingston, ON, K7L 3N6, Canada

Visual working memory experiments typically involve asking a subject to memorize several visual stimuli such as coloured shapes, oriented lines, faces, or objects. Computational accounts of recall performance often assume that each stimulus presented in a trial is encoded independently, ignoring higher-level ensemble statistics that have been shown to bias recall and impact task performance. Here, we analyzed data from a delayed estimation task that required the report of all stimuli (6 coloured squares). We found evidence for serial dependencies in within-trial reports, suggesting that participants clustered similarly coloured stimuli together. These dependencies were supported by estimates of the mutual information of within-trial report distributions. We present a non-parametric clustering model to quantify the clustering properties of randomly-generated stimulus arrays. We believe this is a promising data-driven approach to characterizing the statistical properties of experimental stimuli. Together, these results provide further evidence that humans encode ensemble statistics of visual scenes in working memory.

Acknowledgements

We would like to sincerely thank K Adam, E Vogel, and E Awh for making their experimental data publicly available and therefore for making this project possible.

©(2019) Cuthbert B, Standage D, Paré M, Blohm G

Cite as: Cuthbert B, Standage D, Paré M, Blohm G (2019) Colour clustering in visual working memory. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0164](https://doi.org/10.12751/nncn.bc2019.0164)

[T 16] Constraints on sequence processing speed in biological neuronal networks

Younes bouhadjar^{1,2}, Markus Diesmann^{1,3}, Dirk J Wouters⁴, Tom Tetzlaff¹

1. Institute of Neuroscience and Medicine (INM-6) & Institute for Advanced Simulation (IAS-6) & JARA Institute Brain Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany

2. Peter Grünberg Institute (PGI-7), Jülich Research Centre and JARA, Jülich, Germany

3. Department of Psychiatry, Psychotherapy and Psychosomatics, Medical Faculty & Department of Physics, Faculty 1, RWTH Aachen University, Aachen, Germany

4. Institute of Electronic Materials (IWE 2) & JARA-FIT, RWTH Aachen University, Aachen, Germany

Learning and processing temporal sequences have been suggested to be the fundamental computation performed by the neocortex [1–3]. The Hierarchical Temporal Memory (HTM) model constitutes a mechanistic description of this type of computation [4]. It accounts for the specific anatomical structure of cortical (pyramidal) neurons, explains the functional role of dendritic action potentials and learns continuously by means of local learning rules. The model can simultaneously learn and predict multiple sequences in streams of data and is robust with respect to failure of network elements and noise. So far, implementations of this model are based on highly abstract models of neurons and synapses with discrete-time dynamics. To foster an understanding of the sequence processing characteristics in humans and other mammals, the model needs to be reformulated in terms of biophysical principles and parameters. In this

study, we deliver a continuous-time implementation of the temporal-memory algorithm proposed by the HTM theory [5], which comprises networks of spiking neurons, dendritic action potentials, backpropagating action potentials, lateral inhibition, and spike timing dependent structural plasticity. In the framework of this model, we investigate to what extent the sequence processing speed is constrained by neuronal parameters such as cell-intrinsic time constants and synaptic weights. We test the implementation in a task where the network learns random sequences of letters, and study the role of the inter-stimulus interval on the sequence prediction accuracy, thereby deriving lower and upper bounds for the sequence processing speed.

Acknowledgements

This project was funded by the Helmholtz Association Initiative and Networking Fund (project number SO-092, Advanced Computing Architectures), and the European Union's Horizon 2020 Framework Programme for Research and Innovation under the Specific Grant Agreement No. 785907 (Human Brain Project SGA)

References

- 1 Lashley, K. S. (1951). The problem of serial order in behavior, Volume 21. Bobbs- Merrill.
- 2 Hawkins, J., & Blakeslee, S. (2007). On intelligence: How a new understanding of the brain will lead to the creation of truly intelligent machines. Macmillan.
- 3 Gavornik, J. P., & Bear, M. F. (2014). Learned spatiotemporal sequence recognition and prediction in primary visual cortex. *Nature neuroscience* 17(5), 732.
- 4 Hawkins, J., Ahmad, S., & Dubinsky, D. (2011). Cortical learning algorithm and hierarchical temporal memory. Numenta Whitepaper, 1–68.
- 5 Hawkins, J., & Ahmad, S. (2016). Why neurons have thousands of synapses, a theory of sequence memory in neocortex. *Frontiers in Neural Circuits* 10.

©(2019) bouhadjar Y, Diesmann M, Wouters DJ, Tetzlaff T

Cite as: bouhadjar Y, Diesmann M, Wouters DJ, Tetzlaff T (2019) Constraints on sequence processing speed in biological neuronal networks. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0165](https://doi.org/10.12751/nncn.bc2019.0165)

[T 17] Controlling burst activity enables a multiplexed neural code in cortical circuits

Filip Vercruyse¹, Paola Suarez¹, Henning Sprekeler¹, Richard Naud²

1. Institute of Software Engineering and Theoretical Computer Science, Technical University Berlin, Marchstrasse 23, 10587 Berlin, Germany

2. University of Ottawa Brain and Mind Research Institute, Department of Cellular and Molecular Medicine, University of Ottawa, Ottawa, ON K1H 8M5, Canada

The presence of specialised burst mechanisms in pyramidal cells (PCs) suggests that bursts are likely to be an important temporal feature of neural spike trains. Bursts seem correlated with sensory processing and perception [1], induce synaptic plasticity, and have been proposed as a cellular mechanism to combine sensory and internal information [2]. In deep layer 5 PCs, bursts occur at a low, but consistent rate, and are thought to originate from active dendritic processes. Because burst activity relies on dendritic threshold mechanisms [3], it appears likely that low burst activity requires an intricate homeostatic control mechanism. We hypothesized that this control is mediated by inhibitory plasticity of connections from Martinotti cells, which are known to control apical dendrites of PCs [4]. To investigate this hypothesis, we studied a computational network model comprising layer 5 pyramidal cells with a somatic and dendritic compartment that was fitted to *in vitro* data, as well as different subclasses of interneurons. Our results show that a simple Hebbian plasticity rule on inhibitory synapses leads to robust and self-organized control of dendritic and burst activity. The dendritic learning rule we suggest is based on a homeostatic rule that was previously

proposed to control somatic spiking activity and therefore inherits properties such as a balance of excitation and inhibition [5]. We demonstrate that this E/I balance is necessary for realistic burst firing patterns in biologically inspired cortical microcircuits with inhibitory neurons and recurrent connections. Furthermore, we show that the self-organized control of somatic and dendritic activity in pyramidal cells enables a multiplexed burst code suggested recently [6], by alleviating the need to tune input or noise levels. Finally, we show in simulations that the self-organising properties of inhibitory plasticity rules can be used to multiplex sensory and decision-related signals in decision-making networks [7], allowing us to decode behavioral decisions from burst activity in populations of sensory neurons.

References

- 1 Takahashi N, Oertner TG, Hegemann P, Larkum ME. (2016) Active cortical dendrites modulate perception. *Science*. 354(6319):1587-1590
- 2 Larkum ME (2013) A cellular mechanism for cortical associations: an organizing principle for the cerebral cortex. *Trends Neurosci*. 36(3), 141-151
- 3 Larkum ME, Zhu JJ, Sakmann B. A new cellular mechanism for coupling inputs arriving at different cortical layers. (1999) *Nature*. 398(6725), 338-341
- 4 Murayama M, Pérez-Garcí E, Nevian T, Bock T, Senn W, Larkum ME. (2009) Dendritic encoding of sensory stimuli controlled by deep cortical interneurons. *Nature*. 457(7233), 1137-1141
- 5 Vogels T, Sprekeler H, Zenke F, Clopath C, Gerstner W. (2011) Inhibitory plasticity balances excitation and inhibition in sensory pathways and memory networks. *Science*. 334:1569-1573
- 6 Naud R, Sprekeler H (2018) Sparse bursts optimize information transmission in a multiplexed neural code. *PNAS*. 115(27), 6329-6338
- 7 Wimmer K, Compte A, Roxin A, Peixoto D, Renart A, De La Rocha J. (2015) Sensory integration dynamics in a hierarchical network explains choice probabilities in cortical area MT. *Nature Comm*. 6(6177)

©(2019) Vercruyse F, Suarez P, Sprekeler H, Naud R

Cite as: Vercruyse F, Suarez P, Sprekeler H, Naud R (2019) Controlling burst activity enables a multiplexed neural code in cortical circuits. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0166](https://doi.org/10.12751/nncn.bc2019.0166)

[T 18] Cortical credit assignment by Hebbian, neuromodulatory and inhibitory plasticity

Johnatan Aljadeff¹, James D'amour², Rachel Field³, Robert Froemke⁴, Claudia Clopath¹

1. Imperial College London, UK

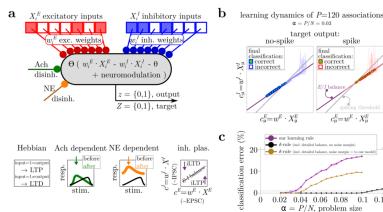
2. NIH, USA

3. Columbia University, USA

4. New York University, USA

The cortex learns to make associations between high-dimensional sensory inputs and spiking activity that supports behaviour, by adjusting synaptic weights over time. The complexity of these transformations implies that individual synapses are appropriately potentiated or depressed without having access to the complete error information associated with the behavioural outcome. This is typically referred to as the "credit-assignment problem". It is unknown how the cortex solves this problem. We propose that a combination of Hebbian, acetylcholine and noradrenaline dependent excitatory plasticity (Pawlak et al. 2010), together with inhibitory plasticity restoring detailed E/I balance (D'amour and Froemke, 2015), can effectively translate the partial error information available to each synapse into learning rules that solve the credit assignment problem. We derive conditions on these plasticity mechanisms that, when met, guarantee that a simple neuron model can robustly learn a number of input-output associations of the same order as the theoretical capacity (Brunel, 2016; Rubin et al., 2017). We use

the theoretical results to make a key prediction: the balance between excitation and inhibition towards which inhibitory plasticity is driving the system should be tilted in favour of excitation. We confirmed this prediction by reanalysing a published *in vitro* dataset (D'amour and Froemke, 2015). Finally, we identified distinct functional roles for each of the plasticity mechanisms in our model. In line with previous literature (Yu and Dayan, 2005), acetylcholine plays a role in making appropriate adjustments to synaptic weights when the output is close but not equal to the desired one; whereas noradrenaline plays a role in "wholesale" changes to the output which is important when the learning process is "stuck" far from the desired state. Importantly, our analysis also suggests a novel role for tight E/I balance: it reduces the dimensionality of the learning problem a neuron faces, thereby allowing imperfect "supervision" by the neuromodulatory systems to guide learning effectively.



a. Schematic of neuromodulated perceptron and modelled plasticity: Hebbian, ACh/NE dependent, inh. plasticity driving toward E/I balance. b. Learning in E-I space: associations move towards E-I balance (purple), then classified relative to spiking threshold (gray). c. Error vs. problem size.

References

- 1 Pawlak, V., Wickens, J.R., Kirkwood, A. and Kerr, J.N., 2010. Timing is not everything: neuromodulation opens the STDP gate. *Frontiers in synaptic neuroscience*, 2, p.146. [10.3389/fnsyn.2010.00146](https://doi.org/10.3389/fnsyn.2010.00146)
- 2 D'amour, J.A. and Froemke, R.C., 2015. Inhibitory and excitatory spike-timing-dependent plasticity in the auditory cortex. *Neuron*, 86(2), pp.514-528. [10.1016/j.neuron.2015.03.014](https://doi.org/10.1016/j.neuron.2015.03.014)
- 3 Brunel, N., 2016. Is cortical connectivity optimized for storing information? *Nature neuroscience*, 19(5), p.749. [10.1038/nn.4286](https://doi.org/10.1038/nn.4286)
- 4 Rubin, R., Abbott, L.F. and Sompolinsky, H., 2017. Balanced excitation and inhibition are required for high-capacity, noise-robust neuronal selectivity. *Proceedings of the National Academy of Sciences*, 114(44), pp.E9366-E9375. [10.1073/pnas.1705841114](https://doi.org/10.1073/pnas.1705841114)
- 5 Yu, A.J., and Dayan, P., 2005. Uncertainty, neuromodulation, and attention. *Neuron*, 46(4), pp.681-692. [10.1016/j.neuron.2005.04.026](https://doi.org/10.1016/j.neuron.2005.04.026)

©(2019) Aljadeff J, D'amour J, Field R, Froemke R, Clopath C

Cite as: Aljadeff J, D'amour J, Field R, Froemke R, Clopath C (2019) Cortical credit assignment by Hebbian, neuromodulatory and inhibitory plasticity. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0167](https://doi.org/10.12751/nncn.bc2019.0167)

[T 19] Deep reinforcement learning in a time-continuous model

Akos Ferenc Kungl¹, Dominik Dold¹, Oskar Riedler², Walter Senn³, Mihai Alexandru Petrovici^{1,3}

1. Departement for Physics and Astronomy, Kirchhoff Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120, Germany

2. Heidelberg University, Heidelberg, Germany

3. Institute for Physiology, University of Bern, Bühlpark 5, 3012 Bern, Switzerland

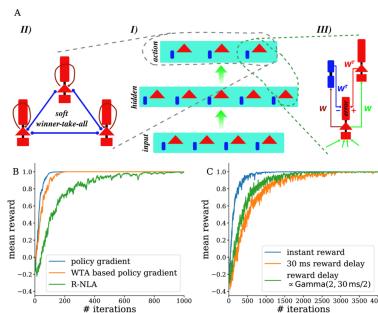
Inspired by the recent success of deep learning [1], several models emerged trying to explain how the brain might realize plasticity rules reaching similar performances as deep learning [2-5]. However, all of these models consider only supervised and unsupervised learning, where an external teacher is needed to produce an error signal that guides plasticity.

In this work, we introduce a model of reinforcement learning based on the principle of Neuronal Least Action (R-NLA). We extend previous works on time-continuous error backpropagation in cortical microcircuits [4, 6] to achieve a biologically plausible model implementing deep reinforcement learning.

In R-NLA the neurosynaptic dynamics is derived from the energy function using the variational principle. In the resulting dynamics the phase-advanced firing of the neurons effectively undoes the network delay introduced by finite membrane time-constants. Errors are introduced to the network by nudging, and they are propagated to deeper layers via cortical microcircuits. Instead of having an explicit teacher, the output neurons, which represent the actions, form a soft winner-take-all network (Fig A). This winner-take-all structure evokes a nudging on the soma of the output neurons, which is subsequently backpropagated through the network. A reward prediction error $\delta = R - \langle R \rangle$ modulates the plasticity multiplicatively as a formally deduced global reward-specific neuromodulator [7]. By construction, the learning rule approximates the policy gradient of the mean expected reward.

Using a simple pattern recognition problem as a toy example, we show that R-NLA can learn classification tasks in the reinforcement learning framework with similar performance as an equivalent deep reinforcement learning model (Fig B). Further, we show that it is robust against time-delayed rewards, even if the reward delay is not constant but randomly distributed (Fig C).

R-NLA constitutes a time-continuous implementation of biologically plausible deep reinforcement learning, robust to delayed reward. The self-teaching soft winner-take-all mechanism removes the necessity of an explicit teacher and the proposed learning rule solves the problem of synaptic consolidation. The model can be extended to an actor-critic model, where a second (deep) critic network learns the state-value function.



A-I) Network schematics. A-II) Soft winner-take-all network in the output layer. A-III) Microcircuit for error backpropagation. B) Comparison to classical reinforcement learning methods. C) Robustness with respect to reward delay.

Acknowledgements

The work leading to these results has received funding from the European Union grant agreements No 720270 and 785907 (Human Brain Project, HBP). We owe particular gratitude to the sustained support of our research by the Manfred Stärk Foundation.

References

- Yann LeCun, Yoshua Bengio, and Geoffrey Hinton. Deep learning. *Nature*, 521(7553):436, 2015. [10.1038/nature14539](https://doi.org/10.1038/nature14539)
- Randall C O'Reilly. Biologically plausible error-driven learning using local activation differences: The generalized recirculation algorithm. *Neural Computation*, 8(5):895–938, 1996. [10.1162/neco.1996.8.5.895](https://doi.org/10.1162/neco.1996.8.5.895)
- James CR Whittington and Rafal Bogacz. An approximation of the error backpropagation algorithm in a predictive coding network with local hebbian synaptic plasticity. *Neural Computation*, 29(5):1229–1262, 2017. [10.1162/NECO_a_00949](https://doi.org/10.1162/NECO_a_00949)
- Joao Sacramento, Rui Ponte Costa, Yoshua Bengio, and Walter Senn. Dendritic cortical microcircuits approximate the backpropagation algorithm. In *Advances in Neural Information Processing Systems*, pages 8721–8732, 2018.
- James CR Whittington and Rafal Bogacz. Theories of error back-propagation in the brain. *Trends in Cognitive Sciences*, 2019. [10.1016/j.tics.2018.12.005](https://doi.org/10.1016/j.tics.2018.12.005)
- Dominik Dold, Akos F Kungl, Joao Sacramento, Mihai A Petrovici, Kaspar Schindler, Jonathan Binas, Yoshua Bengio, and Walter Senn. Lagrangian dynamics of dendritic microcircuits enables real-time backpropagation of errors. In *Cosyne Conference*, 2019.
- Nicolas Fremaux and Wulfram Gerstner. Neuromodulated spike-timing-dependent plasticity, and theory of three-factor learning rules. *Frontiers in Neural Circuits*, 9:85, 2016. [10.3389/fncir.2015.00085](https://doi.org/10.3389/fncir.2015.00085)

©(2019) Kungl AF, Dold D, Riedler O, Senn W, Petrovici MA

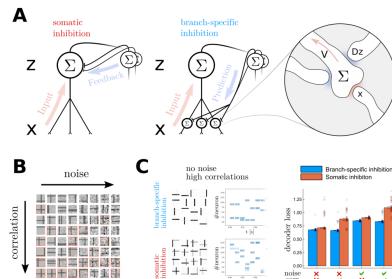
Cite as: Kungl AF, Dold D, Riedler O, Senn W, Petrovici MA (2019) Deep reinforcement learning in a time-continuous model. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0168](https://doi.org/10.12751/nncn.bc2019.0168)

[T 20] Dendritic branches for optimal unsupervised learning in spiking neural networks

Fabian Mikulasch¹, Lucas Rudelt¹, Viola Priesemann¹

¹ Max-Planck-Institute for Dynamics and Self-Organization, Am Fassberg 17, 37077 Göttingen, Germany

It remains an open question why neurons form dendritic trees and branches, and what additional functionality the intricate morphology of dendrites provides. For universal computation point neurons are already sufficient, hence dendritic trees are typically ignored in artificial neural networks. For unsupervised learning, however, we show that in a biologically plausible spike response model [1] branch-specific inhibition onto dendrites is crucial. The idea in unsupervised learning is that an input stream is explained within an internal model, and that the internal model is optimized for a minimal decoding error between the model's prediction and the true input. When applied to a neural network, the network implements an efficient encoding of the input, e.g. for transforming a continuous signal into a spike-based representation [2], or to reduce the dimensionality of the input [3]. However, when a population of neurons learns to encode its input a fundamental problem arises: For optimal spiking and tuning of synaptic weights neurons need access to the full population-code, which is not locally available at each neuron. In previous work, this was solved by introducing inhibitory feedback, either in the form of strong or soft winner-take-all circuits [4,5], or by introducing plastic inhibitory synapses [6, 7]. In all of these solutions, inhibitory feedback acts on the soma, and plasticity leads to a decorrelation of neural responses (Fig. A). We show that somatic inhibition can lead to sub-optimal learning. Because all inputs are summed at the soma, inhibition only suppresses firing and does not extract another neuron's contribution to the decoding error of a specific input. These contributions become increasingly important for learning when salient features in the input are correlated (Fig B,C). We show analytically that when dendritic branches serve as local integration sites (Fig. A), excitatory input and inhibitory feedback synapses can self-organize to minimize the correct decoding error. In simulations this voltage-dependent plasticity substantially improves the learned code (Fig C). Our work stresses the importance of dendritic branches for organizing neural plasticity and provides a possible explanation for the spatial clustering of similarly tuned inhibitory and excitatory synapses [8] from the perspective of unsupervised learning.



We evaluate unsupervised learning in a spiking neural network where inhibitory synapses target specific dendritic branches instead of the soma. (A). We show that when learning stimuli with correlated features (B), branch-specific inhibition outperforms point neurons using somatic inhibition (C).

Acknowledgements

LR and VP received funding from the German Israel Foundation (G-2391-421.13). VP received funding from the German Ministry for Education and Research (BMBF) via the Bernstein Center for Computational Neuroscience Göttingen (01GQ1005B).

References

- 1 Jolivet, R., Rauch, A., Lüscher, H.-R. & Gerstner, W. Predicting spike timing of neocortical pyramidal neurons by simple threshold models. *J Comput Neurosci* 21, 35–49 (2006). [10.1007/s10827-006-7074-5](https://doi.org/10.1007/s10827-006-7074-5)
- 2 Denéve, S. & Machens, C. K. Efficient codes and balanced networks. *Nature Neuroscience* 19, 375–382 (2016). [10.1038/nrn.4243](https://doi.org/10.1038/nrn.4243)
- 3 Nessler, B., Pfeiffer, M. & Maass, W. STDP enables spiking neurons to detect hidden causes of their inputs. in *Advances in Neural Information Processing Systems* 22, 1357–1365 (2009).
- 4 Jonke, Z., Legenstein, R., Habenschuss, S. & Maass, W. Feedback inhibition shapes emergent computational properties of cortical microcircuit motifs. *The Journal of Neuroscience* 2078–16 (2017). [10.1523/JNEUROSCI.2078-16.2017](https://doi.org/10.1523/JNEUROSCI.2078-16.2017)
- 5 Bill, J. et al. Distributed Bayesian Computation and Self-Organized Learning in Sheets of Spiking Neurons with Local Lateral Inhibition. *PLOS ONE* 10, (2015). [10.1371/journal.pone.0134356](https://doi.org/10.1371/journal.pone.0134356)
- 6 Vogels, T. P., Sprekeler, H., Zenke, F., Clopath, C. & Gerstner, W. Inhibitory Plasticity Balances Excitation and Inhibition in Sensory Pathways and Memory Networks. *Science* 334, 1569–1573 (2011). [10.1126/science.1211095](https://doi.org/10.1126/science.1211095)
- 7 Brendel, W., Bourdoukan, R., Vertechi, P., Machens, C. K. & Denéve, S. Learning to represent signals spike by spike. [arXiv:1703.03777 \[q-bio\]](https://arxiv.org/abs/1703.03777) (2017).
- 8 Kastellakis, G., Cai, D. J., Mednick, S. C., Silva, A. J. & Poirazi, P. Synaptic clustering within dendrites: An emerging theory of memory formation. *Progress in Neurobiology* 126, 19–35 (2015). [10.1016/j.pneurobio.2014.12.002](https://doi.org/10.1016/j.pneurobio.2014.12.002)

©(2019) Mikulasch F, Rudelt L, Priesemann V

Cite as: Mikulasch F, Rudelt L, Priesemann V (2019) Dendritic branches for optimal unsupervised learning in spiking neural networks. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0169](https://doi.org/10.12751/nncn.bc2019.0169)

[T 21] Development of sequence memory ability in a balanced recurrent network with spike-timing dependent and homeostatic plasticity: a timescale analysis

Matthias Loidolt^{1,2}, Lucas Rudelt¹, Viola Priesemann^{1,3}

1. Max-Planck-Institute for Dynamics & Self-Organization, Goettingen, Germany

2. Max-Planck-Institute of Cell Biology & Genetics, Dresden, Germany

3. Bernstein Center for Computational Neuroscience, Goettingen, Germany

The network structure emerging from activity-dependent plasticity rules depends on the spatiotemporal structure of input, which differs between brain regions, experimental conditions and developmental states [1, 2]. The picture is complicated by the fact that multiple timescales of different learning rules need to be orchestrated to allow stable learning [3]. We analyse the interplay of different spatiotemporal input structures with homeostatic and synaptic-spike-timing plasticity in a recurrent neural network model capable of sequence memory learning [4,5]. We find different effective timescales dependent on both the activity of other learning rules and spatiotemporal input structure. We show that each effective developmental timescale gives rise to specific motifs in network structure. We propose a staged model of network development and learning, relying on the same set of plasticity rules but defined through different input statistics.

References

- 1 Understanding neural circuit development through theory and models; L.M. Richter, J. Gjorgjieva [10.1016/j.conb.2017.07.004](https://doi.org/10.1016/j.conb.2017.07.004)
- 2 Homeostatic Plasticity and External Input Shape Neural Network Dynamics; J. Zierenberg, J. Wilting, V. Priesemann [10.1103/PhysRevX.8.031018](https://doi.org/10.1103/PhysRevX.8.031018)
- 3 Hebbian plasticity requires compensatory processes on multiple timescales; F. Zenke, W. Gerstner [10.1098/rstb.2016.0259](https://doi.org/10.1098/rstb.2016.0259)
- 4 SORN: a self-organizing recurrent neural network; A. Lazar, G. Pipa, J. Triesch [10.3389/neuro.10.023.2009](https://doi.org/10.3389/neuro.10.023.2009)

- 5 A model of human motor sequence learning explains facilitation and interference effects based on spike-timing dependent plasticity; Q. Wang, C. A. Rothkopf, J. Triesch [10.1371/journal.pcbi.1005632](https://doi.org/10.1371/journal.pcbi.1005632)

©(2019) Loidolt M, Rudelt L, Priesemann V

Cite as: Loidolt M, Rudelt L, Priesemann V (2019) Development of sequence memory ability in a balanced recurrent network with spike-timing dependent and homeostatic plasticity: a timescale analysis. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0170](https://doi.org/10.12751/nncn.bc2019.0170)

[T 22] Distributed representations and learning in neuronal networks

Matthieu Gilson¹, David Dahmen², Ruben Moreno-Bote¹, Andrea Insabato³, Moritz Helias²

1. Center for Brain and Cognition, Universitat Pompeu Fabra, Spain

2. INM-6, Juelich Research Centre, Germany

3. INT, CNRS, Marseille

Many efforts in the study of the brain have focused on representations of stimuli by neurons and learning thereof. We focus on learning an input-output mapping in a network based on second-order statistics, namely spatio-temporal covariances. Relying on the multivariate autoregressive (MAR) dynamics, our theory derives the weight update such that input covariance patterns are mapped to given objective output covariance patterns. It can be as an extension of the classical perceptron [1], a central concept that has brought many fruitful theories in the fields of neural coding and learning in networks. As an example, it performs the categorization of fluctuating time series determined by their hidden dynamics. Conceptually, variability in the time series is the basis for information to be learned, via the co-fluctuations that result in second-order statistics. Our approach is thus a radical change of perspective compared to classical approaches that typically transform time series into a succession of static patterns where fluctuations are noise. We illustrate our framework with an example where recurrent connections are crucial to learn the hidden statistics of input time series. The input time series are generated by a MAR process with a given coupling matrix W in Fig 1A, which determines their second-order statistics (zero-lag and time-lagged covariances, P^0 and P^1 respectively). The network is made of afferent connections B and recurrent connections A . These weights are tuned in a supervised manner such that the output (zero-lag) variance is larger for node 1 than node 2 for the red group (right matrices Q^0 in Fig 1A), and the converse for the blue group. Importantly, the matrices W are chosen such that the zero-lag covariances P^0 are all identical (Fig 1B). An example of generated time series is given in Fig 1C, light brown for inputs and dark brown for outputs. The input and output covariances are evaluated using an observation window of length d , which is used to compute the weight updates. As shown in Fig 1D, the error between the actual and the desired output covariances decreases and remains stable during learning. The accuracy increases as a function of d when tuning both weights B and A (Fig 1E). However, training only the afferent weights B leads to chance-level performance (Fig 1F).

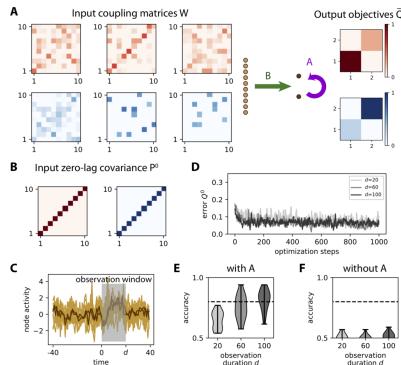


Fig 1: Learning hidden dynamics of input time series for categorization.

References

- 1 CM Bishop (2006) Pattern Recognition and Machine Learning.

©(2019) Gilson M, Dahmen D, Moreno-Bote R, Insabato A, Helias M

Cite as: Gilson M, Dahmen D, Moreno-Bote R, Insabato A, Helias M (2019) Distributed representations and learning in neuronal networks. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0171](https://doi.org/10.12751/nncn.bc2019.0171)

[T 23] Dynamical learning of dynamics

Christian Klos¹, Yaroslav Felipe Kalle Kossio¹, Sven Goedeke¹, Aditya Gilra¹, Raoul-Martin Memmesheimer¹

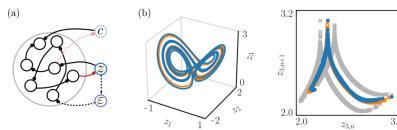
1. Neural Network Dynamics and Computation, Institute of Genetics, University of Bonn, Bonn, Germany

The predominant paradigm for learning in biological or artificial neural networks assumes slow modification of the connection weights between neurons. This is, however, difficult to reconcile with the ability of humans and animals to quickly adapt to novel tasks. A potential solution to this problem is dynamical learning [1], i.e., learning of new tasks purely by dynamics, typically after appropriate weight pretraining (“learning to learn”). Previous work has applied it successfully for reinforcement and supervised learning (see, e.g., [2, 3, 4]). These approaches require teacher feedback also during testing and do not learn autonomous trajectories or dynamical systems.

Here we show how neural networks with fixed connection weights can learn to generate required trajectories or dynamical systems without teacher feedback. We consider recurrent neural networks of rate neurons with a signal output $z(t)$ and a context output $c(t)$. Both are fed back into the network, initially together with an error input $\varepsilon = z(t) - \tilde{z}(t)$, where $\tilde{z}(t)$ is the target output (Fig. 1a). During the weight pretraining, we teach the networks several dynamics from a task family, as well as a corresponding constant context signal. The error input $\varepsilon(t)$ and an additional error signal to the connections supervise this process. For the following dynamical learning, we fix the connection weights. The error input alone nevertheless suffices to teach unseen dynamics from the task family. Further, the network generates a context signal that fluctuates around some temporal mean. When subsequently testing the generation of the dynamics, we remove the teaching error input and fix the context signal to its average. Despite the

lack of supervision, the networks continue to generate a close-to-desired signal output. We illustrate the abilities of the proposed learning scheme by a variety of applications, which range from autonomously generating sinusoidal oscillations to imitating a driven overdamped pendulum and generating chaotic Lorenz attractor dynamics (Fig. 1b). Furthermore, we use dynamical systems theory to analyze the network mechanisms underlying the learning.

Taken together, we present here a paradigm for the learning of autonomous trajectories and dynamical systems without weight modification. Our theory suggests that biological neural networks may well use dynamical learning for generating even complicated dynamics.



(a) Network architecture. (b) Testing after dynamical learning of a Lorenz system. Left: Limit sets of output signal (blue) and target (orange). Right: Tent maps of output signal (blue) and dynamical (orange) and weight-learned targets (gray).

Acknowledgements

We thank Paul Züge for fruitful discussions and the German Federal Ministry of Education and Research (BMBF) for support via the Bernstein Network (Bernstein Award 2014, 01GQ1710).

References

- 1 N. E. Cotter and P. R. Conwell, (1990), Fixed-weight networks can learn, IJCNN International Joint Conference on Neural Networks 3, 553–559 [10.1109/IJCNN.1990.137898](https://doi.org/10.1109/IJCNN.1990.137898)
- 2 M. Oubbati and G. Palm (2010), A neural framework for adaptive robot control, Neural Computing and Applications 19, 103–114 [10.1007/s00521-009-0262-2](https://doi.org/10.1007/s00521-009-0262-2)
- 3 J. X. Wang, Z. Kurth-Nelson, D. Kumaran, D. Tirumala, H. Soyer, J. Z. Leibo, D. Hassabis, and M. Botvinick (2018), Prefrontal cortex as a meta-reinforcement learning system, Nat. Neurosci. 21, 860–868 [10.1038/s41593-018-0147-8](https://doi.org/10.1038/s41593-018-0147-8)
- 4 G. Bellec, D. Salaj, A. Subramoney, R. Legenstein, and W. Maass (2018), Long short-term memory and learning-to-learn in networks of spiking neurons, Adv. Neur. Proc. Sys. 31, 787–797

©(2019) Klos C, Kalle Kossio YF, Goedeke S, Gilra A, Memmesheimer R

Cite as: Klos C, Kalle Kossio YF, Goedeke S, Gilra A, Memmesheimer R (2019) Dynamical learning of dynamics. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0172](https://doi.org/10.12751/nncn.bc2019.0172)

[T 24] From episodic to semantic memory: A computational model

Denis Alevi^{1,2}, Richard Kempter^{2,3}, Henning Sprekeler^{1,2}

1. Modelling of Cognitive Processes, Berlin Institute of Technology, Germany

2. Bernstein Center for Computational Neuroscience Berlin, Germany

3. Institute of Theoretical Biology, Humboldt University of Berlin, Germany

Systems memory consolidation describes the process of transferring and transforming initially hippocampus-dependent declarative memories into stable representations in the neocortex. Experimental evidence indicates that this process is linked to neural replay during sleep [1]. While multiple phenomenological theories of systems consolidation have been proposed [2], a mechanistic theory on the level of neurons and synapses is missing.

Here, we study how episodic memories change over time in a recently suggested computational model for the neuronal basis of systems memory consolidation [3]. In the model, memories are initially stored as cue-response associations in a multisynaptic pathway. During consolidation, these associations are reactivated. Hebbian plasticity in a parallel shortcut pathway then allows the associations to be transferred, whereby the multisynaptic pathway acts as a teacher for the shortcut pathway. This transfer into shortcut pathways – which are widely encountered throughout the brain – can be hierarchically iterated to achieve a transfer of memories from the hippocampus to neocortex.

In the present work, we implement the proposed mechanism in artificial neural networks to investigate how the characteristics of episodic memories change over time. We conceptualize the formation of an episodic memory as overfitting to a single event – thereby learning all of its details. We show that in such a model, the transfer of memory associations into the shortcut pathway facilitates forgetting of random episodic details in memories and enhances the extraction of semantic generalizations. Moreover, we show that i) the amount of episodic details transferred into the shortcut pathway depends on the speed of learning and that ii) neural replay enhances the speed of consolidation and can be necessary for the extraction of semantic memories. The latter appears to be the case specifically for the extraction of semantic content from a rapidly learning hippocampal system. Finally, we hypothesize that the previously suggested hierarchical iteration of the mechanism may provide a mechanistic model for the spatial and temporal gradients of episodic and semantic memories observed in lesion studies [2], which suggest that episodic memory content decreases and semantic memory content increases with distance from the hippocampus.

Acknowledgements

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project number 327654276 – SFB 1315.

References

- 1 Dudai, Y., Karni, A., & Born, J. (2015). The Consolidation and Transformation of Memory. *Neuron*, 88(1), 20–32.
- 2 Squire, L. R., Genzel, L., Wixted, J. T., & Morris, R. G. (2015). Memory consolidation. *Cold Spring Harbor Perspectives in Biology*, 7(8), a021766.
- 3 Remme, M., Bergmann, U., Schreiber, S., Sprekeler, H., & Kempter, R. (2019). A circuit mechanism for systems memory consolidation. Unpublished Manuscript.

©(2019) Alevi D, Kempter R, Sprekeler H

Cite as: Alevi D, Kempter R, Sprekeler H (2019) From episodic to semantic memory: A computational model. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0173](https://doi.org/10.12751/nncn.bc2019.0173)

[T 25] Functional implications of inhibitory plasticity as a homeostatic mechanism

Christoph Miehl¹, Julijana Gjorgjieva^{1,2}

1. Max Planck Institute for Brain Research, Frankfurt, Germany

2. School of Life Sciences Weihenstephan, Technical University of Munich, Germany

Learning and memory are classically implemented by Hebbian plasticity, where pre and postsynaptic activity need to be co-active to induce change in synaptic plasticity. But this mechanism on its own is unstable, leading to runaway neuronal activity. Thus, an additional compensatory mechanism is needed to stabilize the activity in neural circuits. Various homeostatic mechanisms are found in experimental studies, however, theoretical considerations suggest that the timescale of these homeostatic mechanisms is too slow to counteract Hebbian runaway activity. We have investigated the conditions under which inhibitory plasticity can serve as a homeostatic mechanism, based on a computational model of a cortical neuron which receives excitatory and inhibitory spiking inputs. One aspect a candidate homeostatic mechanism needs to fulfill is induction of competition between synapses, which ultimately leads to the formation of a receptive field. We have confirmed that inhibitory plasticity is sufficient to induce competition based on unspecific inhibitory input, independent from the choice of rate-based or correlation-based encoding of input features. Furthermore, we have explored the dependence of excitatory/inhibitory balance formation on the specificity of inhibitory relative to excitatory inputs. Our work specifically investigates correlations between excitatory and inhibitory input spike trains in receptive field formation. The most important aspect of any homeostatic mechanism is to counteract excitatory Hebbian runaway dynamics. Therefore, we identified conditions when inhibitory plasticity can stabilize unbounded growth of excitatory connections using numerical simulations and a mean-field approximation of the weight dynamics based on a linear Poisson neuron model. Assuming that excitatory plasticity is based on the triplet spike-timing-dependent synaptic plasticity rule, we also showed that the interaction of excitatory and inhibitory plasticity is similar to the well-established Bienenstock-Cooper-Munro (BCM) synaptic plasticity rule, which has already been shown to explain several aspects of experience-dependent plasticity.

Acknowledgements

CM and JG thank the Max Planck Society for funding. JG is also supported by a NARSAD Young Investigator Award.

©(2019) Miehl C, Gjorgjieva J

Cite as: Miehl C, Gjorgjieva J (2019) Functional implications of inhibitory plasticity as a homeostatic mechanism. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0174](https://doi.org/10.12751/nncn.bc2019.0174)

[T 26] Generation of sharp wave-ripple events by disinhibition

Roberta Evangelista^{1,2}, Nikolaus Maier³, Dietmar Schmitz^{2,3,4,5,6}, Richard Kempter^{1,2,6}

1. Institute for Theoretical Biology, Humboldt-Universität zu Berlin

2. Bernstein Center for Computational Neuroscience Berlin

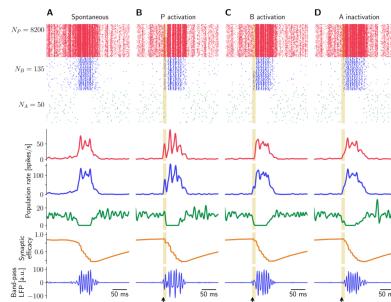
3. Charité Universitätsmedizin Berlin

4. NeuroCure Cluster of Excellence

5. Deutsches Zentrum für Neurodegenerative Erkrankungen in der Helmholtz-Gemeinschaft

6. Einstein Center for Neurosciences Berlin

Sharp wave-ripple complexes (SWRs) are brief (50-100 ms) events of coordinated network activity originating in the CA3 region of the hippocampus. SWRs are thought to mediate the consolidation of explicit memories, but the mechanisms underlying their occurrence remain obscure. Characteristic of SWRs is their modulation of hippocampal cells' firing: pyramidal cells (PYR) and parvalbumin-positive basket cells (PV⁺BCs) preferentially fire during SWRs and are almost silent outside. In this project, we employ computational methods to unveil how the interaction between principal cells and two different interneuron types controls SWR dynamics. In brief, we show that: 1) A biophysically constrained spiking network comprising PYR, PV⁺BCs, and a group of yet unidentified inhibitory anti-SWR cells can generate spontaneous sharp wave-like events (Fig. 1A). In this context, SWRs emerge as fluctuation-driven transitions from a state dominated by active anti-SWR cells to a state where active PV⁺BCs disinhibit pyramidal cells by suppressing anti-SWR cells. A PV⁺BC-mediated short-term synaptic depression regulates the termination of SWRs. 2) SWRs can be triggered in the network by activating PYR [Stark et al., 2014, Bazelot et al., 2016] (Fig. 1B), by activating PV⁺BCs [Schlingloff et al., 2014] (Fig. 1C), or inactivating anti-SWR cells (this is a prediction of the model, Fig. 1D). The counterintuitive effect of PV⁺ cell stimulation leading to SWRs is due to the disinhibition of PYR via suppression of anti-SWR cells. 3) The model displays spontaneous SWR events with features similar to experimental SWRs, including a strong depression-mediated correlation between SWR amplitude and preceding (but not following) inter-event-interval [Kohus et al., 2016]. 4) For fixed, intermediate values of depression, the network displays bistability. We reduce the spiking network to a mean-field approximation, where conditions for the emergence of a bistable configuration are derived analytically. This approximation decreases the model complexity and sheds light onto the mechanisms regulating the existence of bistable disinhibitory networks. Taken together, our results account for a number of so far mechanistically unexplained experimental findings. Furthermore, we predict the existence of a class of interneurons crucially involved in SWR generation, which could include axo-axonic cells [Viney et al., 2013] and enkephalin-expressing interneurons [Fuentealba et al., 2008].



From top to bottom: raster plots for PYR (red), PV+BCs (blue), and anti-SWR cells (green), population firing rates, strength of the PV+BC-to-anti-SWR cells connection, and band-pass filtered (90–180 Hz) LFP displaying ripple-like oscillations. Yellow bars represent periods of injected current.

Acknowledgements

This work is supported by the BMBF (grant 01GQ1001A), by the DFG (grant GRK1589/2) and by the SFB 1315.

References

- 1 Bazelot, M., Telećzuk, M. T., and Miles, R. (2016). Single CA3 pyramidal cells trigger sharp waves in vitro by exciting interneurons. *Journal of Physiology*, 594(10):2565–2577 [10.1113/JP271644](https://doi.org/10.1113/JP271644)
- 2 Fuentealba, P., Tomioka, R., ..., and Somogyi, P. (2008). Rhythmically active enkephalin-expressing GABAergic cells in the CA1 area of the hippocampus project to the subiculum and preferentially innervate interneurons. *Journal of Neuroscience*, 28(40):10017–10022 [10.1523/JNEUROSCI.2052-08.2008](https://doi.org/10.1523/JNEUROSCI.2052-08.2008)
- 3 Kohus, Z., Káli, S., ..., and Gulyás, A. I. (2016). Properties and dynamics of inhibitory synaptic communication within the CA3 microcircuits of pyramidal cells and interneurons expressing parvalbumin or cholecystokinin. *Journal of Physiology*, 82(6):1496–1514 [10.1113/JP272231](https://doi.org/10.1113/JP272231)
- 4 Schlingloff, D., Káli, S., ..., and Gulyás, A. I. (2014). Mechanisms of sharp wave initiation and ripple generation. *Journal of Neuroscience*, 34(34):11385–11398 [10.1523/JNEUROSCI.0867-14.2014](https://doi.org/10.1523/JNEUROSCI.0867-14.2014)
- 5 Stark, E., Roux, L., ..., and Buzsáki, G. (2014). Pyramidal cell-interneuron interactions underlie hippocampal ripple oscillations. *Neuron*, 83:467–480 [10.1016/j.neuron.2014.06.023](https://doi.org/10.1016/j.neuron.2014.06.023)
- 6 Viney, T. J., Lasztoczi, B., ..., and Somogyi, P. (2013). Network state-dependent inhibition of identified hippocampal CA3 axo-axonic cells in vivo. *Nature Neuroscience*, 16(12):1802–11 [10.1038/nn.3550](https://doi.org/10.1038/nn.3550)

©(2019) Evangelista R, Maier N, Schmitz D, Kempfer R

Cite as: Evangelista R, Maier N, Schmitz D, Kempfer R (2019) Generation of sharp wave-ripple events by disinhibition. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0175](https://doi.org/10.12751/nncn.bc2019.0175)

[T 27] **Hodgkin-Huxley type neuron model for activity-dependent non-synaptic plasticity of leech touch cells**

Sonja Meiser¹, Go Ashida^{1,2}, Jutta Kretzberg^{1,2}

1. *Division Computational Neuroscience, Department of Neuroscience, Carl-von-Ossietzky Str. 9-11 26129 Oldenburg, Germany*

2. *Cluster of Excellence Hearing4all, Department of Neuroscience, Carl-von-Ossietzky Str. 9-11 26129 Oldenburg, Germany*

Effects of Na^+/K^+ -pumps on synaptic plasticity have been described in both vertebrates¹ and invertebrates². Here we provide evidence that Na^+/K^+ -pumps are also involved in activity-dependent non-synaptic plasticity in leech sensory neurons. Our electrophysiological recordings of T cells show a hyperpolarization of the resting membrane potential in response to repeated somatic current injection, while the spike count increases at the same time. To investigate the underlying physiological bases of these changes, we modified a single-compartment Hodgkin-Huxley model with an additional Na^+/K^+ -pump current and a M-type slow potassium current. Our modeling results confirm the hypothesis that repetitive action potential discharges lead to increased pump activity through the accumulation of intracellular Na^+ ions. Increased pump activity then hyperpolarizes the resting membrane potential. In consequence, a slow, non-inactivating current decreases, which is presumably mediated by voltage-dependent, low-threshold potassium channels. In response to the first stimulation pulses, T cells present a bursting behavior. And closing of these M-type K^+ channels due to hyperpolarization results in a larger number of tonic spikes in T cells. While our model reproduces these activity-dependent changes in membrane potential and spiking behavior well, some biophysical aspects of the T cell activity are not captured by the model. We found that our model differs from experimentally measured neuronal responses in the amplitude of the hyperpolarization after each spike. The modeled cell shows a larger hyperpolarization than the real T cell, which might be due to the fact that our single-compartment model ignores the spatial extent of the T cell. If the spike initiation site, responding to somatic stimulation, is not located exactly in the cell body, the recorded somatic spikes may only reflect the propagated action potentials that were generated elsewhere. Previous studies suggested that leech T cells have at least two distinct spike-initiation zones, a peripheral one to convey touch stimuli and a central one to process synaptic inputs within the ganglion^{3,4}. Since this hypothesis is supported also by our experimental results that compared somatic current stimulation and tactile skin stimulation, further modeling studies on the effects of the T cell's spatial structure on its spike activity are needed.

Acknowledgements

We thank Birte Groos for fitting the properties of the single T cell spike within the neuron model.

References

- 1 Wyse, A. T. et al [10.1016/J.PHYSBEH.2003.10.002](https://doi.org/10.1016/J.PHYSBEH.2003.10.002)
- 2 Scuri, R., Mozzachiodi, R. & Brunelli, M. [10.1152/jn.01027.2001](https://doi.org/10.1152/jn.01027.2001)
- 3 Kretzberg, J., Kretschmer, F. & Marin-Burgin, A. [10.1016/j.neucom.2006.10.048](https://doi.org/10.1016/j.neucom.2006.10.048)
- 4 Burgin, a M. & Szczupak, L. [10.1007/s00359-002-0377-8](https://doi.org/10.1007/s00359-002-0377-8)

©(2019) Meiser S, Ashida G, Kretzberg J

Cite as: Meiser S, Ashida G, Kretzberg J (2019) Hodgkin-Huxley type neuron model for activity-dependent non-synaptic plasticity of leech touch cells. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0176](https://doi.org/10.12751/nncn.bc2019.0176)

Behaviour and cognition

[T 28] A Multi-Objective Optimization Algorithm to Generate Unbiased Stimuli Sequences for Cognitive Tasks

Morteza Ansarinia¹, Paul Schrater², Pedro Cardoso-Leite¹

1. Research Unit Education, Culture, Cognition & Society (ECCS), University of Luxembourg, Esch-sur-Alzette, Luxembourg

2. Depts. of Computer Science and Psychology, University of Minnesota, Twin Cities, Minneapolis, MN, USA

Cognitive scientists want to ensure that particular cognitive tasks target particular cognitive functions that can be mapped to stable neural markers. Numerous cognitive tasks, like the n-back, involve generating sequence of trials which satisfy certain statistical properties. The common approach to generate these sequences however lacks a theoretical framework and induces unintentional structure in the sequences which affects both behavioral performance and might bias the people's cognitive strategies when completing a task. For example, people might exploit local properties in a random sequence in their decision making process. We argue that optimized experimental design requires cognitive tasks to be served by stimulus sequence generators that satisfy multiple constraints, both at the global and at the local structures of the sequence and that these sequence properties need to be systematically incorporated in the behavioral data analysis pipeline. We then develop a framework to reformulate the sequence generation process as a compositional soft constraint satisfaction problem and offer a multi-objective, genetic-algorithm-based method to generate controlled sequences under behavioral and neural constraints. This approach provides a systematic and coherent framework to handle stimulus sequences which in turn will impact the insights that can be gained from the behavioral and neural data collected on people performing cognitive tasks using those sequences.

Table 1: Structural Variables (X)

Structural Variables	
x_N	N, number of trials to look back for a target.
x_T	Targets ratio describes the number of target trials in a sequence regardless of the stimulus.
x_S	Skewness is maximum deviation of stimuli frequency from uniform distribution.
x_L	Lures ratio represents the number of distractors which would be targets for $N - 1$ or $N + 1$.
x_V	Vocabulary size is the number of all unique stimuli to be presented.
x_{TL}	Recent targets ratio represents the number of targets in recent trials.
x_{LL}	Local lures ratio describes the number of lures in recent trials.
x_{VL}	Local vocabulary size is the number of unique stimuli presented in recent trials.
x_{UL}	Lumpiness is maximum number of repetitions in a sequence.
x_{SL}	Local skewness is the number of unique items shown in recent trials.
x_g	Gap is the number of trials since the last time same stimulus was appeared.

List of local and global structural variables that need to be controlled simultaneously in n-back task sequences.

Acknowledgements

This research was supported by the Luxembourg National Research Fund: ATTRACT/2016/ID/11242114/DIG-ILEARN and INTER Mobility/2017-2/ID/ 11765868/ULALA.

©(2019) Ansarinia M, Schrater P, Cardoso-Leite P

Cite as: Ansarinia M, Schrater P, Cardoso-Leite P (2019) A Multi-Objective Optimization Algorithm to Generate Unbiased Stimuli Sequences for Cognitive Tasks. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0177](https://doi.org/10.12751/nncn.bc2019.0177)

[T 29] Behavioral architecture : A step towards whole-organism behavioral modeling

Panagiotis Parthenios Sakagiannis¹, Martin Paul Nawrot¹

1. Institute of Zoology, University of Cologne, Zulpicherstrasse 47, 50674 Cologne, Germany

In behavioral neuroscience, model evaluation is based on the successful reproduction of experimental behavioral data. Except if lying close to the output end of the neuromuscular system, models of more upstream circuits have to predict behavior through abstract output metrics, denoting premotor tendencies or control signals (e.g. performance index[1]). This approach boldly assumes that downstream circuits faithfully translate discrete signals into discrete behaviors, not contributing to decision making but rather acting as mere effectors. Though unavoidable when modeling complex intractable nervous systems, this assumption nevertheless contradicts with a decentralized embodied nervous system[2],[3], where higher-order circuits modulate downstream targets rather than rigidly command them, a principle not captured in segregated models of distinct neuropils. To address these shortcomings, a modular “behavioral architecture” is proposed, populating a species-naive cognitive architecture with a species-specific behavioral repertoire. Formalization starts from the more default intrinsic not-stimulus-dependent circuits and their homeostatic modulation, and advances upstream . Each level’s behavioral output is evaluated against experimental data. Therefore any higher order module is superimposed onto the already evaluated lower order ones, both preserving their initial behavioral expression and steering them e.g. towards goal-directed behavior upon salient cue presentation. The framework is in principle realizable for any species for which well-defined behavioral modes can be mapped onto sufficient connectomic evidence [4]-[6]. A real-world implementation is planned for the Drosophila olfactory foraging system. Initially, baseline exploratory and consummatory dynamics will be established, reproducing experimentally derived statistics for exploration [7], [8] and feeding activity bouts [9]. These will be both separately and jointly evaluated across internal states (e.g. starvation-satiation continuum) [10]. On top of these fairly low-level modules, wind-detection sensing will be superimposed [11] integrating a central complex module and making goal-directed behavior feasible. This will allow the addition of the innate olfactory pathway [12], evaluated in odor-preference simulations. Finally, the learned olfactory pathway will be added, implemented as a mushroom body module [13],[14], permitting memory and learning task simulations.

Acknowledgements

P.P.S. receives a stipend from the RTG "Neural Circuit Analysis" (DFG-RTG 1960, grant No. 233886668) funded by the GRF. M.P.N. is supported by the GRF (grant no. 403329959) within the Research Unit 'Structure, Plasticity and Behavioral Function of the Drosophila mushroom body' (FOR 2705).

References

- 1 T. Saumweber et al., “Functional architecture of reward learning in mushroom body extrinsic neurons of larval Drosophila,” Nat. Commun., pp. 1–19, 2018. [10.1038/s41467-018-03130-1](https://doi.org/10.1038/s41467-018-03130-1)

- 2 C. Moulin-Frier, J.-Y. Puigbò, X. D. Arsiwalla, M. Sanchez-Fibla, and P. F. M. J. Verschure, "Em-bodied Artificial Intelligence through Distributed Adaptive Control: An Integrated Framework," eprint arXiv:1704.01407, 2017.
- 3 X. E. Barandiaran, "Autonomy and Enactivism: Towards a Theory of Sensorimotor Autonomous Agency," *Topoi*, vol. 36, no. 3, pp. 409–430, 2017. [10.1007/s11245-016-9365-4](https://doi.org/10.1007/s11245-016-9365-4)
- 4 E. J. Izquierdo and R. D. Beer, "Connecting a Connectome to Behavior: An Ensemble of Neuroanatomical Models of *C. elegans* Klinotaxis," *PLoS Comput. Biol.*, vol. 9, no. 2, 2013. [10.1371/journal.pcbi.1002890](https://doi.org/10.1371/journal.pcbi.1002890)
- 5 J. Ledoux and N. D. Daw, "Surviving threats: Neural circuit and computational implications of a new taxonomy of defensive behaviour," *Nat. Rev. Neurosci.*, vol. 19, no. 5, pp. 269–282, 2018. [10.1038/nrn.2018.22](https://doi.org/10.1038/nrn.2018.22)
- 6 V. G. Fiore, R. J. Dolan, N. J. Strausfeld, and F. Hirth, "Evolutionarily conserved mechanisms for the selection and maintenance of behavioural activity," *Philos. Trans. R. Soc. B Biol. Sci.*, vol. 370, no. 1684, p. 20150053, 2015. [10.1098/rstb.2015.0053](https://doi.org/10.1098/rstb.2015.0053)
- 7 B. Soibam, L. Chen, G. W. Roman, and G. H. Gunnarathne, "Exploratory activity and habituation of *Drosophila* in confined domains," *Eur. Phys. J. Spec. Top.*, vol. 223, no. 9, pp. 1787–1803, 2014. [10.1140/epjst/e2014-02226-7](https://doi.org/10.1140/epjst/e2014-02226-7)
- 8 J. R. Martin, R. Ernst, and M. Heisenberg, "Temporal pattern of locomotor activity in *Drosophila melanogaster*," *J. Comp. Physiol. - A Sensory, Neural, Behav. Physiol.*, vol. 184, no. 1, pp. 73–84, 1999. [10.1007/s003590050307](https://doi.org/10.1007/s003590050307)
- 9 P. M. Itsikov et al., "Automated monitoring and quantitative analysis of feeding behaviour in *Drosophila*," *Nat. Commun.*, vol. 5, 2014. [10.1038/ncomms5560](https://doi.org/10.1038/ncomms5560)
- 10 A. López-Cruz, A. Sordillo, N. Pokala, Q. Liu, P. T. McGrath, and C. I. Bargmann, "Parallel Multimodal Circuits Control an Innate Foraging Behavior," *Neuron*, pp. 1–13, 2019. [10.1016/j.neuron.2019.01.053](https://doi.org/10.1016/j.neuron.2019.01.053)
- 11 M. P. Suver, A. M. M. Matheson, S. Sarkar, M. Damati, D. Schoppik, and K. I. Nagel, "Encoding of Wind Direction by Central Neurons in *Drosophila*," *Neuron*, pp. 1–15, 2019. [10.1016/j.neuron.2019.03.012](https://doi.org/10.1016/j.neuron.2019.03.012)
- 12 M.-J. Dolan et al., "Communication from Learned to Innate Olfactory Processing Centers Is Required for Memory Retrieval in *Drosophila*," *Neuron*, pp. 651–668, 2018. [10.1016/j.neuron.2018.08.037](https://doi.org/10.1016/j.neuron.2018.08.037)
- 13 J. Haenicke, H. Zwaka, and M. Nawrot, "Neural Correlates of Odor Learning in the Presynaptic Microglomerular Circuitry in the Honeybee Mushroom Body Calyx," *eNeuro*, pp. 1–29, 2018. [10.1523/ENEURO.0128-18.2018](https://doi.org/10.1523/ENEURO.0128-18.2018)
- 14 J. Horiochi, "Recurrent loops: Incorporating prediction error and semantic/episodic theories into *Drosophila* associative memory models," *Genes, Brain Behav.*, no. February, p. e12567, 2019. [10.1111/gbb.12567](https://doi.org/10.1111/gbb.12567)

©(2019) Sakagiannis PP, Nawrot MP

Cite as: Sakagiannis PP, Nawrot MP (2019) Behavioral architecture : A step towards whole-organism behavioral modeling. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0178](https://doi.org/10.12751/nncn.bc2019.0178)

[T 30] Binocular rivalry predicts differential perceptual performance in development and dysfunction.

Stepan Aleshin^{1,2}, Gergő Ziman^{3,4}, Ilona Kovács^{3,4}, Jochen Braun^{1,2}

1. Institute of Biology, Otto-von-Guericke University, Leipziger Straße 44, Magdeburg, Germany

2. Center for Behavioral Brain Sciences, Leipziger Straße 44, Magdeburg, Germany

3. Institute of Psychology, Pázmány Péter Catholic University, Mikszáth K. tér 1, Budapest, Hungary

4. HAS-PPCU, Adolescent Development Research Group, Mikszáth K. tér 1, Budapest, Hungary

Multistable reversals reflect a dynamical balance of inhibition (between alternative representations), adaptation (of dominant representations), and intrinsic noise (in each representation). Dynamic modeling of these factors reveals distinct regimes, in which either adaptation is sufficient or noise is necessary for reversals. Here we identify precise dynamical regimes that reproduce the average binocular rivalry statistics of developmental, mature, and patient groups [12, 16, 25, 60 y.o., autism spectrum (ASD) and borderline personality disorder (BPD)]. The results reveal group differences in strength of adaptation, time of adaptation, and noise amplitude. To predict the impact on general perceptual performance, we performed *in silico* experiments to characterize the probability of model reversals in response to randomly fluctuating inputs. Distinguishing two components of 'reversing force' (input and adaptation), we define perceptual 'sensitivity' (probability gain per unit force), perceptual 'variability' (variance of reversal state) and perceptual 'stickiness' (relative contribution of input and adaptation). Thus,

we found two developmental trends, namely, an increase of 'stickiness' and in 'sensitivity' relative to 'variability', from children to adolescents to young adults. These trends are reversed entirely in senior adults. Additionally, the analysis predicts immature perceptual characteristics for ASD patients (less sticky, less sensitive relative to variability), but 'hypermature' characteristics for BPD patients (more sticky and more sensitive relative to variability than young adults). Our approach opens new possibilities in computational psychiatry and exemplifies the power of dynamical models in predicting complex behavior and departures from the norm.

Acknowledgements

We acknowledge support from Deutsche Forschungsgemeinschaft BR987/3 and BR987/4 to JB and from NKFI (Nemzeti Kutatási, Fejlesztési és Innovációs Hivatal) 110466 to IK.

©(2019) Aleshin S, Ziman G, Kovács I, Braun J

Cite as: Aleshin S, Ziman G, Kovács I, Braun J (2019) Binocular rivalry predicts differential perceptual performance in development and dysfunction.. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0179](https://doi.org/10.12751/nncn.bc2019.0179)

[T 31] Computational Models of Chronic Pain

Anna-Lena Eckert^{1,2}, Anna Thorwart³, Tanja Hechler⁴, Dominik Endres³

1. Department of Psychiatry and Psychotherapy, Charité University Clinic, Charitéplatz 1, 10117 Berlin, Germany

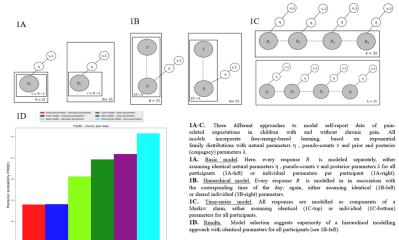
2. Bernstein Center for Computational Neuroscience Berlin, Philippstraße 13, 10115 Berlin, Germany

3. Department of Psychology, Philipps University Marburg, Gutenbergstraße 18, 35032 Marburg, Germany

4. Department of Psychology, University Trier, Universitätsring 15, 54296 Trier, Germany

Pain is ubiquitous in most living creatures and ensures survival through its protective function. Chronic pain, however, is not indicative of imminent threats to physical integrity anymore and burdens millions of patients worldwide. Recent ideas regarding the etiology of chronic pain originate in statistical and computational frameworks. We investigate if pain perception can be viewed as a Bayesian computation, combining prior expectations and current sensory information. Chronic pain might develop over time from unfavorable settings (e.g. increased prior expectation of pain, increased likelihood of pain given sensory input) or events (e.g. repeated exposure to painful stimuli) within this computational process. We describe pain as a posterior state in a probabilistic generative mental model that is used when making sense of incoming sensory information, $P(M_{\text{pain}})$. In chronic pain, this model assigns an aberrantly high prior probability to pain percepts that biases concurrent inference. Additionally, the increased likelihood of perceiving pain given any type of sensory information, $P(M_{\text{pain}}|S)$, could lead to an association between harmless sensations and pain [1]. This would account for the rather common observation of patients reporting pain during low-intensity stimulation that is usually not considered painful by healthy controls. To test this idea, we developed hierarchical Bayesian chronic pain models. In these models, belief-propagation and free-energy learning are implemented to simulate the development towards a state of chronic pain over time. We first tested a 20-step Hidden Markov Model with specific parameter settings for healthy and aberrant processing, respectively. When presented with varying sequences of innocuous and noxious stimuli, the simulations yielded plausible results. The models were fit to survey data of 35 children and adolescents with and without chronic pain who answered questions regarding their pain-related expectations. A model selection was performed to test whether a context- or a time-series model

accounts best for the data (see Fig. 1). Results indicate superiority of a hierarchical model where the expected pain is associated with a certain context or time of day. The described approach adopts a computational perspective on chronic pain. Simulations and a model selection suggest this perspective could be promising to further elucidate the inferential mechanisms underlying this debilitating condition.



Model comparison on pain-related expectations

References

- 1 T. Hechler, D. Endres A. Thorwart: Front. Psychol., 25 October 2016 [10.3389/fpsyg.2016.01638](https://doi.org/10.3389/fpsyg.2016.01638)

©(2019) Eckert A, Thorwart A, Hechler T, Endres D

Cite as: Eckert A, Thorwart A, Hechler T, Endres D (2019) Computational Models of Chronic Pain. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0180](https://doi.org/10.12751/nncn.bc2019.0180)

[T 32] Field-to-field variability of grid cells: A sign of altered burst activity?

Michaela Proell¹, Stefan Haeusler¹, Andreas Herz¹

1. Biologie, LMU Muenchen, Grosshadernerstr. 2 82152 Planegg-Martinsried, Germany

Grid cells in rodent medial entorhinal cortex are thought to play a critical role for spatial navigation. When the animal is freely moving in an open arena the firing fields of each grid cell tend to form a regular hexagonal lattice spanning the environment. Firing rates vary from field to field and are redistributed under contextual modifications, whereas the field locations do not move ("rate remapping"). Such differences in firing rate could result from overall activity changes or hint at altered spike-train statistics. As these two alternatives imply distinct coding schemes, we investigated whether temporal firing patterns change under rate remapping, and focused on short time scales, i.e., burst firing. We found that burst parameters do not explain the representation of nonspatial information in grid-cell rate remapping processes. Furthermore, the proportion of bursts compared to all events is similar in all firing fields of a given grid cell and does not change under rate remapping. As a result, the mean firing rates with and without bursts are proportional for each cell but not across cells. Our analysis indicates that both spatial phenomena, the heterogeneity between firing fields and rate remapping, are not caused by changes in firing behavior on short time scales.

©(2019) Proell M, Haeusler S, Herz A

Cite as: Proell M, Haeusler S, Herz A (2019) Field-to-field variability of grid cells: A sign of altered burst activity?. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0181](https://doi.org/10.12751/nncn.bc2019.0181)

[T 33] **High channel count electrophysiological recordings in prefrontal cortex in a novel spatial memory task.**

Claudia Böhm¹, Albert K Lee¹

1. Janelia Research Campus, HHMI, 19700 Helix Drive, 20147 Ashburn, VA, US

Past research on spatial working memory has largely focused on simple tasks with a binary choice, such as the T-maze. In these tasks, the animal can memorize the location of the goal or the route to the goal from the start location. Such tasks also tend to result in stereotyped behaviors for each goal that may themselves produce goal-associated neural correlates. Thus, the animal's strategy to solve the task and the interpretation of neural correlates can be ambiguous. We have devised a novel spatial memory task where rats are required to flexibly encode three spatially distinct goals on a trial-by-trial basis. The goals can be reached via multiple routes, one of which is available in each trial. Knowledge of the available route is only gained after a delay period in which the animal has to perform a nose poke in one of three randomly chosen start positions. This design forces the animal to memorize the spatial location of the goal instead of planning a route from start position to goal position. This allows us to dissociate between neural correlates of route planning and goal representation. In such cognitively demanding tasks a large population of neurons in several brain regions, including prefrontal areas, are expected to be required to coordinate their activity and encode task-relevant variables and rules. Sampling a sufficiently large number of neurons at high temporal accuracy poses a challenge to current electrophysiological recording technology. Here we have employed Neuropixels probes, a new type of high channel count silicon probe featuring nearly a thousand recording sites along a single 10 mm shank, of which 384 can be recorded simultaneously. The shank spans multiple task-relevant brain regions including anterior cingulate cortex, prelimbic cortex and infralimbic cortex. This technology has allowed us to record activity from 100-200 frontal cortical neurons simultaneously in freely behaving rats performing a complex spatial working memory task. We have found that current spatial location at the start or goal positions can be clearly and unambiguously decoded by the combined firing rates of multiple neurons over a range of timescales, from hundreds of milliseconds to seconds. The intended goal location while the rat is performing the nose poke is not linearly separable in this form. Ongoing analysis is focused on other biologically plausible forms of representation, such as sequences of neural activity or coordinated ensemble activity.

Acknowledgements

We thank R. Gattoni, S. Erwin, J. Chen, J. Arnold, S. Sawtelle, P. Polidoro, B. Karsh, J. Colonell, W. Sun, P.D. Rich, J. Jun, T. Harris, Vidrio, and K. Branson for valuable assistance and comments.

©(2019) Böhm C, Lee AK

Cite as: Böhm C, Lee AK (2019) High channel count electrophysiological recordings in prefrontal cortex in a novel spatial memory task.. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0182](https://doi.org/10.12751/nncn.bc2019.0182)

[T 34] Hippocampal Representation of Cognitive Space in Evidence Accumulation and Decision-making

Edward H Nieh¹, Manuel Schottdorf¹, Nicolas W Freeman¹, Jeff L Gauthier¹, Sue Ann Koay¹, Lucas Pinto¹, Mark L Ioffe¹, David W Tank^{1,2,3}, Carlos D Brody^{1,2,4}

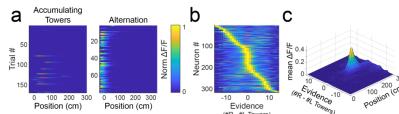
1. Princeton Neuroscience Institute, Princeton University, Princeton, NJ 08544, USA

2. Department of Molecular Biology, Princeton University, Princeton, NJ 08544, USA

3. Bezos Center for Neural Dynamics, Princeton University, Princeton, NJ 08544, USA

4. Howard Hughes Medical Institute, Princeton University, Princeton, NJ 08544, USA

In an ever-changing environment, the ability to accumulate and evaluate evidence is crucial for optimal decision-making. The hippocampus is thought to embody a cognitive map that has historically been well-studied in navigation and foraging tasks, where spatial dimensions are the primary drivers of animal behavior (O'Keefe, 1976; O'Keefe and Burgess, 1996). More recently, hippocampal neurons have been shown to encode other environmental variables, such as time (Pastalkova et al., 2008), odor (Eichenbaum et al., 1987), auditory frequency (Aronov et al., 2017), and even taste (Herzog et al., 2019). However, it is unknown if the hippocampus can encode a complex internally held variable, such as accumulated evidence for an upcoming decision, that isn't explicitly experienced by the animal in the environment. We performed 2-photon imaging in head-fixed mice ($n=7$ mice, $n=3144$ neurons) performing a virtual reality T-maze task, where noisy evidence is accumulated over time to indicate a left or right turn at the end of the maze. Surprisingly, we found that place cells in CA1 showed uncharacteristically unreliable and variable activity in their spatial place fields (Fig. 1a). However, we reveal that inconsistency in neuronal activity in a subpopulation of CA1 neurons can be partially explained by accounting for accumulated evidence (Fig. 1b). These neurons, in this complex cognitive task, jointly encode spatial position and the internally held variable, accumulated evidence, such that place fields form in this shared multidimensional cognitive space, instead of solely in spatial position on the maze (Fig. 1c). Our results suggest that the conceptual framework of the CA1 cognitive map can be extended to internal variables, such as accumulated evidence, and that when task demands require multiple dimensions of thought, the hippocampus multiplexes the activity of CA1 neurons to span a multidimensional cognitive map.



CA1 neurons jointly encode position and evidence in an evidence accumulation task.
 a, CA1 neural activity in the accumulating towers task and alternation task. b, CA1 neurons form sequences through evidence space. c, Example of the average neural activity of a neuron in evidence-by-position space.

Acknowledgements

We would like to acknowledge Stephan Thibierge and Alex Song for their assistance with setting up and using the 2-photon imaging rig.

References

- 1 Aronov, D., Nevers, R., and Tank, D.W. (2017). Mapping of a non-spatial dimension by the hippocampal-entorhinal circuit. *Nature* 543, 719–722. [10.1038/nature21692](https://doi.org/10.1038/nature21692)
- 2 Eichenbaum, H., Kuperstein, M., Fagan, A., and Nagode, J. (1987). Cue-sampling and goal-approach correlates of hippocampal unit activity in rats performing an odor-discrimination task. *J. Neurosci. Off. J. Soc. Neurosci.* 7, 716–732. [10.1523/JNEUROSCI.07-03-00716.1987](https://doi.org/10.1523/JNEUROSCI.07-03-00716.1987)

- 3 Herzog, L.E., Pascual, L.M., Scott, S.J., Mathieson, E.R., Katz, D.B., and Jadhav, S.P. (2019). Interaction of Taste and Place Coding in the Hippocampus. *J. Neurosci.* 39, 3057–3069. [10.1523/JNEUROSCI.2478-18.2019](https://doi.org/10.1523/JNEUROSCI.2478-18.2019)
- 4 O'Keefe, J. (1976). Place units in the hippocampus of the freely moving rat. *Exp. Neurol.* 51, 78–109. [10.1016/0014-4886\(76\)90055-8](https://doi.org/10.1016/0014-4886(76)90055-8)
- 5 O'Keefe, J., and Burgess, N. (2005). The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat. *Brain Res.* 34, 171–175. [10.1016/0006-8993\(71\)90358-1](https://doi.org/10.1016/0006-8993(71)90358-1)
- 6 Pastalkova, E., Itskov, V., Amarasingham, A., and Buzsaki, G. (2008). Internally Generated Cell Assembly Sequences in the Rat Hippocampus. *Science* 321, 1322–1327. [10.1126/science.1159775](https://doi.org/10.1126/science.1159775)

©(2019) Nieh EH, Schottdorf M, Freeman NW, Gauthier JL, Koay SA, Pinto L, Ioffe ML, Tank DW, Brody CD
Cite as: Nieh EH, Schottdorf M, Freeman NW, Gauthier JL, Koay SA, Pinto L, Ioffe ML, Tank DW, Brody CD (2019)
Hippocampal Representation of Cognitive Space in Evidence Accumulation and Decision-making. *Bernstein
Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0183](https://doi.org/10.12751/nncn.bc2019.0183)

[T 35] Idiosyncratic neural coding and neuromodulation of olfactory individuality in *Drosophila melanogaster*

Matthew A Smith^{1,2,3}, Kyle Honneger⁴, Matthew Churgin^{1,2}, Glenn Turner⁵, Benjamin de Bivort^{1,2}

1. Organismal and Evolutionary Biology, Harvard, United States

2. Center for Brain Science, Harvard, United States

3. Molecules, Cells, and Organisms PhD program, Harvard, United States

4. Ann and Robert H. Lurie Children's Hospital of Chicago, United States

5. Janelia Research Campus, Howard Hughes Medical Institution, United States

Innate behavioral biases and preferences can vary significantly among individuals of the same genotype. Though individuality is a fundamental property of behavior, it is not currently understood how individual differences in brain structure and physiology give rise to idiosyncratic behaviors. Here we present evidence for idiosyncrasy in olfactory behavior and neural responses in *Drosophila*. We show that individual female *Drosophila* from a highly inbred lab strain exhibit idiosyncratic odor preferences that persist for days. We leveraged volumetric *in vivo* calcium imaging of neural responses to directly compare projection neuron (second order neurons that convey odor information from the sensory periphery to the central brain) responses to the same odors across animals. We found that, while odor responses appear grossly stereotyped, upon closer inspection, many individual differences are apparent across antennal lobe (AL) glomeruli (compact microcircuits corresponding to different odor channels). To accomplish this we created a semi-automated pipeline to identify the same glomeruli across multiple flies by k-means clustering on volumetric calcium responses and manually sorting. This allowed us to compare the variability of responses to 12 odors in identical glomeruli across flies to understand variability in neural responses in early odor processing. Moreover, we show that neuromodulation, environmental stress in the form of altered nutrition, and the activity of certain AL local interneurons affect the magnitude of inter-fly behavioral variability. We find that measuring variability of behavior, especially in odor context, is inherently noisy, and we found significant day to day and seasonal effects on variability of odor preference. To more accurately estimate how our neural manipulations affect behavior we implemented a bayesian linear modeling framework to estimate uncontrollable environmental effects and determine an estimate for change in variability of behavior. Taken together, this work demonstrates that individual *Drosophila* exhibit idiosyncratic olfactory preferences and idiosyncratic neural responses to odors, and that

behavioral idiosyncrasies are subject to neuromodulation and regulation by neurons in the antennal lobe.

©(2019) Smith MA, Honneger K, Churigin M, Turner G, de Bivort B

Cite as: Smith MA, Honneger K, Churigin M, Turner G, de Bivort B (2019) Idiosyncratic neural coding and neuromodulation of olfactory individuality in *Drosophila melanogaster*. *Bernstein Conference 2019* Abstract.

doi: [10.12751/nncn.bc2019.0184](https://doi.org/10.12751/nncn.bc2019.0184)

[T 36] Induced acute stress reduces reward-seeking in human reinforcement learning

Joana Carvalheiro¹, Ana Mesquita¹, Ana Seara-Cardoso¹

1. Psychology Research Center, University of Minho, Braga, Portugal

Stressful situations are common in everyday life; but, how acute stress affects decision-making is still poorly understood. Previous studies in humans and non-human animals suggest that acute stress influences decision-making via neural mechanisms and circuits involved in reinforcement learning. Yet, the extent to which acute stress impacts human reinforcement learning remains largely unknown and somewhat controversial. Here, we aimed to study the behavioral and computational mechanisms that underpin the effects of acute stress on instrumental learning, using reinforcement learning models. Male participants ($N = 62$) performed a probabilistic instrumental learning task involving monetary gains and losses whilst under acute stress and under control conditions. During the acute stress blocks, participants performed the task while exposed to a constant auditory stimulus, whereas during the control blocks there was no such stressor. Acute stress induction was confirmed by self-report and electrodermal activity. We observed that, relative to control condition, acute stress impaired behavioral performance towards monetary gains, but not to losses. To further understand the nature of this behavioral impairment, we fitted a reinforcement learning model to the behavioral data. Computational modeling revealed that the learning rate for positive feedback was decreased in the acute stress condition comparatively to control condition. In sum, we provide computational evidence that under acute stress individuals incorporate positive information at a lower rate, and that this drives impaired reward-seeking.

©(2019) Carvalheiro J, Mesquita A, Seara-Cardoso A

Cite as: Carvalheiro J, Mesquita A, Seara-Cardoso A (2019) Induced acute stress reduces reward-seeking in human reinforcement learning. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0185](https://doi.org/10.12751/nncn.bc2019.0185)

[T 37] **Language as a tensor**

Kristina Egumenovska¹, Yifan Luo²

1. Department of Psychology, University of Ljubljana, Ljubljana, Slovenia

2. Cognitive Neuroscience, SISSA, Trieste, Italy

In this study we suggest using known facts from language to investigate the nature of computation in the brain, rather than vice-versa. Relying on century-old ideas, we propose a mathematico-logical model which simplifies language only to the level to which it still retains its defining characteristics. Consequently, we define it as a tensor, a multimodal configuration.

Working with language-game data from an EEG experiment, our results are in congruence with major works from the literature and emphasize the importance of fluctuations and latent functional sources consistently across and within subjects.

The purpose of our study was to suggest that the existing gap between two vital, but different research paradigms, such as the neural network approach and the EEG experimental approach, might be integrated through a tensorial dynamic.

Acknowledgements

We are grateful to K.Maranovic and M. Trippa for providing the data-set for the analysis. K.Egumenovska is grateful to A. Treves for hosting her research at SISSA, Cognitive neuroscience lab Liminar Investigations of Memory and Brain Organization.

©(2019) Egumenovska K, Luo Y

Cite as: Egumenovska K, Luo Y (2019) Language as a tensor. *Bernstein Conference 2019 Abstract*.

doi: [10.12751/nncn.bc2019.0186](https://doi.org/10.12751/nncn.bc2019.0186)

[T 38] **Mapping the projectome of the Superior Colliculus to understand visually guided innate behaviors.**

Arnaud Sans Dublanc^{1,2,3}, Anna Chrzanowska^{1,2,3}, Gabriel Montaldo¹, Alan Urban^{1,3,4}, Karl Farrow^{1,2,3}

1. NERF, Kapeldreef 75, Belgium

2. Biology, KU Leuven, Kasteelpark Arenberg 31, Belgium

3. VIB-KU Leuven Center for Brain & Disease Research, Vlaams Instituut voor Biotechnologie (VIB), O&N 4, Herestraat 49, Belgium

4. Neurosciences, KU Leuven, O&N 2, Herestraat 49, Belgium

The Superior Colliculus of mice is a highly organized structure, where sensory modalities are integrated and sent downstream to trigger appropriate innate behaviors (e.g. approach, freezing or escape). However what chain of downstream nuclei are driven by the colliculus to mediate these behaviors is still poorly understood. Our goal is to map the collicular multi-synaptic targets, and uncover how the coordinated activity of the nuclei across the brain relates to specific behavioral responses. To do so, we first optogenetically stimulated collicular cell-types to characterize the evoked behaviors. Secondly, we combined optogenetics with whole brain activity measurements using functional ultrasound imaging (fUSi). Functional data was aligned and co-registered with more than 300 segmented areas of the Allen brain atlas. This allowed us to identify a set of nuclei activated in response to the stimulation of the different collicular cell types, study where the output pathways diverge and converge and how they are related to behavior.

Acknowledgements

This research was funded by Fonds Wetenschappelijk Onderzoek - Vlaanderen (FWO).

©(2019) Sans Dublanc A, Chrzanowska A, Montaldo G, Urban A, Farrow K

Cite as: Sans Dublanc A, Chrzanowska A, Montaldo G, Urban A, Farrow K (2019) Mapping the projectome of the Superior Colliculus to understand visually guided innate behaviors.. *Bernstein Conference 2019 Abstract*.

doi: [10.12751/nncn.bc2019.0187](https://doi.org/10.12751/nncn.bc2019.0187)

[T 39] Modulation of connection strength mediates two mechanisms of mental imagery

Ou Ma¹, Xing Tian²

1. East China Normal University

2. NYU Shanghai

The neural representation can be induced without external stimulation, such as in mental imagery. Our previous study found that imagined speaking and imagined hearing modulated perceptual neural responses in opposite directions, suggesting motor-to-sensory transformation and memory retrieval as two separate routes that induce auditory representation (Tian & Poeppel, 2013). We hypothesized that the precision of representation induced from different types of speech imagery led to different modulation effects. Specifically, we predicted that the one-to-one mapping between motor and sensory domains established during speech production would evoke a more precise auditory representation in imagined speaking than retrieving the same sounds from memory in imagined hearing. To test this hypothesis, we built the function of representational precision as the modulation of connection strength in a neural network model. The model fitted the MEG imagery repetition effects, and the best-fitting parameters showed sharper tuning after imagined speaking than imagined hearing, consistent with the representational precision hypothesis. Moreover, this model predicted that different types of speech imagery would affect perception differently. In an imagery-adaptation experiment, the categorization of /ba/-/da/ continuum from male and female human participants showed more positive shifts toward the preceding imagined syllable after imagined speaking than imagined hearing. These consistent simulations and behavioral results support our hypothesis that distinct mechanisms of speech imagery construct auditory representation with varying degrees of precision and differentially influence auditory perception. This study provides a mechanistic connection between neural-level activity and psychophysics that reveals the neural computation of mental imagery.

Acknowledgements

This work was supported by the National Natural Science Foundation of China 31871131, Major Program of Science and Technology Commission of Shanghai Municipality (STCSM) 17JC1404104, and Program of Introducing Talents of Discipline to Universities, Base B16018.

References

- 1 Tian, X., & Poeppel, D. (2013). The effect of imagination on stimulation: the functional specificity of efference copies in speech processing. *Journal of Cognitive Neuroscience*, 25(7), 1020-1036.

©(2019) Ma O, Tian X

Cite as: Ma O, Tian X (2019) Modulation of connection strength mediates two mechanisms of mental imagery. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0188](https://doi.org/10.12751/nncn.bc2019.0188)

[T 40] **Neuronal dynamics to navigate vowel space**

Mohammadreza Soltanipour^{1,2}, Zeynep Kaya³, Alessandro Treves^{3,4}

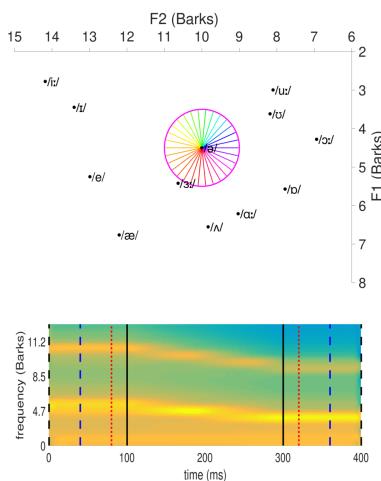
1. *Neural Computation Laboratory, Center for Neuroscience and Cognitive Systems @UniTn, Istituto Italiano di Tecnologia, 38068 Rovereto (TN), Italy*

2. *Center for Mind/Brain Sciences, University of Trento, 38068 Rovereto, Italy*

3. *Cognitive Neuroscience, SISSA—International School for Advanced Studies, Via Bonomea 265, 34136 Trieste, Italy*

4. *Kavli Institute for Systems Neuroscience/Centre for Neural Computation, Norwegian University of Science and Technology, 7491 Trondheim, Norway*

The discovery of Grid Cells has suggested that the rodent brain employs a universal metric to navigate at least flat environments, based on the hexagonal representation of 2D spaces expressed by these cells (Moser et al., 2008). Finding similar cells in other species, e.g. in bats (Yartsev et al., 2011), has raised the question of whether similar mechanisms underlie human spatial navigation. In a human fMRI study, Doeller et al., 2010, participants were asked to explore a 2D virtual environment while cortical activity was being imaged. Interestingly, as a function of virtual movement direction, the BOLD signal showed a six-fold rotational symmetry; which was taken to support the existence of grid-like mechanisms for (virtual) spatial navigation in humans. In a recent study, Constantinescu et al., 2016, the authors claimed that the representation of a more abstract space also shows a grid-like symmetry. In their research, participants were asked to explore a 'conceptual space' where the leg and neck length of the drawing of a bird were continuously morphed, as if along two orthogonal dimensions. The recorded fMRI signal during this task was shown to be modulated by the morphing direction with a 6-fold periodicity, which supported their hypothesis. In our study we tried to test this conceptual grid-like symmetry in humans who 'navigate' between vowels, given that vowel space can be approximated with a continuous trapezoidal 2D plane spanned by the first and second formant frequencies. We created 30 vowel trajectories in the assumedly flat central portion of the trapezoid. Each of these trajectories had a duration of 240 milliseconds with a steady start and end point on the perimeter of a 'wheel'. We supposed that if the neural representation of this plane is similar to that of rodent grid units, there should be a hexagonal symmetry in the EEG response of participants who were navigating this plane. We did not find any dominant n-fold symmetry but instead, using PCAs, we found indications that the vowel representation may reflect phonetic features, as positioned on the vowel plane. The suggestion, therefore, is that vowels are encoded by their sensory-perceptual variables, and are not assigned to arbitrary grid-like abstract maps. Finally, the relationship between the first PCA eigenvector and putative vowel attractors was explored.



Top: 30 vowel trajectories created in the central region of vowel space based on the first and second formant frequencies in Bark scale. Bottom: an example of vowel trajectory (between red dashed lines) on the vowel wheel with two steady parts and one dynamic part.

Acknowledgements

Funded by Human Frontier Science Program RGP0057/2016

References

- 1 Moser, E. I., Kropff, E., and Moser, M.-B. (2008). Place cells, grid cells, and the brain's spatial representation system. *Annual Review Neuroscience*, 31:69–89 [10.1146/annurev.neuro.31.061307.090723](https://doi.org/10.1146/annurev.neuro.31.061307.090723)
- 2 Yartsev, M. M., Witter, M. P., and Ulanovsky, N. (2011). Grid cells without theta oscillations in the entorhinal cortex of bats. *Nature*, 479(7371):103–107 [10.1038/nature10583](https://doi.org/10.1038/nature10583)
- 3 Doeller, C. F., Barry, C., and Burgess, N. (2010). Evidence for grid cells in a human memory network. *Nature*, 463:657–661 [10.1038/nature08704](https://doi.org/10.1038/nature08704)
- 4 Constantinescu, A. O., O'Reilly, J. X., and Behrens, T. E. J. (2016). Organizing conceptual knowledge in humans with a gridlike code. *Science*, 352(6292):1464–1468 [10.1126/science.aaf0941](https://doi.org/10.1126/science.aaf0941)

©(2019) Soltanipour M, Kaya Z, Treves A

Cite as: Soltanipour M, Kaya Z, Treves A (2019) Neuronal dynamics to navigate vowel space. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nnncn.bc2019.0189](https://doi.org/10.12751/nnncn.bc2019.0189)

[T 41] Simple associative learning accounts for the rich dynamics of an operant extinction learning task

José R. Donoso¹, Zhiyin Lederer¹, Julian Packheiser², Roland Pusch², Thomas Walther¹, Onur Güntürkün², Sen Cheng¹

1. Institut für Neuroinformatik, Ruhr-Universität Bochum, Universitätstr. 150, 44801 Bochum, Germany

2. Biopsychologie, Ruhr-Universität Bochum, Iniversitätstr. 150, 44801 Bochum, Germany

Extinction Learning (EL) is the process of changing a previously acquired behaviour as a result of altered reinforcement contingencies, such as the withholding of reinforcements for a previously reinforced behavior. EL is specific to the context in which it occurred, as evidenced by the so-called renewal of the extinguished behaviour after returning to the original context of acquisition (ABA renewal). Typically, changes in behaviour are quantified by comparing post to pre-training blocks. To this end, data are pooled and averaged across many sessions and subjects. Such analysis obscures not only differences across subjects but also changes within single sessions. Here, we report the stunning diversity of learning curves exhibited by pigeons in an operant conditioning task, and offer a simple model that can account for such diversity. Pigeons underwent several sessions, each of which consisted of three phases. In the initial acquisition phase, under context A, animals had to learn to associate two session-unique novel visual stimuli with either a left or a right-peck response, where food was delivered after every correct choice. In the subsequent extinction phase, under either a context B1 or B2, one of the novel stimulus-response associations was no longer rewarded. Once pigeons stopped choosing the associated behaviour, the test phase began with a return to context A, keeping the extinguished association unrewarded. Throughout the session, pigeons were additionally presented with two familiar stimuli that underwent no change in their rewarding contingency. Within single sessions, individual learning curves exhibited a wide repertoire of dynamics, expressing several combinations of different features such as persistent selection of unrewarded responses, abrupt transitions of choice upon onset of the extinction context, and absence and reappearance of the renewal effect, among others. These complex behaviours appear to be strategic and to rely on higher-order cognitive functions. However, using a computational model, we show that simple sensorimotor associations and a winner-takes-all decision process can account for most of the peculiar features observed in the behaviour. The model suggests that the complexity of behaviour stems from the associative history of context and pecking sides within and across sessions. In conclusion, our work demonstrates how studying the learning dynamics can reveal previously unappreciated nuances in the behaviour.

Acknowledgements

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – project number project number 316803389 – SFB 1280, projects F01, A01 and A14.

©(2019) Donoso JR, Lederer Z, Packheiser J, Pusch R, Walther T, Güntürkün O, Cheng S

Cite as: Donoso JR, Lederer Z, Packheiser J, Pusch R, Walther T, Güntürkün O, Cheng S (2019) Simple associative learning accounts for the rich dynamics of an operant extinction learning task. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0190](https://doi.org/10.12751/nncn.bc2019.0190)

[T 42] Updating of priors in magnitude estimation

Nancy B Schmidt¹, Kay Thurley^{1,2}

1. Dept Bio II, LMU Munich, Germany

2. BCCN Munich, Germany

Behavior relies on the combination of current sensory information with expectations based on prior knowledge. In particular in magnitude estimation, such an interaction between immediate and prior experience has been suggested to implement an error minimization strategy that results in characteristic biases namely central tendency or regression effects (the overestimation of small stimuli and the underestimation of large stimuli). Despite numerous reports in line with such an interpretation, it remains unclear how priors are acquired and updated when stimulus conditions change.

We conducted duration reproduction experiments with human participants in which we first provided durations between 2 and 3.5 seconds. Later in the same session, we shifted to longer durations without cueing when the shift happened. Responses for longer durations were in line with previous reports and could be predicted by a computational model of magnitude estimation. Most notably, regression effects became more pronounced for longer durations and the increase in regression depended on the size of shift of the duration range. Both effects indicate optimal combination of sensory evidence and prior experience. Surprisingly, regression effects were reduced for a couple of trials briefly after the shift. This suggests that mainly immediate sensory information was exploited after a shift in the stimulus range and only later weight was readjusted to allow for the combination with prior experience.

Altogether we show that the simple notion is not true that with weak sensory evidence, mostly past experience is used for driving behavior and only strong sensory evidence can dominate past experience. The weighting between both sources of information does not simply depend on their uncertainty but the current behavioral demands to allow for efficient updating of prior knowledge when necessary.

©(2019) Schmidt NB, Thurley K

Cite as: Schmidt NB, Thurley K (2019) Updating of priors in magnitude estimation. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0191](https://doi.org/10.12751/nncn.bc2019.0191)

Data analysis, machine learning, neuroinformatics

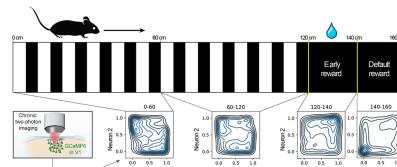
[T 43] Parametric copula models reveal neuronal and behavioral time-dependent relationships in primary visual cortex

Nina Kudryashova¹, Theoklitos Amvrosiadis², Nathalie Dupuy², Nathalie Rochefort², Arno Onken¹

¹. School of Informatics, University of Edinburgh, 10 Crichton St, Edinburgh EH8 9AB, United Kingdom

². Centre for Discovery Brain Sciences, University of Edinburgh, George Square, Edinburgh EH8 9XD, United Kingdom

Recent research in neuroscience shows that neural responses to stimuli are strongly modulated by behavioral context even as early as in primary sensory cortical areas [1, 2]. Many research groups reported alteration in the activity of the primary visual cortex in response to the running speed [3, 4], whisking [5, 6], arousal [7, 8], and even to more subtle and spontaneous face movements [2]. Such mixing of behavioral and sensory data appears to be beneficial for choosing the best action in a given situation and might explain the amazing versatility of sensory processing. Nonetheless, the precise functional interactions underlying behavioral modulation of sensory inputs remain unknown. The unbiased analysis of this modulation proves to be challenging due to the different statistics (e.g. discrete licks or neuronal spikes vs. continuous velocity or calcium signals) and different timescales of the observed variables. In order to overcome these hurdles, we propose parametric copula models with time-varying parameters, which separate the statistics of the variables from their dependence structure. For model fitting, we use Gaussian Process latent variable inference schemes, which are naturally suited to take into account different timescales. Therefore, the doubly stochastic copula approach with underlying temporal profiles provides a complete probabilistic model of the involved joint variables. We applied our model to two-photon calcium imaging data of neuronal populations in the primary visual cortex of awake behaving mice performing a spatial navigation task in a virtual reality setup. We have found pairs of variables showing strong non-trivial changes in the dependence structure subject to the position in the virtual reality and related visual information (see Figure 1). Our preliminary findings agree with previous studies, showing that beyond independent responses, functional connectivity carries additional visual information [9-11]. However, contrary to other commonly applied methods, our parametric copula-based approach makes stochastic relationships explicit and generates interpretable models of dependencies between neural responses, visual stimuli, and behavior.



Example dependence structure for a pair of neurons subject to the position in the virtual reality environment. Top: the pattern on the walls in the virtual reality corridor with labeled early and default reward zones (as in [1]); bottom: dependence structures with uniform marginal distributions.

Acknowledgements

This work was supported by the Engineering and Physical Sciences Research Council (grant EP/S005692/1) and by the Wellcome Trust and the Royal Society (Sir Henry Dale fellowship to N.R.).

References

- 1 Pakan, J. M., Lowe, S. C., Dylda, E., Keemink, S. W., Currie, S. P., Coutts, C. A., & Rochefort, N. L. (2016). Behavioral-state modulation of inhibition is context-dependent and cell type specific in mouse visual cortex. *Elife*, 5, e14985. [10.7554/eLife.14985](https://doi.org/10.7554/eLife.14985)
- 2 Stringer, C., Pachitariu, M., Steinmetz, N., Reddy, C. B., Carandini, M., & Harris, K. D. (2019). Spontaneous behaviors drive multidimensional, brain-wide population activity. *Science*, 364, 255. [10.1126/science.aav7893](https://doi.org/10.1126/science.aav7893)
- 3 Niell, C. M., & Stryker, M. P. (2010). Modulation of visual responses by behavioral state in mouse visual cortex. *Neuron*, 65(4), 472-479. [10.1016/j.neuron.2010.01.033](https://doi.org/10.1016/j.neuron.2010.01.033)
- 4 Dipoppa, M., Ranson, A., Krumin, M., Pachitariu, M., Carandini, M., & Harris, K. D. (2018). Vision and locomotion shape the interactions between neuron types in mouse visual cortex. *Neuron*, 98(3), 602-615. [10.1016/j.neuron.2018.03.037](https://doi.org/10.1016/j.neuron.2018.03.037)
- 5 de Kock, C. P., & Sakmann, B. (2009). Spiking in primary somatosensory cortex during natural whisking in awake head-restrained rats is cell-type specific. *Proceedings of the National Academy of Sciences*, 106(38), 16446-16450. [10.1073/pnas.0904143106](https://doi.org/10.1073/pnas.0904143106)
- 6 Bennett, C., Arroyo, S., & Hestrin, S. (2013). Subthreshold mechanisms underlying state-dependent modulation of visual responses. *Neuron*, 80(2), 350-357. [10.1016/j.neuron.2013.08.007](https://doi.org/10.1016/j.neuron.2013.08.007)
- 7 Vinck, M., Batista-Brito, R., Knoblich, U., & Cardin, J. A. (2015). Arousal and locomotion make distinct contributions to cortical activity patterns and visual encoding. *Neuron*, 86(3), 740-754. [10.1016/j.neuron.2015.03.028](https://doi.org/10.1016/j.neuron.2015.03.028)
- 8 Reimer, J., McGinley, M. J., Liu, Y., Rodenkirch, C., Wang, Q., McCormick, D. A., & Tolias, A. S. (2016). Pupil fluctuations track rapid changes in adrenergic and cholinergic activity in cortex. *Nature communications*, 7, 13289. [10.1038/ncomms13289](https://doi.org/10.1038/ncomms13289)
- 9 Granot-Atedgi, E., Tkačik, G., Segev, R., & Schneidman, E. (2013). Stimulus-dependent maximum entropy models of neural population codes. *PLoS computational biology*, 9(3), e1002922. [10.1371/journal.pcbi.1002922](https://doi.org/10.1371/journal.pcbi.1002922)
- 10 Pillow, J. W., Shlens, J., Paninski, L., Sher, A., Litke, A. M., Chichilnisky, E. J., & Simoncelli, E. P. (2008). Spatio-temporal correlations and visual signalling in a complete neuronal population. *Nature*, 454(7207), 995. [10.1038/nature07140](https://doi.org/10.1038/nature07140)
- 11 Stevenson, I. H., Rebescu, J. M., Miller, L. E., & Kording, K. P. (2008). Inferring functional connections between neurons. *Current opinion in neurobiology*, 18(6), 582-588. [10.1016/j.conb.2008.11.005](https://doi.org/10.1016/j.conb.2008.11.005)

©(2019) Kudryashova N, Amvrosiadis T, Dupuy N, Rochefort N, Onken A

Cite as: Kudryashova N, Amvrosiadis T, Dupuy N, Rochefort N, Onken A (2019) Parametric copula models reveal neuronal and behavioral time-dependent relationships in primary visual cortex. *Bernstein Conference 2019* Abstract.

doi: [10.12751/nncn.bc2019.0192](https://doi.org/10.12751/nncn.bc2019.0192)

[T 44] PECLIDES Neuro - A Personalisable Clinical Decision Support System for Neurological Diseases

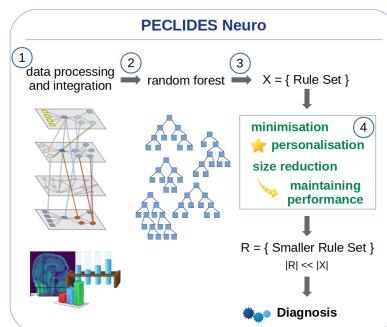
Tamara Tina Müller¹, Pietro Lio^{1*}

¹ Computer Science and Technology, University of Cambridge, William Gates Building JJ Thomson Avenue Cambridge. CB3 0FD, United Kingdom

Neurodegenerative diseases such as Alzheimer's and Parkinson's impact millions of people worldwide. Early diagnosis has proven to greatly increase the chances of slowing down the diseases' progression. Correct diagnosis often relies on the analysis of large amounts of patient data, and thus lends itself well to support from machine learning algorithms, which are able to learn from past diagnosis and see clearly through the complex interactions of a patient's symptoms. Unfortunately, many contemporary machine learning techniques fail to reveal details about how they reach their conclusions, a property considered fundamental when providing a diagnosis. This is one reason why we introduce our Personalisable Clinical Decision Support System PECLIDES, which provides a clear insight into the decision making process on top of the diagnosis. Our algorithm enriches the fundamental work of Masheyekhi and Gras [1] in data integration, personal medicine, usability, visualisation and interactivity.

PECLIDES is an operation of translational medicine. It is based on random forests, is personalisable and allows a clear insight into the decision making process. A well-structured rule set is created and every rule of the decision making process can be observed by the user (physician). Furthermore, the user has an impact on the creation of the final rule set and the algorithm allows the comparison of different diseases as well as regional differences in the same disease. The algorithm can be divided into three major steps. (1) Firstly, a random forest, an ensemble of decision trees, is created that builds the foundation of the algorithm. (2) Secondly, a set of rules is extracted from the random forest. (3) And thirdly, this rule set is reduced using different algorithms. The third step includes the personalisable aspects, where as important considered features can be preferred within the rule set. The algorithm is implemented in Python and we trained it to predict whether patients are likely to suffer from Alzheimer's or Parkinson's disease. But PECLIDES is a generic algorithm that can be applied to any kind of disease.

A graphical user interface allows the algorithm to be used easily. Data of a new patient can be added intuitively and the most likely diagnosis will be shown. Furthermore all rules of the minimised rule set can be printed and inspected by the user.



Main steps of the algorithm PECLIDES: (1) data processing and integration, (2) building and training a random forest, (3) extracting rule set, and (4) minimising the rule set while keeping a high performance and allowing personalisation

References

- 1 [1] [10.1007/978-3-319-18356-5_20](https://doi.org/10.1007/978-3-319-18356-5_20)
- 2

©(2019) Müller TT, Lio' P

Cite as: Müller TT, Lio' P (2019) PECLIDES Neuro - A Personalisable Clinical Decision Support System for Neurological Diseases. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0193](https://doi.org/10.12751/nncn.bc2019.0193)

[T 45] Predicting synchronous firing of large neural populations from sequential recordings

Oleksandr Sorochynskyi¹, Stephane Deny², Olivier Marre¹, Ulisse Ferrari¹

1. Sorbonne Université, Institut de la Vision, 17 rue Moreau, 75012, Paris, France

2. Stanford University, Neural Dynamics and Computation Lab, 450 Serra Mall, Stanford, CA 94305, USA

A major goal in neuroscience is to understand how populations of neurons code for stimuli or actions. While the number of neurons that can be recorded simultaneously is increasing at a fast pace, in most cases these recordings cannot access a complete population: some neurons that carry relevant information remain unrecorded. In particular, it is hard to simultaneously record all the neurons of the same type in a given area. Recent progress have made possible to profile each recorded neuron in a given area thanks to genetic and physiological tools, and to pool together recordings from neurons of the same type across different experimental sessions. However, it is unclear how to infer the activity of a full population of neurons of the same type from these sequential recordings. Neural networks exhibit collective behaviour, e.g. noise correlations and synchronous activity, that are not directly captured by a conditionally-independent model that would just put together the spike trains from sequential recordings. Here we show that we can infer the activity of a full population of retina ganglion cells from sequential recordings, using a novel method based on copula distributions and maximum entropy modeling. From just the spiking response of each ganglion cell to a repeated stimulus, and a few pairwise recordings, we could predict the noise correlations using copulas, and then the full activity of a large population of ganglion cells of the same type using maximum entropy modeling. Remarkably, we could generalize to predict the population responses to different stimuli and even to different experiments. We could therefore use our method to construct a very large population merging cells' responses from different experiments. We predicted synchronous activity accurately and showed it grew substantially with the number of neurons. This approach is a promising way to infer population activity from sequential recordings in sensory areas.

Acknowledgements

We like to thank M. Chalk and G. Tkacik for useful discussions.

©(2019) Sorochynskyi O, Deny S, Marre O, Ferrari U

Cite as: Sorochynskyi O, Deny S, Marre O, Ferrari U (2019) Predicting synchronous firing of large neural populations from sequential recordings. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0194](https://doi.org/10.12751/nncn.bc2019.0194)

[T 46] PyDCM: a Python package for Dynamic Causal Modeling

Thiago Marques de Melo^{1,2}, Jürgen Hennig¹

1. Dept.of Radiology, Medical Physics, University Medical Center Freiburg, Germany

2. Spemann Graduate School of Biology and Medicine (SGBM), University of Freiburg, Germany

Dynamic Causal Modeling [1] is a biophysical framework that links dynamical system models, describing hidden neural states, to observed responses, such as measured blood-oxygen-level-dependent (BOLD) signals from functional Magnetic Resonance Imaging (fMRI). It employs Bayesian statistical inference on generative models of observed signals, which includes estimation of parameters that describe effective connectivity between neural populations. Its reference implementation is part of Statistical Parametric Mapping (SPM) [2], an open source software package for MATLAB (The MathWorks). SPM is also provided in a standalone form that doesn't require a MATLAB license. However, this standalone version is limited to core modules, precluding its extension with new DCM models.

In this work, we provide a Python implementation of DCM, called PyDCM (<https://github.com/tmdemelo/pydcm>). It aims to be more accessible, portable, and increase the reproducibility of DCM analyses and simulations. Currently, it includes the single [1] and two state [3] neuronal models of DCM from the most recent reference implementation, SPM12, as well as routines for estimation of DCM parameters from BOLD fMRI signals and corresponding generative model. In addition, we implemented the physiologically informed DCM model described by Havlicek et al. [4]. PyDCM is under active development and, even though not yet optimized for performance, performs model estimation at the same order of magnitude of time as the reference implementation. It might be further optimized with the use of Numba [5], application of sparse matrices and optimized libraries such as Intel MKL. Planned features include implementation of a NeuroML format for DCM and leveraging variational inference algorithms from PyMC3 [6] for model estimation.

References

- 1 K.J. Friston, L. Harrison, and W. Penny. Dynamic causal modelling. *NeuroImage*, 19(4):1273-1302, 2003. [10.1016/s1053-8119\(03\)00202-7](https://doi.org/10.1016/s1053-8119(03)00202-7)
- 2 Statistical parametric mapping. [Accessed: 02- Jul- 2019]
- 3 A.C. Marreiros, S.J. Kiebel, and K.J. Friston. Dynamic causal modelling for fmri: a two-state model. *NeuroImage* , 39(1):269-278, 2008. [10.1016/j.neuroimage.2007.08.019](https://doi.org/10.1016/j.neuroimage.2007.08.019)
- 4 Martin Havlicek, Alارد Roebroek, Karl Friston, Anna Gardumi, Dimo Ivanov, and Kamil Uludag. Physiologically informed dynamic causal modeling of fmri data. *NeuroImage*, 122(15):355-372, 2015. [10.1016/j.neuroimage.2015.07.078](https://doi.org/10.1016/j.neuroimage.2015.07.078)
- 5 Numba: A High Performance Python Compiler. [Accessed: 02- Jul- 2019]
- 6 J. Salvatier, T.V. Wiecki, and C. Fonnesbeck. Probabilistic programming in Python using PyMC3. *PeerJ Computer Science* 2:e55, 2016 [10.7717/peerj-cs.55](https://doi.org/10.7717/peerj-cs.55).

©(2019) Marques de Melo T, Hennig J

Cite as: Marques de Melo T, Hennig J (2019) PyDCM: a Python package for Dynamic Causal Modeling. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0195](https://doi.org/10.12751/nncn.bc2019.0195)

[T 47] Refining an Intelligent Look-Ahead Toolset for Clinical Neurology that employs robust and flexible computational brain function network models

Martin Joseph Dudziak¹

1. Technology, Informatics and Education, Memorial Healthcare Institute for Neurosciences and Multiple Sclerosis, Owosso, Michigan, USA

A challenge in the practice of treating many neurological disorders, particularly those involving progressive autoimmune pathology dynamics with concomitant often severe cognitive and emotional dysfunction, such as multiple sclerosis, Alzheimer's and Parkinson's, is mapping the degenerative processes and predicting next-stage likely progression, remission or stasis in the disease. Furthermore, interpretation of lesion damage, for instance within MS, can be compounded by the difficulty in assessing functional deterioration in relation to observed MRI, MEG, EEG, and other established clinical-practice observables. Decisions for change in medication, particularly pharmacological agents with substantive side-effect and contraindication risks, and strongly for treatments of depression and behavioral disorders, can be aided through incorporating, directly into the clinical assessment process, multiple and even competing brain activity network dynamic models. We review the progress over the past decade in particular and describe the architecture and integrative functions of NIAM (Neuroscience Interactive Assessment Module), an clinical + research resource currently in development and testing. NIAM employs a suite of machine-learning and human-machine-interface algorithms that enable mapping clinical observations with dynamic computational connectome-based functional models.

©(2019) Dudziak MJ

Cite as: Dudziak MJ (2019) Refining an Intelligent Look-Ahead Toolset for Clinical Neurology that employs robust and flexible computational brain function network models. *Bernstein Conference 2019 Abstract.*
doi: [10.12751/nncn.bc2019.0196](https://doi.org/10.12751/nncn.bc2019.0196)

[T 48] Slow Waves Analysis Pipeline for extracting features of slow oscillations from the cerebral cortex of anesthetized mice

Giulia De Bonis¹, Miguel Dasilva², Antonio Pazienti³, Maria Victoria Sanchez-Vives², Maurizio Mattia³, Pier Stanislao Paolucci¹

1. Istituto Nazionale di Fisica Nucleare (INFN) - Sezione di Roma, P.le Aldo Moro 2, Roma, Italy

2. Institut d'Investigacions Biomèdiques August Pi i Sunyer (IDIBAPS), Carrer del Rosselló, Barcelona, Spain

3. Istituto Superiore di Sanità (ISS), Viale Regina Elena 299, Roma, Italy

Cortical slow oscillations are an emergent property of the cortical network that integrate connectivity and physiological features. This rhythm, highly revealing of the characteristics of the underlying dynamics, is a hallmark of low complexity brain states like sleep, and represents a default activity pattern [1]. Here, we present a methodological approach for quantifying the spatial and temporal properties of this emergent activity. We improved and enriched a robust analysis procedure that has already been successfully applied to both in vitro and in vivo data acquisitions [2]. We tested the new tools of the methodology by analyzing the electrocorticography (ECoG) traces recorded from a custom 32-channel multi-electrode array in wild-type isoflurane-anesthetized mice [3].

The enhanced analysis pipeline, named SWAP (Slow Waves Analysis Pipeline), detects Up and Down states, enables the characterization of the spatial dependency of their statistical properties, and supports the comparison of different subjects. The SWAP is implemented in a data-independent way, allowing its application to other data sets (acquired from different subjects, or with different recording tools), as well as to the outcome of numerical simulations. By using SWAP, we report statistically significant differences in the observed slow oscillations (SO) across cortical areas and cortical sites. Computing cortical maps by interpolating the features of SO acquired at the electrode positions, we give evidence of gradients at the global scale along an oblique axis directed from fronto-lateral towards occipito-medial regions, further highlighting some heterogeneity within cortical areas. The results obtained using SWAP will be essential for producing data-driven brain simulations [4]. A spatial characterization of slow oscillations will also trigger a discussion on the role of, and the interplay between, the different regions in the cortex, improving our understanding of the mechanisms of generation and propagation of delta rhythms and, more generally, of cortical properties. The work here presented has been released as a Pre-Print [5].

Acknowledgements

This study was carried out in the framework of the Human Brain Project (<https://www.humanbrainproject.eu/en/>), funded under Specific Grant Agreements No. 785907 (HBP SGA2) and No. 720270 (HBP SGA1), in particular within activities of sub-project SP3 ("Systems and Cognitive Neuroscience")

References

- 1 Sanchez-Vives MV, Massimini M, Mattia M. Shaping the default activity pattern of the cortical network [10.1016/j.neuron.2017.05.015](https://doi.org/10.1016/j.neuron.2017.05.015)
- 2 Ruiz-Mejias M, Ciria-Suarez L, Mattia M, Sanchez-Vives MV. Slow and fast rhythms generated in the cerebral cortex of the anesthetized mouse. [10.1152/jn.00440.2011](https://doi.org/10.1152/jn.00440.2011)
- 3 Pazzini L, Polese D, Weinert JF, Maiolo L, Maita F, Marrani M, et al. An ultra-compact integrated system for brain activity recording and stimulation validated over cortical slow oscillations *in vivo* and *in vitro*. [10.1038/s41598-018-34560-y](https://doi.org/10.1038/s41598-018-34560-y)
- 4 Pastorelli E, Paolucci PS, Simula F, Biagioni A, Capuani F, Cretaro P, et al. Gaussian and exponential lateral connectivity on distributed spiking neural network simulation [10.1109/PDP2018.2018.00110](https://doi.org/10.1109/PDP2018.2018.00110)
- 5 arXiv:1902.08599 [q-bio.NC]

©(2019) De Bonis G, Dasilva M, Pazienti A, Sanchez-Vives MV, Mattia M, Paolucci PS

Cite as: De Bonis G, Dasilva M, Pazienti A, Sanchez-Vives MV, Mattia M, Paolucci PS (2019) Slow Waves Analysis Pipeline for extracting features of slow oscillations from the cerebral cortex of anesthetized mice. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0197](https://doi.org/10.12751/nncn.bc2019.0197)

[T 49] Sparse reduced-rank regression for visualisation of Patch-seq recordings in mouse motor cortex

Yves Bernaerts^{1,2,3}, Dmitry Kobak^{1,2}, Federico Scala⁴, Jesus Castro⁴, Philipp Berens^{1,2,3}, Andreas S. Tolias⁴

1. Bernstein Centre for Computational Neuroscience, Tübingen, Germany

2. Center of Integrative Neuroscience, University of Tübingen, Otfried-Müller-Str. 25 72076 Tübingen, Germany

3. International Max Planck Research Schools for Intelligent Systems, Max Planck Institute, Tübingen, Germany

4. Department of Neuroscience, Baylor College of Medicine, One Baylor Plaza, 77030 Houston, Texas, USA

The mammalian neocortex is divided in several layers, each performing different computations and consisting of a wide variety of cell types. A complete census of the cell types based on their morphology, electrophysiology (e-phys) and transcriptome has so far remained difficult to establish. A recently developed method called Patch-seq allows performance of e-phys recordings of a neuron using patch-clamp, extraction and sequencing of its RNA content, and recovering its morphology from a biocytin staining; thus, obtaining multimodal characterisation of single neurons. Here, we used sparse reduced-rank regression (sRRR) to obtain a visualisation of the relationship between the transcriptomic data and the electrophysiological properties of neurons in adult mouse motor cortex (M1), using a data set of >1000 neurons spanning all layers and cell types. SRRR constructs a low-dimensional mapping representing latent features of the transcriptomic data and revealing a small set of genes that are useful to predict variation in the electrophysiological space. In this data set, sRRR was able to visualize the differences and the relationships between cell types in a concise manner. In addition, sRRR captured more variance and showed more interpretable lower dimensional visualisations than principal component analysis (PCA). In summary, with an increasing amount of multimodal data in neuroscience, it becomes increasingly important to integrate different modalities, and sRRR can become a useful tool for visual exploratory data analysis of such data sets.

References

- 1 Kobak D., et al. Sparse reduced-rank regression for exploratory visualization of single cell patch-seq recordings. *BioRXiv* (2018).
- 2 Cadwell R C., et al. Multimodal profiling of single-cell morphology, electrophysiology, and gene expression using Patch-seq. *Nature Protocols* volume 12, pages 2531–2553

©(2019) Bernaerts Y, Kobak D, Scala F, Castro J, Berens P, Tolias AS

Cite as: Bernaerts Y, Kobak D, Scala F, Castro J, Berens P, Tolias AS (2019) Sparse reduced-rank regression for visualisation of Patch-seq recordings in mouse motor cortex. *Bernstein Conference 2019 Abstract*.

doi: [10.12751/nncn.bc2019.0198](https://doi.org/10.12751/nncn.bc2019.0198)

[T 50] Spike afterpotentials shape the burst activity of MEC principal cells *in vivo*

Dora Eva Csordas^{1,2,3}, Caroline Fischer^{1,2,3}, Johannes Nagele^{1,2,3}, Martin Stemmler^{1,2,3}, Andreas Herz^{1,2,3}

1. Graduate School of Systemic Neurosciences, Großhaderner Straße 2, 82152 Martinsried-Planegg, Germany

2. Bernstein Center for Computational Neuroscience Munich, Großhaderner Straße 2, 82152 Martinsried-Planegg, Germany

3. Faculty of Biology, Ludwig-Maximilians-Universität München, Großhaderner Straße 2, 82152 Martinsried-Planegg, Germany

Principal cells in the medial entorhinal cortex (MEC) of navigating rodents encode the animal's spatial environment. Their spike trains are organized on multiple time scales and include high-frequency bursts in the 150-300 Hz range. A mechanistic understanding of these burst sequences is, however, largely missing. In this study, we reanalyzed whole-cell recordings from mice running in a virtual corridor (Domnisoru et al., 2013) and tetrode data obtained during movements in a real two-dimensional arena (Latuske et al., 2015). The membrane potentials of some principal cells recorded in virtual reality showed depolarizing afterpotentials (DAPs) known from *in-vitro* MEC studies. All such cells were located in Layer II, generated bursts, and their inter-spike intervals (ISIs) were typically between 5 and 15 milliseconds. The ISI distributions of all other Layer-II cells peaked sharply and below 5 milliseconds, and varied only minimally across that group. This dichotomy in burst behavior is shown in both data sets and is explained by cell-group-specific dynamics of spike afterpotentials. Layer III neurons were sparsely bursting and had no DAPs. No significant difference in the spatial coding properties of bursting cells with and without DAPs was discernible. As the ion-channels underlying DAPs can be modulated in various ways, our results suggest that temporal features of MEC activity can be altered to serve different functions without affecting the cells' spatial tuning characteristics.

©(2019) Csordas DE, Fischer C, Nagele J, Stemmler M, Herz A

Cite as: Csordas DE, Fischer C, Nagele J, Stemmler M, Herz A (2019) Spike afterpotentials shape the burst activity of MEC principal cells *in vivo*. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0199](https://doi.org/10.12751/nncn.bc2019.0199)

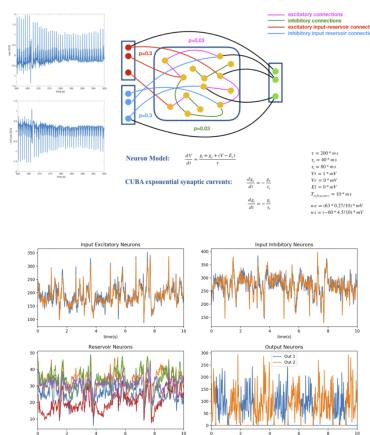
[T 51] Spiking Reservoir Computing Model for Patient-customized ECG Monitoring

Fatemeh Hadaeghi¹

1. Institute of Computational Neuroscience, Universitätsklinikum Hamburg-Eppendorf (UKE), Martinistraße 52, Germany

Echo state network (ESN) with leaky-integrated-and-fire (LIF) neurons is employed to address the classical electrocardiogram (ECG) beat classification problem. Due to its computational efficiency and the fact that training amounts to a simple linear regression, this supervised learning algorithm for recurrent neural network (RNN) has been variously considered as a strategy to implement useful computations not only on digital computers but also on emerging unconventional hardware platforms such as neuromorphic microchips. Here, this biological-inspired learning framework is exploited to devise an accurate patient-adaptive model that has the potential to be integrated in wearable cardiac events monitoring devices. The patient-customized network was trained and tested on ECG recordings from MIT-BIH arrhythmia database. The results of simulations showed a functional ESN with spiking neurons can provide accurate, cheap and fast patient-customized heartbeat classifier.

Keywords: Echo state network, Reservoir computing, Spiking Neurons, Cardiac monitoring, ECG, Weighted least squares regression



The proposed model and the activity of input, reservoir and output neurons.

Acknowledgements

This work was supported by European H2020 collaborative project Neu-RAM3 [grant number 687299]. I would also like to thank Herbert Jaeger, who provided insight and expertise that greatly assisted this research.

References

- 1 W. Maass, T. Natschläger, H. Markram, Real-time computing without stable states: A new framework for neural computation based on perturbations, *Neural Computation* 14 (11) (2002) 2531–2560.
- 2 H. Jaeger, H. Haas, Harnessing nonlinearity: Predicting chaotic systems and saving energy in wireless communication, *science* 304 (5667) (2004) 78–80.
- 3 S. Moradi, N. Qiao, F. Stefanini, G. Indiveri, A scalable multicore architecture with heterogeneous memory structures for dynamic neuromorphic asynchronous processors (DYNAPS), *IEEE Transactions on Biomedical Circuits and Systems* 12 (1) (2018) 106–122.
- 4 M. Faezipour, A. Saeed, S. C. Bulusu, M. Nourani, H. Minn, L. Tamil, A patient-adaptive profiling scheme for ECG beat classification, *IEEE Transactions on Information Technology in Biomedicine* 14 (5) (2010) 1153– 1165.
- 5 M. Freiberger, A. Katumba, P. Bienstman, J. Dambre, On-chip passive photonic reservoir computing with integrated optical readout, in: 2017 IEEE International Conference on Rebooting Computing (ICRC), IEEE, 2017, pp. 1–4.

©(2019) Hadaeghi F

Cite as: Hadaeghi F (2019) Spiking Reservoir Computing Model for Patient-customized ECG Monitoring. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0200](https://doi.org/10.12751/nncn.bc2019.0200)

[T 52] Statistical inference for analyzing sloppiness in neuroscience models

Michael Deistler¹, Pedro J. Goncalves^{1,2}, Kaan Öcal^{2,3,4}, David S. Greenberg¹, Jakob H. Macke¹

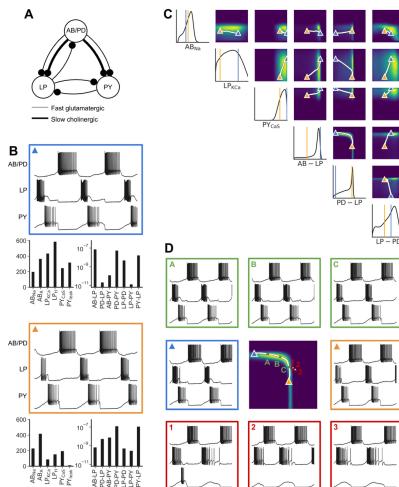
1. Chair for Computational Neuroengineering, Department of Electrical and Computer Engineering, Technical University of Munich, Munich, Germany
2. Max Planck Research Group Neural Systems Analysis, Center of Advanced European Studies and Research (caesar), Bonn, Germany
3. School of Informatics, University of Edinburgh, Edinburgh, United Kingdom
4. School of Biology, University of Edinburgh, Edinburgh, United Kingdom

Many dynamical systems in biology exhibit sloppiness: their behavior is invariant to some perturbations of parameters, but highly sensitive to others. A classical example in neuroscience is the crustacean stomatogastric ganglion, where it has been shown that similar activity can arise from highly different sets of membrane and synaptic conductances [1]. Identifying and visualizing which perturbations lead to the same network behavior is important for uncovering compensatory and homeostatic mechanisms that contribute to preserved network function. Here, we present statistical tools for studying how perturbations in parameter space affect the output in dynamical models of biological systems. We approach the investigation of sloppy models as a Bayesian inference problem, using recently developed simulation-based inference techniques [2,3]. These approaches can be applied to simulator-based stochastic models and are able to identify a richly structured manifold in the form of a posterior distribution over parameters.

We demonstrate this approach on a model of the pyloric network of the crustacean stomatogastric ganglion [4]. Our methods identify the manifold of membrane and synaptic conductances consistent with experimental data (panel C). In agreement with previous work [1], we find that similar network output can emerge in spite of large parameter variations. We use the inferred posterior distribution to study the sensitivity of the pyloric network to local perturbations. We show that parameter sets producing similar outputs are connected in parameter space and find that network output can be preserved even under large perturbations within the manifold defined by the posterior (panels C-D, white path, points A,B,C). We then investigate how finely parameters have

to be tuned to retain similar network output. Our methods allow us to find directions in the parameter space where even small perturbations lead the circuit to break down, demonstrating high sensitivity of network activity to changes in circuit parameters (panel D, points 1-3).

These results reveal that network output is preserved even under large perturbations, but that circuit parameters need to be tightly regulated for this to be achieved. The simulation-based inference tools presented here will be applicable to study sensitivities and invariances in a wide range of dynamical models of neural circuits.



A. Pyloric network B. Similar network activity from disparate parameters C. Subspace of the posterior distribution over the conductances D. Consistent samples along the high probability path (green; A,B,C). Ill-formed samples along an orthogonal path (red; 1,2,3).

References

- 1 Prinz, Astrid A., Dirk Bucher, and Eve Marder. "Similar network activity from disparate circuit parameters." *Nature neuroscience* 7.12 (2004): 1345. [10.1038/nn1352](https://doi.org/10.1038/nn1352)
- 2 Goncalves, P., et al. "Flexible Bayesian inference for complex models of single neurons." (2017): 58-58.
- 3 Greenberg, David S., Marcel Nonnenmacher, and Jakob H. Macke. "Automatic Posterior Transformation for Likelihood-Free Inference." *arXiv preprint arXiv:1905.07488* (2019).
- 4 Marder, Eve, and Dirk Bucher. "Understanding circuit dynamics using the stomatogastric nervous system of lobsters and crabs." *Annu. Rev. Physiol.* 69 (2007): 291-316. [10.1146/annurev.physiol.69.031905.161516](https://doi.org/10.1146/annurev.physiol.69.031905.161516)

©(2019) Deistler M, Goncalves PJ, Öcal K, Greenberg DS, Macke JH

Cite as: Deistler M, Goncalves PJ, Öcal K, Greenberg DS, Macke JH (2019) Statistical inference for analyzing sloppiness in neuroscience models. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0201](https://doi.org/10.12751/nncn.bc2019.0201)

[T 53] Statistical Models Discover an Accurate Low-Dimensional Latent Representation of Zebrafish Neural Activity

Thijs L van der Plas¹, Jérôme Tubiana², Guillaume Le Goc³, Geoffrey Migault³, Volker Bormuth³, Bernhard Englitz¹, Georges Debrégeas³

1. Donders Institute, Radboud University, Nijmegen, The Netherlands

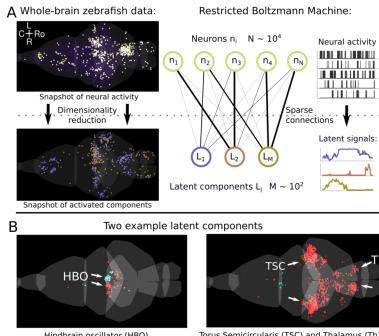
2. Blavatnik School of Computer Science, Tel Aviv University, Tel Aviv, Israel

3. Laboratoire Jean Perrin, Sorbonne Université, Paris, France

Present-day neuroscience maintains the growing consensus that the activity of a large population of neurons can effectively be described by a low number of latent sources. Different techniques are commonly used to infer such a low-dimensional representation, targeting specific characteristics of neural data. However, several popular techniques induce biases in the low-dimensional components by construction, such as orthogonality (Principal Component Analysis) or statistical independence (Independent Component Analysis), which hinder physiological interpretation.

In the current study, we merge principles from statistical mechanics and machine learning, and adapt a maximum entropy approach to construct the latent space. The maximum entropy principle defines a model that learns to reproduce the data statistics (e.g. mean activity, pairwise correlations), while remaining unconstrained otherwise. We show that our method, sparse Restricted Boltzmann Machines (RBM [1]), discovers a low-dimensional latent representation of neural activity (figure A), that accurately captures data statistics and outperforms prevalent methods in dynamic activity prediction. This is accomplished by tailoring the RBM training algorithm to process high-dimensional data, for which we use state-of-the-art whole-brain calcium imaging data sets of zebrafish larvae. These are obtained by light-sheet microscopy, which simultaneously records the activity of 30,000+ neurons *in vivo* [2–4].

Specifically, RBM learn to decompose the zebrafish brain's high-dimensional (10^4) activity into a low number (10^2) of components that are sparse, densely localized in space, and together span the entire brain, paving the way for brain-wide mesoscopic functional connectivity analysis. Each component connects to an ensemble of neurons that are either excited (figure B: red) or inhibited (figure B: blue) by the activation of the component. While some emergent components represent previously identified systems, such as the hindbrain oscillator [3, 5] (figure B left), other components uncover novel multi-region co-activation (e.g. torus semicircularis and thalamus, figure B right). Hence we consolidate, in a data-driven approach, the concept of low-dimensional latent signals that describe the majority of neural activity. Assessment of these unsupervised-constructed latent states promises to augment our understanding of neural processing.



A) Neural data (top) is mapped to latent components (bottom) with RBM. Only 3 active components are shown to enhance visibility. Orientation: Rostral (Ro), Caudal (C), Right (R), Left (L). B) Two example components. Red (blue) neurons are excited (inhibited) by the activation of their component.

Acknowledgements

We thank Rémi Monasson for constructive discussions and the IBPS fish facility staff.

References

- 1 [1] Tubiana & Monasson (2017) [10.1103/PhysRevLett.118.138301](https://doi.org/10.1103/PhysRevLett.118.138301)
- 2 [2] Panier et al., 2013 [10.3389/fncir.2013.00065](https://doi.org/10.3389/fncir.2013.00065)
- 3 [3] Ahrens et al., 2013 [10.1038/nmeth.2434](https://doi.org/10.1038/nmeth.2434)
- 4 [4] Migault et al., 2018 [10.1016/j.cub.2018.10.017](https://doi.org/10.1016/j.cub.2018.10.017)
- 5 [5] Wolf et al., 2017 [10.1038/s41467-017-00310-3](https://doi.org/10.1038/s41467-017-00310-3)

©(2019) van der Plas TL, Tubiana J, Le Goc G, Migault G, Bormuth V, Englitz B, Debrégeas G
Cite as: van der Plas TL, Tubiana J, Le Goc G, Migault G, Bormuth V, Englitz B, Debrégeas G (2019) Statistical Models Discover an Accurate Low-Dimensional Latent Representation of Zebrafish Neural Activity. Bernstein Conference 2019 Abstract. doi: [10.12751/mncn.be2019.0202](https://doi.org/10.12751/mncn.be2019.0202)

[T 54] Testing burst coding models of working memory with spike trains from primate prefrontal cortex

Daming Li¹, Christos Contantidinis², John David Murray^{1,3}

1. Department of Physics, Yale University, 217 Prospect Street New Haven, CT 06511, USA

2. School of Medicine, Wake Forest University, Bowman Gray Center, 475 Vine Street Winston-Salem, NC 27101, USA

3. Department of Psychiatry, Yale University, 300 George Street New Haven, CT 06511, USA

Working memory (WM) is the brain's ability to actively maintain information over a span of seconds, for which a hallmark neuronal correlate is stimulus-selective persistent spiking activity in prefrontal cortex. It was recently proposed, based on local field potential analysis, that this persistent activity might be an artifact of trial averaging, and that WM is instead subserved on single trials by sharp intermittent bursts of activity. However, this proposal remains untested on single-neuron spiking activity. We built and solved a doubly-stochastic statistical model of neuronal spiking to derive testable predictions for how burst-coding proposals impact measures of spiking variability, such as Fano factor (FF). Next, we simulated and analyzed computational models of WM circuits, which can subserve WM by persistent attractor dynamics, or by burst coding via short-term synaptic plasticity, demonstrating analyses that dissociate distinct circuit

mechanisms. These analyses suggest that the burst-coding proposal implies a significant increase in FF during the delay. We finally tested these predictions with datasets of single-neuron spike trains recorded from macaque prefrontal cortex during three WM tasks. We found very few neurons showing increased WM-dependent burstiness. Furthermore, during two parametric WM tasks neurons exhibit a global decrease in FF during the delay relative to foreperiod, while in the other match/non-match WM task there is no global increase in FF predicted by the burst-coding proposal either. In summary, prefrontal spiking variability supports theoretical frameworks of persistent activity supporting WM, and provides strong constraints on proposals for WM coding through intermittent single-neuron bursting.

References

- 1 Lundqvist et al. (2016): Gamma and beta bursts underlie working memory [10.1016/j.neuron.2016.02.028](https://doi.org/10.1016/j.neuron.2016.02.028)

©(2019) Li D, Contantidinis C, Murray JD

Cite as: Li D, Contantidinis C, Murray JD (2019) Testing burst coding models of working memory with spike trains from primate prefrontal cortex. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0203](https://doi.org/10.12751/nncn.bc2019.0203)

[T 55] The Effect of Anterior Thalamus Lesions on Bursting in The Subiculum

Seán Kieran Martin¹, Bethany Esther Frost¹, John Patrick Aggleton², Shane Michael O'Mara¹

1. School of Psychology, Institute of Neuroscience, Trinity College Dublin, Ireland

2. School of Psychology, Cardiff University, Wales

Introduction: The subiculum is one of the primary outputs of the hippocampus and projects to multiple cortical and subcortical structures. The subiculum has been implicated to play a role in spatial navigation and memory, and control the response to stress (O'Mara 2005). Subicular neurons have been observed to classify into bursting and non-bursting groups from *in vitro* and *in vivo* studies (Stewart and Wong 1993; Sharp and Green 1994). Evidence shows that bursting in subicular cells is vital to spatial information processing, and that switching between bursting and single spiking modes is imperative to information routing (Simonnet and Brecht 2019; Cooper, Chung, and Spruston 2005). Here, we sought to investigate the effect of anterior thalamus (ATN) lesion-induced dysfunction on the bursting properties of subicular neurons. **Methods:** We performed *in vivo* extracellular single-unit and local field potential recordings in the dorsal subiculum using multiple indwelling electrodes while simultaneously recording the local field potential in the retrosplenial cortex. A total of 18 rats (3 control, 3 sham, 6 ATN-lesioned, 6 with temporary inactivation of ATN using muscimol) were recorded during exploration and behavioural tasks. Single-unit activity was isolated using automatic clustering with TINT software (Axona Ltd, St Albans, UK) followed by manual adjustment of the clusters. **Statistical analysis:** Single unit properties were determined using NeuroChaT (Islam 2019) to separate cells into bursting units, regular spiking units, theta-modulated units, and fast spiking units following previous *in-depth* *in vivo* analysis (Anderson and O'Mara 2003). To further test cell groupings, hierarchical clustering using Ward's method was performed on the principal components of the inter-spike interval and the autocorrelation histogram of detected single-units in Python (Simonnet and Brecht 2019). **Results:** Place, head-direction and grid cells were recorded

in the dorsal subiculum of control rats. However, the absence of ATN input to the hippocampal formation led to a degradation in spatial properties of subicular cells and no spatially tuned cells were recorded in the subiculum of ATN-lesioned rats. Given the evidence that burst firing in the subiculum is relevant to spatially tuned neurons (Simonnet and Brecht 2019), we show the effect of spatial information degradation by ATN-lesion induced dysfunction on bursting in subicular principal cells.

Acknowledgements

This work was funded by the Wellcome Trust.

References

- 1 Anderson, Michael I., and Shane M. O'Mara. 2003. "Analysis of Recordings of Single-Unit Firing and Population Activity in the Dorsal Subiculum of Unrestrained, Freely Moving Rats." *Journal of Neurophysiology* 90 (2): 655–65 [10.1152/jn.00723.2002](https://doi.org/10.1152/jn.00723.2002)
- 2 Cooper, Donald C., Sungkwon Chung, and Nelson Spruston. 2005. "Output-Mode Transitions Are Controlled by Prolonged Inactivation of Sodium Channels in Pyramidal Neurons of Subiculum." *PLOS Biology* 3 (6): e175 [10.1371/journal.pbio.0030175](https://doi.org/10.1371/journal.pbio.0030175)
- 3 Islam, Md Nurul. 2019. "An Analysis Platform and Tools to Understand the Dynamics of Neuronal Encoding in Rodents." Thesis, Trinity College Dublin. School of Psychology. Discipline of Psychology
- 4 O'Mara, Shane. 2005. "The Subiculum: What It Does, What It Might Do, and What Neuroanatomy Has yet to Tell Us." *Journal of Anatomy* 207 (3): 271–82 [10.1111/j.1469-7580.2005.00446.x](https://doi.org/10.1111/j.1469-7580.2005.00446.x)
- 5 Sharp, P. E., and C. Green. 1994. "Spatial Correlates of Firing Patterns of Single Cells in the Subiculum of the Freely Moving Rat." *Journal of Neuroscience* 14 (4): 2339–56 [10.1523/JNEUROSCI.14-04-02339.1994](https://doi.org/10.1523/JNEUROSCI.14-04-02339.1994)
- 6 Simonnet, Jean, and Michael Brecht. 2019. "Burst Firing and Spatial Coding in Subicular Principal Cells." *Journal of Neuroscience* 39 (19): 3651–62 [10.1523/JNEUROSCI.1656-18.2019](https://doi.org/10.1523/JNEUROSCI.1656-18.2019)
- 7 Stewart, M., and R. K. Wong. 1993. "Intrinsic Properties and Evoked Responses of Guinea Pig Subicular Neurons in Vitro." *Journal of Neurophysiology* 70 (1): 232–45 [10.1152/jn.1993.70.1.232](https://doi.org/10.1152/jn.1993.70.1.232)

©(2019) Martin SK, Frost BE, Aggleton JP, O'Mara SM

Cite as: Martin SK, Frost BE, Aggleton JP, O'Mara SM (2019) The Effect of Anterior Thalamus Lesions on Bursting in The Subiculum. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0204](https://doi.org/10.12751/nncn.bc2019.0204)

[T 56] Undervalued potential of data augmentation

Alex Hernandez-Garcia¹, Peter König¹

1. Institute of Cognitive Science, University of Osnabrück, 27 Wachsbleiche, 49090 Osnabrück, Germany

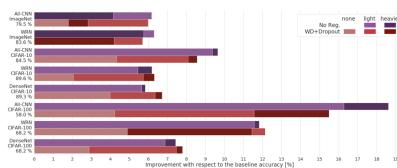
Data augmentation (DA) has been long used in machine learning as a tool to synthetically expand a data set by transforming the available examples. However, it has often been considered, at best, just one more regularization technique from the machine learning toolbox, and even a sort of "cheating" method that should not be used to properly assess the potential of other elements of the models. As a result, DA has been heavily understudied and only recently has it received renewed attention, boosted by new proposals that allow learning transformations automatically [1].

We argue that data augmentation, rather than a mere regularization technique, has remarkable undervalued potential and interesting properties in connection with computational neuroscience. Whereas the visual cortex becomes a robust, efficient object recognition system by being continuously exposed to richly varied visual stimuli, deep artificial neural networks (DNNs) trained for object categorization are expected to become comparably robust and even good models of the visual brain, by being trained with large, but still limited data sets of still images. Although DA cannot achieve the richness of real world stimuli, it can provide virtually infinite variations of the data, and thus a more similar stimuli diet to that of biological systems.

First, we present theoretical insights from statistical learning theory that emphasize the benefits of training with increased variability in the training data, especially compared to

common explicit regularization techniques such as weight decay and dropout. Moreover, we provide empirical evidence that removing the explicit regularization from the models achieves comparable performance or better if DA is applied (Fig 1). This casts doubt on the need for weight decay and dropout and highlights the potential of data augmentation. Importantly, this is accentuated when few training data are available.

A well-established property of the primate visual cortex is the invariance towards identity-preserving transformations, that is, the kind of variation provided by DA. Here, we propose that DA, rather than simply increasing the number of training examples, may help learn more robust features. In this regard, we present empirical evidence that DNNs trained with DA on just a fraction of the data achieve comparable results to training on the full data sets without augmentation and are remarkably more accurate at classifying transformed examples.



Relative improvement of adding data augmentation and explicit regularization to the baseline models, $(\text{accuracy} - \text{baseline})/\text{accuracy} * 100$. The baseline accuracy is shown on the left. The results suggest that data augmentation alone (purple bars) can achieve even better performance than the baseline

References

- 1 Cubuk, E. D., Zoph, B., Mane, D., Vasudevan, V., & Le, Q. V. (2018). Autoaugment: Learning augmentation policies from data. arXiv preprint arXiv:1805.09501.

©(2019) Hernandez-Garcia A, König P

Cite as: Hernandez-Garcia A, König P (2019) Undervalued potential of data augmentation. Bernstein Conference 2019
Abstract. doi: [10.12751/nncn.bc2019.0205](https://doi.org/10.12751/nncn.bc2019.0205)

[T 57] What does the adult zebrafish retina tell the brain?

Paul A Roberts¹, Marvin Seifert¹, Tom Baden^{1,2}

1. School of Life Sciences, University of Sussex, Brighton, UK

2. Institute for Ophthalmic Research, University of Tübingen, Germany

While basic retinal architecture is conserved across vertebrates, each species' retina is unique, having evolved to detect and interpret the visual scenes particular to its environment. It is therefore important to build towards a broad understanding of the types of computations performed within the eyes of different species. Here, adult zebrafish are of particular interest. While considerable work has gone into studying the structure and function of the larval visual system, we know comparatively little about visual function in adults which differ vastly in size, swimming speed and visual-ecological niche. Anatomically, the mere 4,000 RGCs of the larval eye increase to around 150,000 in the adult, all crammed into an eye that remains substantially smaller than that of the mouse with its 50,000 RGCs. What do all these "extra" RGCs encode, and how uniformly are any computations performed across different parts of the eye?

Here, we use a 4,096-channel multielectrode array (MEAs) to record the activity of large populations of zebrafish retinal ganglion across the majority of the retinal surface cells in response to a variety of spectrally-appropriate visual stimuli. We aim to build towards a first overview of the major visual computations performed by the adult zebrafish eye.

©(2019) Roberts PA, Seifert M, Baden T

Cite as: Roberts PA, Seifert M, Baden T (2019) What does the adult zebrafish retina tell the brain?. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0206](https://doi.org/10.12751/nncn.bc2019.0206)

[T 58] When noise and broken wiring is not necessarily grounds for alarm and dramatic change to the music - an integrative data-fusion approach to neurorestorative medicine

Martin Joseph Dudziak¹

1. Technology, Informatics and Education, Memorial Healthcare Institute for Neurosciences and Multiple Sclerosis, Owosso, Michigan, USA

In the course of treatment for a number of brain-centric diseases including relapsing-remitting and secondary-progressive forms of multiple sclerosis, new MRI and MRE results may show an apparent increase in lesion count/density. But where are these lesions, both past and new, with respect to cognitively and behaviorally significant brain functions, and specifically those that are most impactful for the patient's current and future life activities? The traditional clinical response has often to make significant changes in the pharmacological type or dosage. In many cases there will be increased risk and future incidence of unfavorable and even life-threatening/shortening side effects as a result. "Not all lesions are the same signs of future progressions" when there can be effective meta-knowledge. We describe the process of incorporating multi-spectral data, particularly molecular spectroscopy (SMD) and more in-depth first-person and third-person observations including a variety of real-time and non-clinical video and audio data collection. Much of this is enabled by the maturation of wearable, wi-fi and internet technology capabilities. Such data types, coupled with integration of computational models of brain functional network dynamics drawn from both normal and diseased brains, can lead to significantly different assessments of pathogenic criticality and prognoses for disease progression and patient adaptation. The outcome can lead to different encouragements and prescriptions for pharmacological, biomagnetic, and physical/cognitive therapy practices that will result in an improved neurorestorative health outcome with a reduction in complications, side-effects and patient discomforts.

©(2019) Dudziak MJ

Cite as: Dudziak MJ (2019) When noise and broken wiring is not necessarily grounds for alarm and dramatic change to the music - an integrative data-fusion approach to neurorestorative medicine. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0207](https://doi.org/10.12751/nncn.bc2019.0207)

[T 59] Why higher order principal components may be irrelevant

Allan Mancoo¹, Christian Machens¹

1. Champalimaud Research, Champalimaud Centre for the Unknown, Av. Brasília, 1400-038 Lisboa, Portugal

Large-scale recordings of neural activity are now widely carried out in many experimental labs, leading to the question of how to capture the essential structure in population data. One common way of doing so is through the use of dimensionality reduction methods. However, interpretation of the results of these tools can be fraught with difficulties. Most commonly, linear methods such as Principal Component Analysis (PCA) work well in capturing the linear manifolds where most variance in data reside. At the same time, they usually display a tail of 'higher-order' components, which suggests that the true underlying manifold is non-linear. While general-purpose non-linear methods (e.g. Isomap) can compute low-dimensional embeddings of high-dimensional data onto non-linear manifolds, they are often infeasible (due to the noisy nature of neuronal data) or they do not add to our understanding of how these non-linear manifolds could emerge.

Here, we study the effect of one well known non-linearity - individual neuronal activity is constrained to be non-negative – using a geometric approach. We lead our investigation with the crucial assumptions that linear readouts of population activity should be low dimensional and that overall firing rates should be limited for reasons of efficiency. Both assumptions are motivated by the literature on efficient, balanced networks (Deneve and Machens, *Nat Neurosci*, 2016.). We show in simulations, that these simple assumptions lead to population trajectories that move on specific, piecewise-linear surfaces in the neural space that we can characterise.

When neural activities are generated under these assumptions, then methods such as PCA extract not only the low-dimensional linear readouts, but also a tail of higher-order components due to kinks in the manifold of piecewise linear surfaces. We explain these findings geometrically and show that such higher-order components often appear in real data. We build a set of dimensionality reduction methods that incorporate these non-negativity constraints in a meaningful way which we validate against ground truth data and we show some preliminary results when applied to in-vivo electrophysiological recordings.

Acknowledgements

Allan Mancoo thanks Fundacão Champalimaud and French Ministry of Education for funding

References

- 1 Denève, Sophie, and Christian K. Machens. "Efficient codes and balanced networks." *Nature neuroscience* 19, no. 3 (2016): 375. [10.1038/nn.4243](https://doi.org/10.1038/nn.4243)

©(2019) Mancoo A, Machens C

Cite as: Mancoo A, Machens C (2019) Why higher order principal components may be irrelevant. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0208](https://doi.org/10.12751/nncn.bc2019.0208)

Other

[T 60] A mathematical framework for vesicle release from a retinal bipolar cell

Hassan Bassereh^{1,2}, Frank Rattay¹, Stefan Glasauer²

1. Institute for Analysis and Scientific Computing, Vienna University of Technology, Vienna, Austria

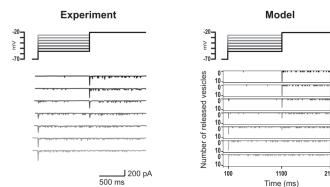
2. Brandenburg University of Technology, Cottbus, Germany

Introduction In some presynaptic terminals there is an extra protein structure called 'ribbon' that is perpendicular to the active zones. Therefore, these synapses are called "ribbon synapses". There are three types of vesicles in axon terminals of the cells containing ribbons: (i) a few vesicles primed for fast release (< 10 ms, Singer and Diamond, 2003), making the rapidly (or readily) releasable pool (RRP). (ii) Vesicles are also tethered to the ribbon making the releasable pool (RP). The RP pool can be depleted over several hundreds of milliseconds. (iii) vesicles moving freely in the terminal that make up the cytoplasmic pool (CP), and their number reaches the thousands (Sterling and Matthews, 2005). Tethered vesicles cannot leave the ribbon to be added to CP, but they can fill the empty places in the RRP, if there are any. When a vesicle leaves the ribbon, a vesicle from CP is replaced (Graydon et al., 2014).

In retinal bipolar neurons containing ribbons, two types of vesicle release are defined, i) vesicles released by a quick large depolarization of the terminal membrane called 'transient vesicle release', and 'sustained release' done with a slower constant rate during prolonged stimulations.

In here, we simulate behavior of a rat rod bipolar cell (RBC) using multi-compartment model, then present a mathematical model for vesicle (neurotransmitter) release from a single ribbon synapse of the cell. Transmembrane voltage of the axon terminal plays role of the variable in the model. The model explains dynamics of RRP based on experiments done by Oesch and Diamond in (2011).

Conclusion: In here, we present a model for vesicle release from a ribbon synapse then the model was combined with a multi-compartment model to demonstrate characteristic differences in vesicle release when spikes or graded potentials are the driving forces. The simulation suggests that a spike makes the RRP empty. The spiking bipolar cell was also stimulated extracellularly with periodic pulses in both intra- and extracellular stimulation. Extracellular stimulation is similar to the stimulation via electrodes of a subretinal implant (Chuang et al., 2014). In both cases all of the 10 vesicles existing in the pool are released by the first pulse and 3 vesicles are released by the next pulses.



Comparison of coupled RBC-All paired-pulse experiment and number of released vesicles simulated for a single ribbon. Transient and sustained releases show the same characteristics.

References

- 1 Oesch NW and Diamond JS. Ribbon synapses compute temporal contrast and encode luminance in retinal rod bipolar cells. [10.1038/nn.2945](https://doi.org/10.1038/nn.2945).
- 2 Chuang A, Margo C, Greenberg P. Retinal implants: a systematic review. [10.1136/bjophthalmol-2013-303708](https://doi.org/10.1136/bjophthalmol-2013-303708)
- 3 Graydon CW, Zhang J, Oesch NW, Sousa AA, Leapman RD, Diamond JS. Passive diffusion as a mechanism underlying ribbon synapse vesicle release and resupply. [10.1523/JNEUROSCI.1022-14.2014](https://doi.org/10.1523/JNEUROSCI.1022-14.2014).
- 4 Rattay F, Bassereh H, Stiennon I. Compartment models for the electrical stimulation of retinal bipolar cells. [10.1371/journal.pone.0209123](https://doi.org/10.1371/journal.pone.0209123)
- 5 Singer JH and Diamond JS. Vesicle depletion and synaptic depression at a mammalian ribbon synapse. [10.1152/jn.01309.2005](https://doi.org/10.1152/jn.01309.2005)
- 6 Werginz P and Rattay F. The impact of calcium current reversal on neurotransmitter release in the electrically stimulated retina. [10.1088/1741-2560/13/4/046013](https://doi.org/10.1088/1741-2560/13/4/046013)

©(2019) Bassereh H, Rattay F, Glasauer S

Cite as: Bassereh H, Rattay F, Glasauer S (2019) A mathematical framework for vesicle release from a retinal bipolar cell. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0209](https://doi.org/10.12751/nncn.bc2019.0209)

[T 61] BIOPHYSICAL MODELING OF EEG SIGNALS

Solveig Næss¹, Geir Halnes², Espen Hagen³, Donald Hagler⁴, Anders M. Dale⁵, Gaute T. Einevoll^{2,3}, Torbjørn V. Ness²

1. Department of Informatics, University of Oslo, Oslo, Norway

2. Faculty of Science and Technology, Norwegian University of Life Sciences, Ås, Norway

3. Department of Physics, University of Oslo, Oslo, Norway

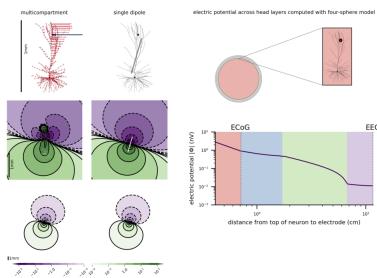
4. Department of Radiology, University of California, San Diego, USA

5. Departments of Neurosciences and Radiology, University of California, San Diego, USA

For many decades scientists have studied the human brain by recording electromagnetic brain signals with techniques such as electroencephalography (EEG) and electrocorticography (ECoG), that is, recordings of electrical potentials at the skull or scalp, as well as magnetoencephalography (MEG), that is magnetic fields recorded outside of the head. These brain signals have by now become an inevitable part of both basic research and clinical medicine. The interpretation of such signals has however mostly been based on statistical analysis, and the proper link to the biophysical activity of the underlying neurons is still lacking.

For a neuron receiving a single synaptic input, it is well established that the ensuing electric potential will take the shape of a dipole in the far-field limit, i.e., sufficiently far away from the neuron. This can greatly simplify the link between the measured brain signals and the underlying neural sources, but this link has not yet been taken full advantage of in the framework of detailed biophysical forward modeling of brain signals.

Here, we present a framework for reducing complex simulated neural activity to simple current dipoles, and test the applicability of the approach. We find that the framework works excellently for calculating EEG, but not ECoG signals. We demonstrate the power of the approach in large-scale simulations of neural activity, by showing that EEGs calculated from a neural population can be well represented by reducing it to a single current dipole, based on the average obtained from the cells in the neural population. This greatly simplifies the link between the experimentally measurable EEG signals and the underlying neural sources, in a manner that is firmly grounded in the underlying biophysics. This can help us to better understand EEG signals, and to take better advantage of this important brain signal in the future.



Electric potential from simulation of morphologically reconstructed human L23 pyramidal cell with single synaptic input, computed with multicompartmental modeling and current dipole approximation. ECoG and EEG signals modeled with four-sphere head model.

References

- 1 Einevoll et al., Nat Rev Neurosci, 2013 10.1038/nrn3599
- 2 Hamalainen et al., Rev Mod Phys, 1993 10.1103/RevModPhys.65.413
- 3 Srinivasan et al., IEEE Trans Biomed Eng, 1998 10.1109/10.686789
- 4 Lindén et al., J Comput Neurosci, 2010 10.1007/s10827-010-0245-4
- 5 Eyal et al., eLife 2016;5:e16553 10.7554/eLife.16553

©(2019) Næss S, Halnes G, Hagen E, Hagler D, Dale AM, Einevoll GT, Ness TV

Cite as: Næss S, Halnes G, Hagen E, Hagler D, Dale AM, Einevoll GT, Ness TV (2019) BIOPHYSICAL MODELING OF EEG SIGNALS. Bernstein Conference 2019 Abstract. doi: 10.12751/nncn.bc2019.0210

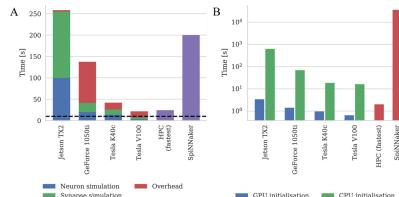
[T 62] GPUs Outperform Current HPC and Neuromorphic Solutions in Terms of Speed and Energy When Simulating a Highly-Connected Cortical Model

James C. Knight¹, Thomas Nowotny¹

1. School of Engineering and Informatics, University of Sussex, Falmer, Brighton BN1 9QJ, United Kingdom

Traditionally, spiking neural network models are developed and simulated on traditional CPU-based computers or clusters of such computers in High Performance Computing (HPC) centres. Over the last decade, as well as becoming a common component in many workstations, NVIDIA GPU accelerators have also entered the High Performance Computing (HPC) field and are now used in about 50% of the Top 10 super computing sites worldwide. In this work we used the GPU enhanced Neuronal Networks (GeNN) code generator [1] to implement a neocortex-inspired, circuit-scale spiking neural network model [2] on GPU hardware. We verified the correctness of the GPU implementation by comparing simulation results against previous results obtained with the NEST simulator [3], running on traditional HPC hardware [4]. We then compared the performance of the GPU implementation with respect to speed and energy consumption against the published data of the NEST implementation and of an implementation run on the SpiNNaker neuromorphic hardware [5]. The full-scale model of a cortical micro-column can be simulated at speeds approaching 0.5× real-time using a single NVIDIA Tesla V100 accelerator - faster than is currently possible using a CPU based cluster or the SpiNNaker neuromorphic system. In addition, we found that, across a range of GPU systems, the energy to solution as well as the energy per synaptic event of the

microcircuit simulation is as much as $14\times$ lower than either on SpiNNaker or in CPU-based simulations. Besides performance of the simulation itself, efficient initialisation of models is also a crucial concern, in particular in a research context where repeated runs and parameter-space exploration are required. We, therefore, also developed and tested novel parallel initialisation methods that enable the initialisation of connectivity matrices on the GPU. We are able to demonstrate that they enable further significant speed and energy advantages. This suggests that in future simulation solutions, the entire lifetime of a simulation from setting up the network to downloading and processing the results should be considered and optimised.



(A) Simulation times of the microcircuit model running on various GPU hardware, HPC (12 nodes) and SpiNNaker, for 10 s of biological time. "Overhead" in GPU simulations refers to time spent in the simulation loop but not within CUDA kernels. (B) Initialisation times of the microcircuit model.

Acknowledgements

This work was funded by the EPSRC (Brains on Board project, grant number EP/P006094/1). We would like to thank Andrew Webb and Sacha van Albada for helpful comments and the Gauss Centre for Supercomputing e.V. for providing computing time on JUWELS.

References

- Yavuz, E., Turner, J., and Nowotny, T. (2016). GeNN: a code generation framework for accelerated brain simulations. *Sci. Rep.* 6:18854. [10.1038/srep18854](https://doi.org/10.1038/srep18854)
- Potjans, T. C., and Diesmann, M. (2014). The cell-type specific cortical microcircuit: relating structure and activity in a full-scale spiking network model. *Cereb. Cortex* 24, 785–806. [10.1093/cercor/bhs358](https://doi.org/10.1093/cercor/bhs358)
- Gewaltig, M.-O., and Diesmann, M. (2007). NEST (NEural Simulation Tool). *Scholarpedia* 2:1430. [10.4249/scholarpedia.1430](https://doi.org/10.4249/scholarpedia.1430)
- van Albada, S. J., Rowley, A. G., Senk, J., Hopkins, M., Schmidt, M., Stokes, A. B., et al. (2018). Performance comparison of the digital neuromorphic hardware SpiNNaker and the neural network simulation software NEST for a full-scale cortical microcircuit Model. *Front. Neurosci.* 12:291. [10.3389/fnins.2018.00291](https://doi.org/10.3389/fnins.2018.00291)
- Furber, S. B., Galluppi, F., Temple, S., and Plana, L. A. (2014). The SpiNNaker Project. *Proc. IEEE* 102, 652–665. [10.1109/JPROC.2014.2304638](https://doi.org/10.1109/JPROC.2014.2304638)

©(2019) Knight JC, Nowotny T

Cite as: Knight JC, Nowotny T (2019) GPUs Outperform Current HPC and Neuromorphic Solutions in Terms of Speed and Energy When Simulating a Highly-Connected Cortical Model. *Bernstein Conference 2019 Abstract.*
doi: [10.12751/nncn.bc2019.0211](https://doi.org/10.12751/nncn.bc2019.0211)

[T 63] History dependence in neural spike trains differs strongly among brain areas

Lucas Rudelt¹, Michael Wibral², Viola Priesemann¹

¹ Max-Planck-Institute for Dynamics and Self-Organization, Am Fassberg 17, 37077 Göttingen, Germany

² Georg-August-Universität Göttingen, Faculty of Biology and Psychology, Kellnerweg 6, 37077 Göttingen, Germany

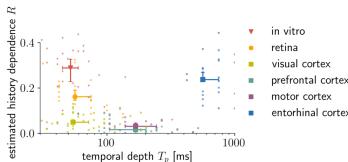
It is still unknown how much neural spiking activity depends on its own past. Yet, such history dependence crucially shapes neural information processing. On the one hand, efficient information transmission for low noise implies temporal redundancy reduction by quenching history dependence. On the other hand, temporal integration requires maintenance of past information and thus high history dependence. To learn how this trade-off is handled across different brain areas, we use information theory to directly quantify history dependence from neural spiking recordings. Precisely, history dependence R is defined as the fraction of a neuron's spiking information [1] in a small time window Δt

$$H(\text{spiking}) = -r\Delta t \log_2 r\Delta t - (1 - r\Delta t) \log_2 (1 - r\Delta t),$$

that is occupied by mutual information with the neuron's past $I(\text{spiking}; \text{past})$, i.e.

$$R \equiv \frac{I(\text{spiking}; \text{past})}{H(\text{spiking})} = 1 - \frac{H(\text{spiking}|\text{past})}{H(\text{spiking})} \in [0, 1].$$

For $R = 0$ spiking is independent of its past, whereas for $R = 1$ spiking is entirely predictable. Because the estimation of statistical dependency is an extremely challenging inference problem, we developed an embedding optimization approach for representing past spiking activity, which preserves as much statistical dependency as possible while keeping estimation bias in check [2]. We benchmarked the approach on a realistic model neuron [3], where it accurately estimates history dependence over several hundred milliseconds. When applying the approach to experimental spike recordings, we found that history dependence R as well as its temporal depth T_p differ substantially among brain areas. Strikingly, we find that R decreases for higher processing areas in line with efficient coding [1], while its temporal depth T_p increases, consistent with the idea of a temporal hierarchy in the cortex [4]. Entorhinal cortex, on the contrary, displays high history dependence with high temporal depth, presumably reflecting its contribution to memory formation. For the first time, our approach allowed to compare history dependence for recordings of brain areas as diverse as retina [5] as well as visual [6], prefrontal [6], motor [6] and entorhinal cortex [7]. Furthermore, we propose embedding optimization as a generally applicable tool for analyzing statistical dependency in neural spiking data.



History dependence R and its temporal depth T_p were estimated from spike recordings of several neurons ($n = 22$ to $n = 43$) per brain area. Big dots and errorbars show median over recorded neurons and 95% confidence intervals via bootstrapping.

Acknowledgements

LR and VP received funding from the German Israel Foundation (G-2391-421.13). VP received funding from the German Ministry for Education and Research (BMBF) via the Bernstein Center for Computational Neuroscience Göttingen (01GQ1005B).

References

- 1 Barlow, H. B. Possible Principles Underlying the Transformations of Sensory Messages. in *Sensory Communication* (ed. Rosenblith, W. A.) 216–234 (The MIT Press, 2012). [10.7551/mitpress/9780262518420.003.0013](https://doi.org/10.7551/mitpress/9780262518420.003.0013)
- 2 Rudelt L., Wibral M., Priesemann V., in preparation.
- 3 Pozzorini C., Naud R., Mensi S., Gerstner W. Temporal whitening by power-law adaptation in neocortical neurons. *Nature Neuroscience*, 16(7), 942–948, 2013. [10.1038/nn.3431](https://doi.org/10.1038/nn.3431)
- 4 Murray, J. D. et al. A hierarchy of intrinsic timescales across primate cortex. *Nature Neuroscience* 17, 1661–1663 (2014). [10.1038/nn.3862](https://doi.org/10.1038/nn.3862)
- 5 Prentice, J. S. et al. Error-Robust Modes of the Retinal Population Code. *PLOS Computational Biology* 12, e1005148 (2016). [10.1371/journal.pcbi.1005148](https://doi.org/10.1371/journal.pcbi.1005148)
- 6 Dotson, N. M., Hoffman, S. J., Goodell, B. & Gray, C. M. A Large-Scale Semi-Chronic Microdrive Recording System for Non-Human Primates. *Neuron* 96, 769–782.e2 (2017). [10.1016/j.neuron.2017.09.050](https://doi.org/10.1016/j.neuron.2017.09.050)
- 7 Mizuseki K., Sirotta A., Pastalkova E., Buzsáki G. Theta Oscillations Provide Temporal Windows for Local Circuit Computation in the Entorhinal-Hippocampal Loop. *Neuron*, 64, 267–280, 2009. [10.1016/j.neuron.2009.08.037](https://doi.org/10.1016/j.neuron.2009.08.037)

©(2019) Rudelt L, Wibral M, Priesemann V

Cite as: Rudelt L, Wibral M, Priesemann V (2019) History dependence in neural spike trains differs strongly among brain areas. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0212](https://doi.org/10.12751/nncn.bc2019.0212)

[T 64] MEA-based classification of retinal ganglion cells for bionic vision.

Hamed Shabani¹, Mahdi Sadeghi², Zohreh Hosseinzadeh³, Eberhart Zrenner¹, Daniel Rathbun¹

1. Tuebingen University, Institute for Ophthalmic Research, Elfriede-Auhorn-Str, 7, Germany

2. Tuebingen University, Germany

3. Technical University of Dresden, Germany

Purpose Although there has been significant progress in developing retina implants during last two decades, due to the inability to selectively stimulate different Retina Ganglion Cell (RGC) types, visual perception for retina implant patients remains limited. We hypothesize that different types of RGCs can be selectively activated by deriving stimuli from their different electrical input filters. The input filters of cells are extracted from their response to electrical noise stimulation using the Spike Triggered Averaging (STA) method. To begin testing this hypothesis, we first classify RGC types using a set of visual stimuli and then examine the properties of each cell type's electrical input filters. **Method** In this study we used the data recorded from nine dark adapted retinas of seven adult wild type mice. A 60 channel microelectrode array in contact with the ganglion cell side of the retina was used to record the spiking neural activity of RGCs. The visual stimulation set was adapted from Baden et al. (Nature 2016), including moving bars, contrast and temporal frequency chirps, blue-green color flashes, and spatiotemporal white noise. In order to extract electrical input filters, a sequence of filtered and interpolated Gaussian white noise voltage steps was used. Similar to Baden et al. we used sparse principle component analysis (sPCA) to extract response features to the visual stimuli. After projecting data into a lower-dimensional space, we assigned each neuron to one of the 75 clusters reported by Baden et al., by finding the highest correlation between a neuron's response and the clustered response data provided by Baden et al. **Results** We recorded visual responses from 426 RGCs. These responses mapped onto about half of the previously described clusters. Despite convolving our

spike trains with a filter to create pseudo-calcium traces for correlation with the previous dataset, many of our responses were significantly more transient than previously reported. ON and OFF cells had different electrical input filters as we have previously reported. Discussion Adaptation of the Baden et al. methodology for spike trains instead of calcium recordings was partially successful. For better classification results, new cluster definitions should be derived from a large spike train data set. Electrical input filters do appear to vary with RGC type, but more precise cluster definitions are needed to refine this result.

Acknowledgements

his study is part of the research program of the Bernstein Centre for Computational Neuroscience, Tuebingen, funded by the BMBF (01GQ1002). Additional support was received from the Tistou and Charlotte Kerstan Foundation, and SysRetPro (FKZ: 031A308).

References

- 1 [1] Baden, T. et al. "The functional diversity of retinal ganglion cells in the mouse." *Nature* 529.7586 (2016): 345. [2] Sekhar, S., et al. "Correspondence between visual and electrical input filters of ON and OFF mouse retinal ganglion cells." *Journal of Neural Engineering* 14.4 (2017): 046017.

©(2019) Shabani H, Sadeghi M, Hosseinzadeh Z, Zrenner E, Rathbun D

Cite as: Shabani H, Sadeghi M, Hosseinzadeh Z, Zrenner E, Rathbun D (2019) MEA-based classification of retinal ganglion cells for bionic vision.. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0213](https://doi.org/10.12751/nncn.bc2019.0213)

[T 65] PCle: a novel data robust perturbational complexity index

Thierry Nieuw¹, Silvia Casarotto¹, Adenauer Casali², Marcello Massimini¹

1. Department of Biomedical and Clinical Sciences "L. Sacco", University of Milan, G.B. Grassi 74, Italy

2. Institute of Science and Technology, Federal University of São Paulo, São José dos Campos, Brazil

The Perturbational Complexity Index (PCI) has been recently validated as a neurophysiological marker of the potentiality for consciousness in severely brain-injured patients [1]. Starting from the electroencephalographic (EEG) responses to transcranial magnetic stimulation (TMS), this index measures the complexity of the spatiotemporal pattern of cortical activations significantly evoked by TMS [2]. The following computational steps are required: (i) estimation of distributed cortical currents from scalp potentials at the single-trial level; (ii) non-parametric bootstrap-based statistical analysis to detect the spatiotemporal pattern of significant cortical activations; (iii) representation of significant cortical activations in space and time as a binary 2D matrix (labelled SS); (iv) sorting of SS rows – which represent distinct cortical sources – by the total amount of significant activations across all time samples for minimizing the complexity simply generated by the arbitrary ordering of sources; (v) computation of the Lempel-Ziv complexity and normalization by the source entropy of matrix SS, assuming a fully random rearrangement of ones and zeros. Although the effectiveness and clinical usefulness of PCI are not questioned, some methodological aspects related to its computational procedure could be further improved. Here some methodological modifications are proposed that allow to: 1) test different inverse models; 2) use different statistical approaches to assess significant activations; 3) univocally sort the sources; 4) derive a more plausible data driven normalization factor. The procedure, named PClev, is faster to compute, less sensitive to noise and more robust to source ordering. The analysis pipeline to compute PClev has been tested on a large TMS/EEG database previously employed in related works [1,2]. Overall, the performances of PClev on the benchmark

population and on patients with disorders of consciousness [1,2] are comparable with the original formulation of PCI. We will release the Python-based pipeline on GitHub and on the Human Brain Platforms in order to make the computational procedure of PClev freely available to other researchers in the TMS/EEG field. This effort will simplify the applicability of the complexity index to human data and hopefully motivate its use on non-human data (e.g. cell culture, slices, and in-vivo preparations) as well as to non-biological preparations (e.g. computer simulations).

Acknowledgements

This work was supported by European Union's Horizon 2020 Framework Programme for Research and Innovation, grant 720270-Human Brain Project SGA1 and grant 785907-Human Brain Project SGA2.

References

- 1 Stratification of unresponsive patients by an independently validated index of brain complexity: Complexity Index. Casarotto et al. 2016 [10.1002/ana.24779](https://doi.org/10.1002/ana.24779)
- 2 A Theoretically Based Index of Consciousness Independent of Sensory Processing and Behavior. Casali et al. 2013 [10.1126/scitranslmed.3006294](https://doi.org/10.1126/scitranslmed.3006294)

©(2019) Nieuw T, Casarotto S, Casali A, Massimini M

Cite as: Nieuw T, Casarotto S, Casali A, Massimini M (2019) PCle: a novel data robust perturbational complexity index. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0214](https://doi.org/10.12751/nncn.bc2019.0214)

[T 66] Short-term ITD (interaural time difference) estimation of natural sound stimuli via effective models of binaural brainstem nuclei

Sebastian Groß^{1,2,3}, Christian Leibold^{1,2}

1. LMU, Munich, Germany

2. BCCN, Munich, Germany

3. GSN-LMU, Munich, Germany

The most important cue to localize low-frequency sounds (<1,500 Hz) in the azimuthal plane is the interaural time difference (ITD). Extraction of ITDs in the mammalian brainstem is performed by neurons of the medial superior olive (MSO) and the low-frequency limb of the lateral superior olive (ILSO). However, a single neuron responds differently for varying stimulus frequencies and it is thus unclear how ITDs are read out on a neuronal population level when considering non-trivial (non-sinusoidal) sound stimuli which have a broad spectrum.

To determine a possible encoder of ITDs for non-trivial stimuli, we have developed fast and effective models of the gerbil MSO and ILSO to simulate large populations of neurons, identified by the three parameters which fully characterize each individual neuron: the best frequency (BF), the characteristic delay (CD) and the characteristic phase (CP). The distribution of these parameters is taken from experiment.

In our model, the hemispheric difference model (2-channel model) fails to decode large ITDs (>300 microseconds) for high best frequencies (>1,000 Hz). We find that a possible decoding strategy can be formulated in the two-dimensional space spanned by the firing rates of MSO vs. ILSO in each hemisphere. We decode ITDs from this two-dimensional space via short-term estimates, where the length of the estimation window is optimized to approximate the ground truth ITD. This method of ITD estimation can be applied to analyze complex auditory scenes such as multiple concurring sound sources at different locations (cocktail party effect) and sound sources moving along the azimuthal plane (ITD variation).

Acknowledgements

This work was funded by the SFB870.

©(2019) Groß S, Leibold C

Cite as: Groß S, Leibold C (2019) Short-term ITD (interaural time difference) estimation of natural sound stimuli via effective models of binaural brainstem nuclei. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0215](https://doi.org/10.12751/nncn.bc2019.0215)

[T 67] The critical role of sodium channel parameters in the cardiac action potential

Pia Rose^{1,2}, Jan-Hendrik Schleimer^{1,2}, Susanne Schreiber^{1,2}

1. Institute for Theoretical Biology, Humboldt-Universität zu Berlin, Germany

2. Bernstein Center for Computational Neuroscience, Germany

The Long-QT syndrome is a heart-rhythm disorder which can lead to ventricular heart arrhythmias. It can be caused by different mutations including mutations of the $NaV1.5$ sodium channel [1]. In order to explain the arrhythmia-promoting effect of the channel mutations, many experimental studies have focussed on the persistent component of sodium currents [2]. However, mutated sodium channels often also exhibit changes in other parameters such as the voltage-dependence of their activation curves as well as timeconstants of channel activation and inactivation [3]. Although a number of modeling studies has derived predictions how the altered sodium channel parameters impair the cardiac action potential shape [2], a systematic analysis of the relative impact of the relevant parameters is currently lacking. Here, we present modelling results demonstrating that the sodium channel time-constants alone have no major effect on the cardiac action potential shape. In contrast, we find that shifts in the sodium channels' voltage dependence of the activation and inactivation curves can induce a bistability in the resting potential. The voltage shifts required for the bistability lie within the typically reported range for sodium channel mutations that are associated with Long-QT syndrome. Taken together, our results demonstrate that it is the modulation of the midpoint voltages of sodium channel (in-)activation, i.e., the channel's voltage dependence, that is primarily responsible for the most fundamental changes in the cardiac action potential shape. We thus present a conclusive mechanisms that explains the generic nature of the sodium-channel mediated induction of heart arrhythmias. The model also allows us to assess the importance of other parameters, such as the persistent sodium current, for better understanding the relation between ionic conductances and heart arrhythmias in the Long-QT-syndrome.

Acknowledgements

The project was supported by the German Federal Ministry of Education and Research (BMBF, 01GQ1403).

References

- 1 Schwartz, Peter J., Lia Crotti, and Roberto Insolia. "Long-QT syndrome: from genetics to management." *Circulation: Arrhythmia and Electrophysiology* 5.4 (2012): 868-877. [10.1161/CIRCEP.111.962019](https://doi.org/10.1161/CIRCEP.111.962019)
- 2 Moreau, Adrien, et al. "Sodium overload due to a persistent current that attenuates the arrhythmogenic potential of a novel LQT3 mutation." *Frontiers in pharmacology* 4 (2013): 126. [10.3389/fphar.2013.00126](https://doi.org/10.3389/fphar.2013.00126)
- 3 Chadda, Karan R., et al. "Sodium channel biophysics, late sodium current and genetic arrhythmic syndromes." *Pflügers Archiv-European Journal of Physiology* 469.5-6 (2017): 629-641. [10.1007/s00424-017-1959-1](https://doi.org/10.1007/s00424-017-1959-1)

©(2019) Rose P, Schleimer J, Schreiber S

Cite as: Rose P, Schleimer J, Schreiber S (2019) The critical role of sodium channel parameters in the cardiac action potential. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0216](https://doi.org/10.12751/nncn.bc2019.0216)

[T 68] Testing the state-dependent model of time perception against experimental evidence

Pirathitha Ravichandran^{1,2,3}, Joachim Hass^{2,3}

1. Ruprecht-Karls Universität Heidelberg, Heidelberg

2. SRH Hochschule Heidelberg, Heidelberg, Germany

3. Bernstein Center for Computational Neuroscience

Time plays an important role in our daily life. Coordinated movements, speech, and many other perceptions and actions are impossible without precise timing. Realistic computational models of interval timing in the mammalian brain are expected to provide key insights. Existing computational models of time perception have only been partially tested against experimental observations, such as the linear increase of time-encoding variables with time, the dopaminergic modulation of this increase, and the scalar property, i.e. the linear increase of the standard deviation of temporal estimates with time. Testing these properties has partially been hindered by the varying levels of abstraction of the models, many of which are lacking important biophysical properties constrained by experimental data. In this work, we incorporate existing computational models, namely ramping activity, synfire chains, state-dependent model and striatal beat model [1], into a biological plausible computational prefrontal cortex (PFC) model based on *in vivo* and *in vitro* recordings of rodents [2]. Here, we focus on the state-dependent model [3], which encodes time in the dynamic evolution of network states without the need for a specific network structure. We show that the naturally occurring heterogeneity in cellular and synaptic parameters incorporated in the PFC is sufficient to encode time over several hundreds of milliseconds. We also test the above-mentioned experimental properties. The model readout faithfully represents the duration between two stimuli applied to the superficial layers of the network, thus fulfilling the requirement of a linear encoding of time. Furthermore, a simulated activation of the D2 dopamine receptor leads to an underestimation of a given duration, consistent with experimental observations. While the model shows a sublinear increase of standard deviations of time estimates not reproducing the scalar property, this is in line with reported deviations of the scalar property for intervals of several hundred milliseconds [4]. For durations longer than a second, standard deviations quickly increase due to a deterioration of the time estimate. We conclude that this model is capable of representing durations of less than a second in a biophysically plausible setting compatible with all experimental findings in this regime. For larger durations, however, other mechanisms will likely come into play, as has been suggested by a recent theoretical study [5].

References

- 1 Hass, J., & Durstewitz, D. (2016) [10.1016/j.cobeha.2016.02.030](https://doi.org/10.1016/j.cobeha.2016.02.030)
- 2 Hass, J., Hertäg, L., & Durstewitz, D. (2016)
- 3 Buonomano, D.V. (2000) [10.1523/JNEUROSCI.20-03-01129.2000](https://doi.org/10.1523/JNEUROSCI.20-03-01129.2000)
- 4 Gibbon, J., Malapani, C., Dale, C. L., & Gallistel, C. R. (1997) [10.1016/S0959-4388\(97\)80005-0](https://doi.org/10.1016/S0959-4388(97)80005-0)
- 5 Hass, J., & Herrmann, J. M. (2012) [10.1162/NECO_a_00280](https://doi.org/10.1162/NECO_a_00280)

Sensory processing and perception

[T 69] How well do critical dynamics perform information integration in cortical networks?

Udo Alexander Ernst¹, Maik Schünemann¹, Nergis Tomen¹

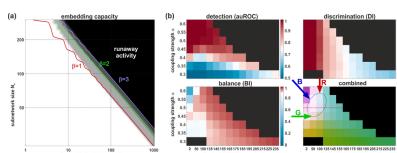
1. Theoretical Physics, University of Bremen, Bremen, Germany

Cortical networks have been shown to exhibit critical dynamics, a state between order and chaos characterized by scale-free distributions of synchronized events. Even though a functional role in optimizing information processing has long been attributed to criticality, it is not clear how it can support typical cortical computations, in particular in a strongly driven, inhomogeneous system such as the brain.

To establish a link between criticality and cortical function, we focus on the visual system. Here stimulus information is typically represented by large ensembles of neurons signalling the presence of elementary, local features in a scene. For making sense of this input, the brain has to quickly integrate local features into more global representations of contours, textures, shapes, or more abstract, into "figures". We suggest that such a task may be optimally performed by critical networks which can rapidly engage large neuronal groups.

We investigate this hypothesis by analysing a structured, recurrently coupled network of leaky integrate-and-fire neurons. As a "figure" we understand a particular configuration of local features. Each neuron is activated by a local feature's presence in a visual scene. Excitatory connections link neurons representing feature conjunctions typical for a figure, while inhibitory connections suppress uninformative conjunctions. When activated by external input, we required the network to realize some fundamental computations as rapidly and efficiently as possible: to detect a figure among distracters and to discriminate two figures presented simultaneously, while keeping a balance between representations of equally salient figures. As readout mechanism we assumed coincidence detection since it is easily realized by neurons.

Analysis of how many figure configurations the network can dynamically represent revealed a high capacity whose dependence on network parameters we describe analytically (Fig. a). Furthermore, we found spike avalanches supporting excellent detection and discrimination performances with low latencies. Hereby each functional requirement is optimized in a different region of parameter space (Fig. b). A global optimum is reached at the intersection of these regions, containing the point where an isolated figure subnetwork would be critical. From this observation we conclude that criticality in cortex arises as a consequence of optimizing neural systems for different functional requirements in parallel.



(a) Embedding capacity in dependence on subnetwork size (=number of local features in figure configuration). (b) Detection performance, discrimination index, and balance index in dependence on recurrent coupling strength and number of embeddings. Lower right: Combination of these three measures.

Acknowledgements

This project was supported by the BMBF (grant no. 01GQ1106) and the DFG (grant no. ER 324/3-2).

©(2019) Ernst UA, Schünemann M, Tomen N

Cite as: Ernst UA, Schünemann M, Tomen N (2019) How well do critical dynamics perform information integration in cortical networks?. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0218](https://doi.org/10.12751/nncn.bc2019.0218)

[T 70] Hue tuning curves in V4 change with visual context

Ari S. Benjamin¹, Pavan Ramkumar², Hugo Fernandes², Matthew Smith³, Konrad P. Kording^{1,2}

1. Dept. of Bioengineering, University of Pennsylvania, 210 South 33rd Street, Philadelphia PA 19104, United States

2. Shirley Ryan AbilityLab, 355 East Erie, Chicago, IL 60611, United States

3. Dept. of Ophthalmology, University of Pittsburgh, 203 Lothrop St., Pittsburgh, PA 15213, United States

To understand activity in the visual cortex, researchers often record how stimuli affect neural activity. A fundamental tenet of this approach is that knowledge obtained from visual responses in one context, say color stimuli, will generalize to other contexts, say natural scenes. This assumption is not often tested. Here, for neurons in macaque area V4, we first estimated tuning curves for hue using simplified stimuli of a single uniform hue, and then tested whether these would agree with hue tuning curves estimated using responses to natural images. To control for confounds affecting natural image responses, we developed a method to estimate hue tuning from a nonlinear encoding model of V4 neurons built from a pretrained convolutional network that accounts for visual features besides color. We found that neurons' hue tuning on single hues was not representative of their hue tuning on natural images. Thus, neurons in V4, including those that respond robustly to hue, respond to interactions between hue and other visual features. This finding exemplifies how tuning curves built from low-dimensional contexts can result in misleading understandings of neurons' general physiology.

Acknowledgements

A.B. and K.K. acknowledge U.S. National Institutes of Health grant number MH103910.

©(2019) Benjamin AS, Ramkumar P, Fernandes H, Smith M, Kording KP

Cite as: Benjamin AS, Ramkumar P, Fernandes H, Smith M, Kording KP (2019) Hue tuning curves in V4 change with visual context. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0219](https://doi.org/10.12751/nncn.bc2019.0219)

[T 71] Influence of chromatic contexts on the metric of perceptual color space

Nicolás Vattuone^{1,2,3,4}, Thomas Wachtler^{1,2}, Inés Samengo^{3,4}

1. Department of Biology II, Ludwig-Maximilians-Universität München, Martinsried, Germany

2. Bernstein Center for Computational Neuroscience, Munich, Germany

3. Department of Medical Physics, CNEA, Centro Atómico Bariloche, Argentina

4. Instituto Balseiro, CNEA, Centro Atómico Bariloche, Argentina

Understanding the way our brain processes visual information requires linking the physiological events registered along the visual pathways with the results of psychophysical experiments. The human ability to discriminate colors is known to vary across color space. For example, two lights near 600 nm, appearing orange, with a small wavelength difference $\Delta\lambda$ are more easily discriminated than two green lights near 500 nm with the same wavelength difference. Such non-uniformities can be explained in terms of the properties of the retinal cone photoreceptors. We modeled the absorption of photons as a Poisson process, with mean and variability depending on wavelength as dictated by the cone spectral sensitivities of the S, M and L cones, respectively. The trial-to-trial variability of the absorption process limits the discriminability of the electrical signals that represent the two compared colors in later processing stages. Fisher Information allowed us to construct a metric in the space of colors based on such maximal discriminability. The Crámer-Rao bound translated the Fisher metric into a prediction of discrimination experiments that reproduced psychophysical results, thereby bridging the gap between the photoreceptor absorption properties and visual performance. More recently, the behavioral experiments were extended to more complex situations, by surrounding the stimuli by a colored background. Not only did the background change the perceived color of each stimulus, but also, the degree of perceived similarity between stimuli was shown to depend on the chromaticity of the background. To explain these results, here we extend the previous theoretical model proposing that the effect of the background is to displace the representation of the chromaticity of each stimulus away from the chromaticity of the background, thereby enhancing the difference between stimulus and background. This repulsive effect allowed us to introduce a modified notion of similarity between colors emerging from Fisher Information Theory and to reproduce the experimental results.

References

- 1 Visual Sensitivities to Color Differences in Daylight. MacAdam, D. L. (1942) [10.1364/JOSA.32.000247](https://doi.org/10.1364/JOSA.32.000247)
- 2 Color discrimination and adaptation. (1992) J. Krauskopf and K. Gegenfurtner. [10.1016/0042-6989\(92\)90077-V](https://doi.org/10.1016/0042-6989(92)90077-V)
- 3 Human Wavelength Discrimination of Monochromatic Light Explained by Optimal Wavelength Decoding of Light of Unknown Intensity. (2011) L. Zhaoping, W.S. Geisler, K.A. May. [10.1371/journal.pone.00171](https://doi.org/10.1371/journal.pone.00171)
- 4 Derivation of human chromatic discrimination ability from an information-theoretical notion of distance in color space. (2016) da Fonseca and Samengo. [10.1162/NECO_a_00903](https://doi.org/10.1162/NECO_a_00903)
- 5 "Tilt" in color space: Hue changes induced by chromatic surrounds. T.Wachtler, S. Klauke. (2015) [10.1167/15.13.17](https://doi.org/10.1167/15.13.17)

©(2019) Vattuone N, Wachtler T, Samengo I

Cite as: Vattuone N, Wachtler T, Samengo I (2019) Influence of chromatic contexts on the metric of perceptual color space. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0220](https://doi.org/10.12751/nncn.bc2019.0220)

[T 72] Models of allocentric coding for reaching in naturalistic visual scenes

Parisa Abedi Khoozani¹, Paul Schrater², Dominik Endres³, Katja Fiehler⁴, Gunnar Blohm¹

1. Center for Neuroscience, Queen's university, 99 University Ave., Canada

2. Psychology & Computer Science, University of Minnesota, 75 E. River Rd., US

3. Psychology, Philipps-University Marburg, Gutenbergstr. 18, Germany

4. Psychology and sports science, Giessen University, Otto-Behaghel-Str. 10F, Germany

To reach objects, humans rely on relative positions of target objects to surrounding objects (allocentric) as well as to their own bodies (egocentric). Previous studies showed that in a memory task contextual factors of the scene modulate the combination weight of allocentric and egocentric information when reaching to visual targets. Egocentric coding for reaching is studied extensively; however, how allocentric information is coupled and used in reaching is unknown. Using a computational approach, we show that clustering mechanisms for allocentric coding combined with causal Bayesian integration of allocentric and egocentric information can account for the observed reaching behavior. To further understand allocentric coding, we propose two strategies, global vs. distributed landmark clustering (GLC vs. DLC). The GLC encodes the scene by creating a global landmark (cluster) and calculates the distance of objects from this point. The DLC encodes the position of the target using Barycentric coordinates relative to a distributed set of landmark points (object clusters). At the decoding phase, the goal is to infer the position of the target from a new scene (allocentric) and remembered information from encoding (egocentric). To make this inference, the GLC combines the egocentric and the new scene's global cluster points, in a causal Bayesian manner, to reconstruct target position, while the DLC combines the reconstructed target position from the new scene's clusters and encoding Barycentric coordinates with its remembered egocentric position, also in a causal Bayesian manner. Both models reproduced the reported data, but with different implications. GLC efficiently encodes the scene relative to a single virtual reference but loses all the local structure information. In contrary, DLC stores more redundant inter-object relationship information. Consequently, DLC is more sensitive to the changes in the scene. Further experiments must differentiate between the two proposed strategies. Future experiments should examine which of these strategies, if any, the brain might use.

Acknowledgements

This project was funded by NSERC (Canada) and DAAD (Germany) and DFG (Germany).

References

- 1 Mathias Klinghammer, Gunnar Blohm, Katja Fiehler; Contextual factors determine the use of allocentric information for reaching in a naturalistic scene. *Journal of Vision* 2015;15(13):24. doi: 10.1167/15.13.24 [10.1167/15.13.24](https://doi.org/10.1167/15.13.24)
- 2 Klinghammer, M., Blohm, G., & Fiehler, K. (2017). Scene Configuration and Object Reliability Affect the Use of Allocentric Information for Memory-Guided Reaching. *Frontiers in neuroscience*, 11, 204. doi:10.3389/fnins.2017.00204 [10.3389/fnins.2017.00204](https://doi.org/10.3389/fnins.2017.00204)
- 3 Kording, K. P., Beierholm, U., Ma, W. J., Quartz, S., Tenenbaum, J. B., & Shams, L. (2007). Causal inference in multisensory perception. *PLoS ONE*, 2(9). [10.1371/journal.pone.0000943](https://doi.org/10.1371/journal.pone.0000943)

©(2019) Abedi Khoozani P, Schrater P, Endres D, Fiehler K, Blohm G

Cite as: Abedi Khoozani P, Schrater P, Endres D, Fiehler K, Blohm G (2019) Models of allocentric coding for reaching in naturalistic visual scenes. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0221](https://doi.org/10.12751/nncn.bc2019.0221)

[T 73] Natural image statistics and contextual information modulate monkey V1 activity

Cem Uran¹, Alina Peter¹, Johanna Klon-Lipok^{1,2}, Rasmus Roese¹, Andreea Lazar¹, Sylvia van Stijn¹, William Barnes¹, Wolf Singer^{1,2}, Pascal Fries¹, Martin Vinck¹

1. Ernst Strüngmann Institute (ESI) for Neuroscience in Cooperation with Max Planck Society, Frankfurt am Main, Germany

2. Max Planck Institute for Brain Research, Frankfurt am Main, Germany

V1 neurons have receptive fields that are small and highly overlapping. This redundancy allows a basis for the visual scene that is robust to noise and loss of information. Various computational principles (efficient, predictive, and sparse coding) have been proposed considering the over-complete structure of V1 neurons and the regularities in natural scenes. We quantify the contextual information of V1 neurons using a deep learning network model, and show that contextual information, together with contrast of the stimuli explains the modulation of V1 activity.

Acknowledgements

We acknowledge the support of NVIDIA Corporation with the donation of the Titan X Pascal GPU used for this research.

©(2019) Uran C, Peter A, Klon-Lipok J, Roese R, Lazar A, van Stijn S, Barnes W, Singer W, Fries P, Vinck M

Cite as: Uran C, Peter A, Klon-Lipok J, Roese R, Lazar A, van Stijn S, Barnes W, Singer W, Fries P, Vinck M (2019)

Natural image statistics and contextual information modulate monkey V1 activity. Bernstein Conference 2019

Abstract. doi: [10.12751/nncn.bc2019.0222](https://doi.org/10.12751/nncn.bc2019.0222)

[T 74] Naturalistic stimuli for mice: a hemispheric dome setup

Magdalena Kautzky^{1,2}, Yongrong Qiu^{3,4}, Zhijian Zhao^{3,4}, Davide Crombie^{1,2}, Gregory Born^{1,2}, Martin Spacek¹, Thomas Euler^{3,4,5,6}, Laura Busse^{1,6,7}

1. Division of Neurobiology, Department Biology II, LMU Munich, Germany

2. Graduate School of Systemic Neuroscience (GSN), LMU Munich, Germany

3. Institute for Ophthalmic Research, University of Tuebingen, Germany

4. Centre for Integrative Neuroscience (CIN), University of Tuebingen, Germany

5. Bernstein Centre for Computational Neuroscience, Tuebingen, Germany

6. Senior authors

7. Bernstein Centre for Computational Neuroscience, Munich, Germany

For any given species, the design of an animal's visual system reflects the challenges of its ecological niche; thus, a promising approach to study visual system function is to probe the system with natural stimuli. However, presenting naturalistic stimuli in laboratory settings to non-primate species, such as mice, is challenging, because mice have a >300° wide field of view, including most of overhead space [4], and have cone opsins sensitive to light in the UV range [5]. These specializations are not well served by off-the-shelf consumer displays. To better match display technology to the specific adaptations of the mouse visual system, we here describe a hemispheric dome setup for controlled presentation of wide-field, naturalistic stimuli with appropriate spectral content [2]. In the dome setup, visual stimuli are generated by a video projector (TI) and projected onto the inner surface of the dome via a spherical mirror (Phenosys), which allows wide-field stimulation, but introduces spatial distortions [1]. Thus, the setup requires spatial calibration, which involves creating a warping mesh, such that stimulus textures applied to the mesh will be displayed without distortion. To create

the warping mesh, we project dots arranged in a radial grid onto the dome, where lines of longitude should appear vertical and circles of latitude should appear horizontal. We designed a calibration device consisting of a laser pointer that can be rotated around three spatial axes to indicate the true position of the individual dots. The projected dots can then be moved via keyboard interface to their desired locations. Finally, mesh vertices are fit to the calibrated dot locations, and the remaining pixels are calculated via interpolation. Our calibration method is relatively fast and precise, without assumptions about the specific geometry of the spherical mirror or the lens used for image capture. To provide our dome setup with naturalistic stimuli, we also established a light-weight, head-mounted camera, which can capture the visual environment from the perspective of freely roaming mice. We will improve the naturalism of this video footage by considering simultaneous eye movements. To this end, we adapted an eye tracking system for freely moving mice [3]. In summary, we have developed methods for acquisition and replay of naturalistic stimuli for mice, which consider both the mouse's large field of view and its spectral sensitivities.

Acknowledgements

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) Projektnummer 276693517 SFB 1233. We thank A. Meyer for assistance with setting up the eye tracking in freely moving mice, and M. Sotgia for general lab support.

References

- 1 P. Bourke. Spherical mirror: a new approach to hemispherical dome projection. Proceedings of the 3rd international conference on Computer graphics and interactive techniques in Australasia and South East Asia
- 2 K. Franke, A. M. Chagas, Z. Zhao, M. J. Y. Zimmermann, Y. Qiu, K. Szatko, T. Baden, and T. Euler. An arbitrary-spectrum spatial visual stimulator for vision research. bioRxiv, page 649566, May 2019 [10.1101/649566](https://doi.org/10.1101/649566)
- 3 A. F. Meyer, J. Poort, J. O'Keefe, M. Sahani, and J. F. Linden. A Head-Mounted Camera System Integrates Detailed Behavioral Monitoring with Multichannel Electrophysiology in Freely Moving Mice. Neuron, 100(1), 2018 [10.1016/j.neuron.2018.09.020](https://doi.org/10.1016/j.neuron.2018.09.020)
- 4 T. A. Seabrook, T. J. Burbidge, M. C. Crair, and A. D. Huberman. Architecture, Function, and Assembly of the Mouse Visual System. Annual Review of Neuroscience, 40 (1):499–538, 2017 [10.1146/annurev-neuro-071714-033842](https://doi.org/10.1146/annurev-neuro-071714-033842)
- 5 A. Szél, P. Röhlich, A. R. Caffé, B. Juliussen, G. Aguirre, and T. Van Veen. Unique topographic separation of two spectral classes of cones in the mouse retina. The Journal of Comparative Neurology, 325(3):327–342, Nov. 1992 [10.1002/cne.903250302](https://doi.org/10.1002/cne.903250302)

©(2019) Kautzky M, Qiu Y, Zhao Z, Crombie D, Born G, Spacek M, Euler T, Busse L

Cite as: Kautzky M, Qiu Y, Zhao Z, Crombie D, Born G, Spacek M, Euler T, Busse L (2019) Naturalistic stimuli for mice: a hemispheric dome setup. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0223](https://doi.org/10.12751/nncn.bc2019.0223)

[T 75] Neural correlations that limit stimulus information coding can facilitate discrimination performance

Martina Valente^{1,2}, Giuseppe Pica¹, Christopher D Harvey³, Stefano Panzeri¹

1. Neural Computation Laboratory, Istituto Italiano di Tecnologia, 38068 Rovereto (TN), Italy

2. Center for Mind/Brain Sciences, University of Trento, 38068 Rovereto (TN), Italy

3. Department of Neurobiology, Harvard Medical School, 02115 Boston (MA), USA

The ability to discriminate between sensory stimuli depends on the sensory information encoded in the activity of neuronal populations. Experimental and theoretical studies have reported that trial-by-trial correlations in neural activity at fixed stimulus, often referred to as noise correlations, can either increase or decrease the amount of information that can be extracted by a population of neurons [1]–[5]. The role of correlations in information coding is usually thought to propagate unchanged to behavioral performance, so that correlations that decrease (resp., increase) the encoded information are considered a limiting (resp., enhancing) factor for discrimination performance. However, this view relies on an often implicit and yet untested assumption: that the readout mechanism optimally converts the information carried by the whole population into a behavioral output.

To address how correlations in neural activity across time or between cells impact discrimination accuracy, we analyzed population activity recorded from the posterior parietal cortex of mice performing auditory or visual discrimination tasks [6], [7]. We studied perceptual discrimination as the intersection between sensory coding and information readout [8]. By comparing the performance of a decoder of stimulus identity applied to real and trial-shuffled population vectors, we found that cross-time and cross-neurons correlations decreased population coding accuracy. We characterized the information readout using a model that describes how the animal's choice depends on both the total population stimulus information (which is the variable that an optimal readout would use) and the redundancy of stimulus information across time or neurons (which an optimal readout would ignore, but which may be practically important for signal propagation). By fitting the model to the experimental data we show that redundancy influences the readout: population information is more efficiently translated into a behavioral output when the population code is redundant, across time or neurons. We used the fitted readout model to predict perceptual discrimination performance in the absence of neural correlations. We found that the negative effect of correlations on stimulus coding was compensated or over-compensated by the benefits of a more efficient readout, suggesting that neural correlations can be beneficial for task performance even if they decrease the overall information in neural activity.

Acknowledgements

We are grateful to Caroline Runyan and Ari Morcos for sharing the data they collected and published in Chris Harvey's Lab. This research was supported by the NIH BRAIN INITIATIVE Grant RO1 NIH NS108410 to SP and CDH.

References

1. E. Zohary, M. N. Shadlen, and W. T. Newsome, "Correlated neuronal discharge rate and its implications for psychophysical performance," *Nature*, vol. 370, no. 6485, pp. 140–143, Jul. 1994. [10.1038/370140a0](https://doi.org/10.1038/370140a0)
2. R. Romo, A. Hernández, A. Zainos, and E. Salinas, "Correlated Neuronal Discharges that Increase Coding Efficiency during Perceptual Discrimination," *Neuron*, vol. 38, no. 4, pp. 649–657, May 2003. [10.1016/S0896-6273\(03\)00287-3](https://doi.org/10.1016/S0896-6273(03)00287-3)
3. L. F. Abbott and P. Dayan, "The Effect of Correlated Variability on the Accuracy of a Population Code," *Neural Comput.*, vol. 11, no. 1, pp. 91–101, Jan. 1999. [10.1162/08997669300016827](https://doi.org/10.1162/08997669300016827)
4. S. Panzeri, S. R. Schultz, A. Treves, and E. T. Rolls, "Correlations and the encoding of information in the nervous system," *Proceedings. Biol. Sci.*, vol. 266, no. 1423, pp. 1001–12, May 1999.

10.1098/rspb.1999.0736

- 5 B. B. Averbbeck, P. E. Latham, and A. Pouget, "Neural correlations, population coding and computation," *Nat. Rev. Neurosci.*, vol. 7, no. 5, pp. 358–366, May 2006. [10.1038/nrn1888](https://doi.org/10.1038/nrn1888)
- 6 C. A. Runyan, E. Piasini, S. Panzeri, and C. D. Harvey, "Distinct timescales of population coding across cortex," *Nature*, vol. 548, no. 7665, pp. 92–96, Jul. 2017. [10.1038/nature23020](https://doi.org/10.1038/nature23020)
- 7 A. S. Morcos and C. D. Harvey, "History-dependent variability in population dynamics during evidence accumulation in cortex," *Nat. Neurosci.*, vol. 19, no. 12, pp. 1672–1681, Dec. 2016. [10.1038/nn.4403](https://doi.org/10.1038/nn.4403)
- 8 S. Panzeri, C. D. Harvey, E. Piasini, P. E. Latham, and T. Fellin, "Cracking the Neural Code for Sensory Perception by Combining Statistics, Intervention, and Behavior," *Neuron*, vol. 93, no. 3, pp. 491–507, Feb. 2017. [10.1016/j.neuron.2016.12.036](https://doi.org/10.1016/j.neuron.2016.12.036)

©(2019) Valente M, Pica G, Harvey CD, Panzeri S

Cite as: Valente M, Pica G, Harvey CD, Panzeri S (2019) Neural correlations that limit stimulus information coding can facilitate discrimination performance. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0224](https://doi.org/10.12751/nncn.bc2019.0224)

[T 76] Neuromorphic implementation of a brain-inspired spiking network for sparse stimulus encoding

Afshin Khalil¹, Anna-Maria Jürgensen¹, Giacomo Indiveri^{2,3}, Martin Paul Nawrot^{1,3}

1. Computational Systems Neuroscience, Institute of Zoology, University of Cologne, Biocenter, Zülpicherstr. 47B, 50674 Köln, Germany
2. Institute of Neuroinformatics, University of Zurich and ETH, Winterthurerstrasse 190, CH-8057 Zurich, Switzerland
3. Equal contribution

The insect olfactory sensory and memory pathway is a generic model system for the transformation from dense to sparse population coding. We implemented this circuit model using the SW BRIAN simulator and mapped it on a neuromorphic chip to compare their performances. Conventional approaches to the study of spiking neural networks (SNN) typically employ unrealistically precise neuron models and homogeneous parameters across the network. The Dynamic Neuromorphic Asynchronous Processor (DYNAP-SE) [1] used here is a full-custom analog/digital VLSI chip, which has both biologically plausible neural dynamics and parameter variability. Our circuit model is based on the full connectome available for the fly larva [2]. The recurrent network comprises three stages with less than 200 neurons. Peripheral stimulus encoding in broadly tuned sensory neurons (OSN, 1st stage) translates into a dense combinatorial rate code across the population of excitatory projection neurons (PNs) in the antennal lobe (2nd stage). At the level of the Kenyon cells (KC) in the mushroom body (3rd stage) the representation is population sparse (each stimulus activates only a fraction of KCs), and temporally sparse (a change in stimulus elicits only few spikes in activated KCs). A single GABAergic feedback neuron receives input from KCs and provides recurrent inhibition to KCs. In our model population sparseness is supported by (i) net divergent connectivity from PNs to KCs, (ii) lateral inhibition [3], and (iii) recurrent feedback inhibition from a single GABAergic neuron [4]. Temporal sparseness is facilitated by the cellular mechanism of spike frequency adaptation [3, 5] in OSNs and KCs [6]. Our preliminary data show that the neuromorphic implementation, despite intrinsic thermal noise and device mismatch (parameter heterogeneity), captures the functional aspects of transforming the sensory code allowing for a sparse and reliable representation of input data. Our circuit model can be extended to incorporate associative learning as presented by Jürgensen et al. (this volume). We propose that neuromorphic implementations of fundamental neural processing circuits for e.g. sparse encoding and data classification

[7] may find technical application in the real-time processing of data from multiple types of sensory devices.

Acknowledgements

Funded by the German Research Foundation (Grant No. 403329959) within the Research Unit 'Structure, Plasticity and Behavioral Function of the Drosophila Mushroom Body' (DFG-FOR 2705) and by the European Research Council (ERC) NeuroAgents (Grant No. 724295).

References

- 1 Moradi, S. et al. A Scalable Multicore Architecture with Heterogeneous Memory Structures for Dynamic Neuromorphic Asynchronous Processors (DYNAPs). *IEEE Trans. Biomed. Circuits Syst.* (2018) [10.1109/TBCAS.2017.2759700](https://doi.org/10.1109/TBCAS.2017.2759700)
- 2 Eichler, K. et al. The complete connectome of a learning and memory centre in an insect brain. *Nature* (2017) [10.1038/nature23455](https://doi.org/10.1038/nature23455)
- 3 Betkiewicz, R. et al. Circuit and cellular mechanisms facilitate the transformation from dense to sparse coding in the insect olfactory system. *bioRxiv* 240671 (2017) [10.1101/240671](https://doi.org/10.1101/240671)
- 4 Lin, A. C. et al. Sparse, decorrelated odor coding in the mushroom body enhances learned odor discrimination. *Nat. Neurosci.* (2014) [10.1038/nn.3660](https://doi.org/10.1038/nn.3660)
- 5 Farkhooi, F. et al. Cellular Adaptation Facilitates Sparse and Reliable Coding in Sensory Pathways. *PLoS Comput. Biol.* (2013) [10.1371/journal.pcbi.1003251](https://doi.org/10.1371/journal.pcbi.1003251)
- 6 Demmer, H. & Kloppenburg, P. Intrinsic Membrane Properties and Inhibitory Synaptic Input of Kenyon Cells as Mechanisms for Sparse Coding? *J. Neurophysiol.* (2009) [10.1152/jn.00183.2009](https://doi.org/10.1152/jn.00183.2009)
- 7 Schmuken, M. et al. A neuromorphic network for generic multivariate data classification. *Proc. Natl. Acad. Sci.* 111, 2081–2086 (2014) [10.1073/pnas.1303053111](https://doi.org/10.1073/pnas.1303053111)

©(2019) Khalili A, Jürgensen A, Indiveri G, Nawrot MP

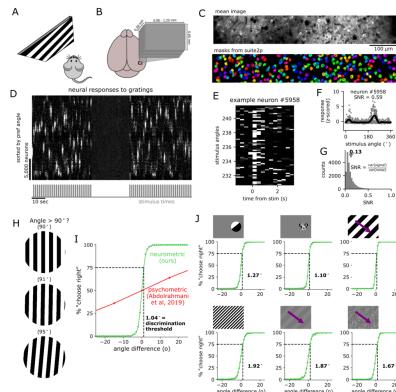
Cite as: Khalili A, Jürgensen A, Indiveri G, Nawrot MP (2019) Neuromorphic implementation of a brain-inspired spiking network for sparse stimulus encoding. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0225](https://doi.org/10.12751/nncn.bc2019.0225)

[T 77] One degree decoding error in mouse visual cortex

Carsen Stringer¹, Michalis Michaelos¹, Marius Pachitariu¹

1. HHMI Janelia Research Campus, Ashburn, VA, USA

Single neurons in visual cortex provide unreliable measurements of visual features, such as the orientation of a grating, due to high trial-to-trial variability or "noise". This noise is potentially detrimental to sensory coding, but only if it is of the information-limiting type, which cannot be averaged out over large numbers of neurons [1]. Here we show that information-limiting noise in visual cortex is negligible: on single trials we could decode the orientation of a visual stimulus with a median accuracy of 1° from 18,000 neuron recordings in awake, untrained mice. The decoding error was 0.5° smaller during locomotion, and $0.2\text{--}0.9^\circ$ larger to stimuli of reduced contrast, reduced duration, reduced extent, increased spatial frequency, with added noise or moving. These results imply that the limits of sensory perception are not set by neural noise in sensory cortex, but by the limitations of downstream decoders.



(A,B) Imaging setup. (C) Subset of imaging output. (D) Neural recording. (E,F) Single neuron single trial responses. (G) SNR across population. (H,I) Orientation discrimination performance using all neurons (green). (J) Decoding from other stimuli.

References

1 Ruben Moreno-Bote et al. (2014). Information Limiting Correlations. *Nature Neuroscience* [10.1038/nn.3807](https://doi.org/10.1038/nn.3807)

©(2019) Stringer C, Michaelos M, Pachitariu M

Cite as: Stringer C, Michaelos M, Pachitariu M (2019) One degree decoding error in mouse visual cortex. *Bernstein Conference 2019* Abstract. doi: [10.12751/nnnc.bn2019.0226](https://doi.org/10.12751/nnnc.bn2019.0226)

[T 78] Predictive coding in salamander retina

Danica Despotović¹, Olivier Marre¹, Corentin Joffrois¹, Matthew Chalk¹

1. Institut de la Vision, Sorbonne Université, INSERM, CNRS, 17 rue Moreau, F-75012, Paris, France

The influential efficient coding hypothesis proposes that early sensory neurons transmit maximal information about sensory stimuli, given internal constraints, such as energy and wiring [1]. According to this theory, neurons should invest most resources into encoding stimuli that are unexpected/surprising. Previous results [2] showed that many cells in the salamander retina respond strongly to an omitted flash in a periodic sequence of flashes (termed the omitted stimulus response; OSR). Additionally, the latency of the OSR varies linearly with the frequency of presented flashes, suggesting that neurons were responding to the violation of the temporal pattern. These results suggest that these cells may code for unexpected stimuli rather than for physical luminance. However, this hypothesis has not yet been tested rigorously. To investigate whether retinal ganglion cells (RGCs) encode surprise, we recorded their response to sequences of full-field flashes with various statistics. We found that the responses of a large fraction of neurons were consistent with the hypothesis that they encode surprise, given a simple internal (Markov) model of the stimulus statistics, and (additive gaussian) input noise. Our model could account for several qualitative aspects of the RGCs responses, including how the amplitude of the OSR increases with the number of flashes presented in a sequence. In addition, observed differences between the responses of different neurons could be well accounted for by assuming that the inputs to different neurons are corrupted by

varying levels of noise. These results suggest that encoding surprise, rather than physical luminance, could be a functional objective of retinal ganglion cells.

References

- 1 Barlow HB. Possible principles underlying the transformation of sensory messages. *Sensory communication*. 1961 Sep;1:217-34. [10.7551/mitpress/9780262518420.003.0013](https://doi.org/10.7551/mitpress/9780262518420.003.0013)
- 2 Schwartz G, Harris R, Shrom D, Berry II MJ. Detection and prediction of periodic patterns by the retina. *Nature neuroscience*. 2007 May;10(5):552. [10.1038/nn1887](https://doi.org/10.1038/nn1887)

©(2019) Despotović D, Marre O, Joffrois C, Chalk M

Cite as: Despotović D, Marre O, Joffrois C, Chalk M (2019) Predictive coding in salamander retina. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0227](https://doi.org/10.12751/nncn.bc2019.0227)

[T 79] Presynaptic inhibition normalises responses and gates the interpretation of sensory stimuli in recurrent networks

Laura Bella Naumann^{1,2}, Henning Sprekeler^{1,2}

1. *Modelling of Cognitive Processes, TU Berlin, Marchstr. 23, 10587 Berlin, Germany*

2. *Bernstein Center for Computational Neuroscience, Philippstr. 13, 10115 Berlin, Germany*

Sensory processing in neural circuits requires integration of input signals under a broad range of conditions. It is believed that networks of neurons are nevertheless held in an operational regime by the process of response normalisation, the multiplicative scaling of neural responses depending on local population activity. Normalisation has been observed in primary visual cortex as well as other sensory modalities, and can explain a variety of population response effects, such as sublinear stimulus summation, contrast adaptation and surround suppression [1].

Although normalisation of responses is widely observed in experiments, it does not trivially emerge in models of neural circuits [1]: Existing models are either limited to a particular normalisation phenomenon, do not account for the underlying biophysical mechanisms, or rely on restrictive assumptions such as supralinear input-output functions [2].

In this work we argue for presynaptic inhibition as a simple mechanism that can perform different types of response normalisation in neural circuits. Experimental studies have revealed that signal transmission at excitatory synapses is suppressed by activation of presynaptic GABA(B) receptors [3]. This presynaptic inhibition can be triggered by interneuron activity through GABA spillover from inhibitory synapses. The suppressive effect is activity-dependent and reversible, making presynaptic inhibition a candidate mechanism for normalisation.

Using computational modelling, we show that presynaptic inhibition divisively scales neural responses in recurrent circuits. The underlying mechanism depends on the activity of nearby neurons, resulting in both sublinear summation of inputs and surround suppression. Moreover, we find that in networks with Hebbian assemblies, presynaptic inhibition amplifies weak stimuli compared to stronger ones. This differs from previously proposed models [2] but is in accordance with the notion that weak stimuli require more interpretation than strong, unambiguous signals. Consequently, presynaptic inhibition gates the gradual transition between pattern completion for weak and representation of strong afferent signals depending on stimulus strength.

In summary, the multiplicative character of presynaptic inhibition can not only account for a range of response normalisation effects, but also serves as a gating mechanism for the interpretation of sensory stimuli.

References

- 1 Carandini, M. and Heeger, D.J., 2012. Normalization as a canonical neural computation. *Nature Reviews Neuroscience*, 13(1), p.51.
- 2 Rubin, D.B., Van Hooser, S.D. and Miller, K.D., 2015. The stabilized supralinear network: a unifying circuit motif underlying multi-input integration in sensory cortex. *Neuron*, 85(2), pp.402-417.
- 3 Urban-Ciecko, J., Fanselow, E.E. and Barth, A.L., 2015. Neocortical somatostatin neurons reversibly silence excitatory transmission via GABA_A receptors. *Current Biology*, 25(6), pp.722-731.

©(2019) Naumann LB, Sprekeler H

Cite as: Naumann LB, Sprekeler H (2019) Presynaptic inhibition normalises responses and gates the interpretation of sensory stimuli in recurrent networks. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0228](https://doi.org/10.12751/nncn.bc2019.0228)

[T 80] Pupil-indexed arousal modulates thalamic activity at multiple time-scales

Davide Crombie^{1,2}, Martin Spacek¹, Christian Leibold^{1,3}, Laura Busse^{1,3}

1. Department Biology II, Division of Neuobiology, LMU Munich, Grosshaderner Str. 2, D-82152, Planegg-Martinsried, Germany
2. Graduate School of Systemic Neurosciences, LMU Munich, Großhaderner Str. 2, D-82152, Planegg-Martinsried, Germany
3. Bernstein Center for Computational Neuroscience, Großhaderner Str. 2, D-82152, Planegg-Martinsried, Germany

Neural activity, spontaneous and evoked, is highly variable. One source of this variability is arousal, which fluctuates spontaneously during wakefulness [1, 2]. Two distinct arousal-associated firing modes have been reported in thalamus [3], which transmits information from the sensory periphery to cortex while receiving various modulatory inputs [4]. Here we investigate the timescales at which thalamic firing mode is modulated by arousal.

To infer spontaneous fluctuations of arousal, we exploited pupil size as a well known behavioral correlate [5, 6, 7, 8]. We used video-based eye tracking to extract pupil size time-courses. These are complex signals resulting from multiple non-linear and non-stationary processes, violating the basic assumptions of the DTFT. We thus used the Hilbert-Huang transform [9] to decompose the pupil size signal into a physically meaningful set of intrinsic mode functions (IMFs) and their associated Hilbert phases. We show that these IMF basis sets are largely orthogonal and statistically independent, and capture 99% of the variance of the original signal in frequency ranges of 0.5 to 0.004 Hz after removal of components with low energy [10].

To test how these pupil signal components relate to thalamic activity, we performed extracellular silicon probe recordings from the dLGN of awake, behaving mice. We separated spiking activity of each single unit (34 units from 5 mice) into burst spikes, associated with low arousal, and tonic spikes, associated with high arousal. We then compiled phase histograms for each of these firing modes and concurrent IMFs. We found that burst and tonic spikes were associated with opposing phases of the IMFs in a frequency band centred around 0.3 Hz. Burst spikes tended to occur during phases of contraction and tonic spikes during dilation (0.38 and -0.45 respectively; MWU $p=2.8 \times 10^{-20}$). Phase preferences were weaker during periods of locomotion than

during quiescence. At lower IMF frequencies (<0.1 Hz) burst spikes were associated with IMF troughs and tonic spikes with peaks, likely reflecting gross locomotor activity. Firing mode phase preference for fluctuations above 0.1 Hz show that activity in the thalamus is modulated over several seconds in accordance with recent findings in the cortex [5, 6, 7]. These fluctuations should thus be included in models of corticothalamic activity to capture the impact of firing mode on information transfer to cortex [11, 12].

Acknowledgements

This work was funded by the Deutsche Forschungsgemeinschaft SFB 870 project 19 (to LB), and by a SmartStart2 Fellowship (Volkswagen Stiftung; to DC).

References

- 1 M. J. McGinley, M. Vinck, J. Reimer, R. Batista-Brito, E. Zagha, C. R. Cadwell, A. S. Tolias, J. A. Cardin, and D. A. McCormick. Waking state: rapid variations modulate neural and behavioral responses. *Neuron* , 87(6):1143–1161, 2015. [10.1016/j.neuron.2015.09.012](https://doi.org/10.1016/j.neuron.2015.09.012)
- 2 E. Zagha and D. A. McCormick. Neural control of brain state. *Current Opinion in Neurobiology* , 29:178–186, 2014. [10.1016/j.conb.2014.09.010](https://doi.org/10.1016/j.conb.2014.09.010)
- 3 S. M. Sherman. Tonic and burst firing: dual modes of thalamocortical relay. *Trends in neurosciences* , 24(2):122–126, 2001. [10.1016/S0166-2236\(00\)01714-8](https://doi.org/10.1016/S0166-2236(00)01714-8)
- 4 D. Kerschensteiner and W. Guido. Organization of the dorsal lateral geniculate nucleus in the mouse. *Visual neuroscience* , 34, 2017. [10.1017/S0952523817000062](https://doi.org/10.1017/S0952523817000062)
- 5 M. J. McGinley, S. V. David, and D. A. McCormick. Cortical membrane potential signature of optimal states for sensory signal detection. *Neuron* , 87(1):179–192, 2015. [10.1016/j.neuron.2015.05.038](https://doi.org/10.1016/j.neuron.2015.05.038)
- 6 J. Reimer, E. Froudarakis, C. R. Cadwell, D. Yatsenko, G. H. Denfield, and A. S. Tolias. Pupil fluctuations track fast switching of cortical states during quiet wakefulness. *Neuron* , 84(2):355–362, 2014. [10.1016/j.neuron.2014.09.033](https://doi.org/10.1016/j.neuron.2014.09.033)
- 7 J. Reimer, M. J. McGinley, Y. Liu, C. Rodenkirch, Q. Wang, D. A. McCormick, and A. S. To-lias. Pupil fluctuations track rapid changes in adrenergic and cholinergic activity in cortex. *Nature communications* , 7:13289, 2016. [10.1038/ncomms13289](https://doi.org/10.1038/ncomms13289)
- 8 M. Vinck, R. Batista-Brito, U. Knoblich, and J. A. Cardin. Arousal and locomotion make distinct contributions to cortical activity patterns and visual encoding. *Neuron* , 86(3):740–754, 2015. [10.1016/j.neuron.2015.03.028](https://doi.org/10.1016/j.neuron.2015.03.028)
- 9 N. E. Huang, Z. Shen, S. R. Long, M. C. Wu, H. H. Shih, Q. Zheng, N.-C. Yen, C. C. Tung, and H. H. Liu. The empirical mode decomposition and the hilbert spectrum for nonlinear and non-stationary time series analysis. *P ROY SOC A MATH PHY*, 454(1971):903–995, 1998. [10.1098/rspa.1998.0193](https://doi.org/10.1098/rspa.1998.0193)
- 10 Z. Wu and N. E. Huang. A study of the characteristics of white noise using the empirical mode decomposition method. *P ROY SOC A MATH PHY*, 460(2046):1597–1611, 2004. [10.1098/rspa.2003.1221](https://doi.org/10.1098/rspa.2003.1221)
- 11 H. A. Swadlow and A. G. Gusev. The impact of bursting thalamic impulses at a neocortical synapse. *Nature neuroscience* , 4(4):402, 2001. [10.1038/86054](https://doi.org/10.1038/86054)
- 12 C. J. Whitmire, D. C. Millard, and G. B. Stanley. Thalamic state control of cortical paired-pulse dynamics. *Journal of neurophysiology* , 117(1):163–177, 2016. [10.1152/jn.00415.2016](https://doi.org/10.1152/jn.00415.2016)

©(2019) Crombie D, Spacek M, Leibold C, Busse L

Cite as: Crombie D, Spacek M, Leibold C, Busse L (2019) Pupil-indexed arousal modulates thalamic activity at multiple time-scales. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0229](https://doi.org/10.12751/nncn.bc2019.0229)

[T 81] Reconstruction of vibrissa deflection direction from neuronal activity in the rat barrel cortex

Roman Makarov¹, Azat Nasretdinov¹, Guzel Valeeva¹, Mikhail Sintsov¹

1. Laboratory of Neurobiology, Kazan Federal University, Kazan, Russia

Information transfer and processing in the mammalian brain is mediated by the activity of individual neurons. Cracking the neural code is a crucial yet challenging problem. One of the important questions related to this problem is whether the information in the brain is represented by the exact spike timing or by the firing rate. To address this question, we attempted to reconstruct the direction of a vibrissa deflection, using the evoked neuronal activity in the barrel cortex of anesthetized rats. To reduce the baseline bias, the deflections were randomized using an in-house 2D piezo deflector. To record neuronal activity, we first localized the principal cortical column using optical intrinsic signal imaging (OISi) and then implanted a multisite silicon probe into the column. We then performed the spike cluster analysis to extract the activity of individual cells and constructed spike features of cluster N-grams ranging from 1 to 3. We then trained a machine learning model based on the tree gradient boosting algorithm to reconstruct the vibrissa deflection angle from the N-grams scored by the Pearson correlation coefficient. First, we showed that using just cluster monograms, the model successfully reconstructed angles of vibrissa deflections with the score reaching 0.8. Second, we showed that accounting for the bi- and trigrams failed to improve the score significantly. We thus conclude that, in practice, the spike rate is a sufficient measure of neuronal activity to study vibrissae state in the rat's somatosensory cortex.

©(2019) Makarov R, Nasretdinov A, Valeeva G, Sintsov M

Cite as: Makarov R, Nasretdinov A, Valeeva G, Sintsov M (2019) Reconstruction of vibrissa deflection direction from neuronal activity in the rat barrel cortex. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0230](https://doi.org/10.12751/nncn.bc2019.0230)

[T 82] The emergence of multiple retinal cell types through efficient coding of natural movies

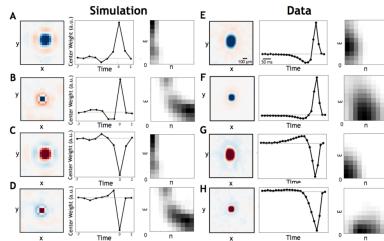
Samuel A. Ocko¹, Jack Lindsey¹, Surya Ganguli^{1,2}, Stephane Deny¹

1. Applied Physics, Stanford University, Stanford, USA

2. Google Brain, Google, Mountain View, California

One of the most striking aspects of early visual processing in the retina is the immediate parcellation of visual information into multiple parallel pathways, formed by different retinal ganglion cell types each tiling the entire visual field. Existing theories of efficient coding have been unable to account for the functional advantages of such cell-type diversity in encoding natural scenes. Here we go beyond previous theories to analyze how a simple linear retinal encoding model with different convolutional cell types efficiently encodes naturalistic spatiotemporal movies given a fixed firing rate budget. We find that optimizing the receptive fields and cell densities of two cell types makes them match the properties of the two main cell types in the primate retina, midget and parasol cells, in terms of spatial and temporal sensitivity, cell spacing, and their relative ratio. Moreover, our theory gives a precise account of how the ratio of midget to parasol cells decreases with retinal eccentricity. Also, we train a nonlinear encoding model with a rectifying nonlinearity to efficiently encode naturalistic movies, and again find emergent receptive

fields resembling those of midget and parasol cells that are now further subdivided into ON and OFF types. Thus our work provides a theoretical justification, based on the efficient coding of natural movies, for the existence of the four most dominant cell types in the primate retina that together comprise 70% of all ganglion cells.



A nonlinear convolutional autoencoder reproduces primate retinal cell types. Within each panel, Left: spatial receptive field (RF). Center: temporal RF. Right: Space-time power spectrum of the RF.

©(2019) Ocko SA, Lindsey J, Ganguli S, Deny S

Cite as: Ocko SA, Lindsey J, Ganguli S, Deny S (2019) The emergence of multiple retinal cell types through efficient coding of natural movies. Bernstein Conference 2019 Abstract. doi: 10.12751/nncn.bc2019.0231

[T 83] Theoretical principles of population coding of static stimuli

Shuai Shao^{1,2}, Kai Röth^{1,3}, Julijana Gjorgjieva^{1,3}

1. Max Planck Institute for Brain Research, Frankfurt, Germany

2. Department of Neurophysiology, Radboud University, Nijmegen, Netherlands

3. School of Life Sciences Weihenstephan, Technical University Munich, Munich, Germany

In the view of evolution, neurons should be optimally configured to encode information most efficiently. This is the main point of the efficient coding theory. The efficiency of neuron encoding is commonly quantified with the Shannon mutual information between a stimulus and the neuron's spikes. Previous work has shown that for a single neuron with Poisson noise, a discrete tuning curve maximizes the Shannon mutual information between stimulus and spikes, with the number of discrete steps determined by the expected spike count (Shamai IEE 1990; Nikitin et al. PRL 2009). However, in neuronal systems information is usually processed simultaneously by many neurons in parallel, which form a population code. This poses the question of how should multiple neurons that together code for a common stimulus optimize their tuning curves to provide the optimal stimulus encoding. Previous theoretical approaches have solved this optimal population coding problem with binary neurons (Gjorgjieva et al. bioRxiv 2017). However, binary neurons are not always optimal, especially when the expected spike count increases. In biological systems in particular, tuning curves usually do not manifest as binary and appear continuous due to the presence of noise. We first extended the theory for a single neuron, demonstrating that the optimal tuning curves remain discrete for any type of noise, as long as the state with zero expected spike count is non-noisy. Next, we explored optimal configurations of a population of neurons with discrete tuning curves of any number of steps beyond two. We found that the best configuration is one where all the neurons in the population should have the same shape of tuning

curves in the probability space of stimuli, and that they should position the thresholds of each step to divide the probability space equally. In addition to deriving the theory for monotonically increasing curves (ON cells), we also showed that one can replace any one of them with a monotonically decreasing curve (OFF cells) without losing any information. Since systems with ON-OFF splitting have been observed in a wide range of neuronal sensory systems experimentally (Berens et al. Nature 2017, Ratiff et al. PNAS 2010, Mamiya et al. Neuron 2018) our work provides a neural coding principle applicable to multiple scenarios.

Acknowledgements

Shuai Shao, Kai Röth and Julijana Gjorgjieva would like to thank the support from Max Planck Society.

References

- 1 Nikitin, A. P., Stocks, N. G., Morse, R. P., & McDonnell, M. D. (2009). Neural population coding is optimized by discrete tuning curves. *Physical Review Letters*, 103(13), 1–4. [10.1103/PhysRevLett.103.138101](https://doi.org/10.1103/PhysRevLett.103.138101)
- 2 Gjorgjieva, J., Meister, M., & Sompolinsky, H. (2017). Optimal sensory coding by populations of ON and OFF Neurons. *bioRxiv*, 131946. [10.1101/131946](https://doi.org/10.1101/131946)
- 3 Shamai, S. (1990). Capacity of a pulse amplitude modulated direct detection photon channel. *IEE Proceedings I Communications, Speech and Vision*, 137(6), 424. [10.1049/ip-i-2.1990.0056](https://doi.org/10.1049/ip-i-2.1990.0056)
- 4 Berens, P., Schubert, T., Euler, T., Bethge, M., Baden, T., & Franke, K. (2017). Inhibition decorrelates visual feature representations in the inner retina. *Nature*, 542(7642), 439–444. [10.1038/nature21394](https://doi.org/10.1038/nature21394)
- 5 Charles P. Ratiff, B. G. Borghuis, Y.-H. Kao, P. Sterling, and V. Balasubramanian. Retina is structured to process an excess of darkness in natural scenes. *Proc Natl Sci USA*, 107:17368–17373, 2010. [10.1073/pnas.1005846107](https://doi.org/10.1073/pnas.1005846107)
- 6 Mamiya, A., Gurung, P., & Tuthill, J. C. (2018). Neural Coding of Leg Proprioception in Drosophila. *Neuron*, 100(3), 636–650.e6. [10.1016/j.neuron.2018.09.009](https://doi.org/10.1016/j.neuron.2018.09.009)

©(2019) Shao S, Röth K, Gjorgjieva J

Cite as: Shao S, Röth K, Gjorgjieva J (2019) Theoretical principles of population coding of static stimuli. *Bernstein Conference 2019* Abstract. doi: [10.12751/mncn.bc2019.0232](https://doi.org/10.12751/mncn.bc2019.0232)

[T 84] The Symmetry Within: The Head Direction Circuit of Two Species

Ioannis Pisokas¹

1. School of Informatics, University of Edinburgh, 10 Crichton St, Edinburgh, EH8 9AB, United Kingdom

Recent studies of the Central Complex brain area of the fruit fly *Drosophila melanogaster* have identified neurons with localised activity that tracks the animal's heading direction, in a similar fashion to rat 'head direction' cells. These neurons are part of a neural circuit with dynamics resembling those of a ring attractor. Other insects have a homologous circuit sharing a generally similar topographic structure but with some important differences. Most salient are the differences in the pattern of inhibitory connections and the shape of the Ellipsoid Body that forms a torus in *Drosophila melanogaster* but has open edges in other insects.

In this study, we reverse engineer and compare the neural circuits found in the fruit fly *Drosophila melanogaster* and the desert locust *Schistocerca gregaria*. We demonstrate that once the neural circuitry is untangled the effective circuits in the two species are identical. Both effective circuits have an eight-fold symmetry with each class of neurons assuming the same roles in both species. That is, even though in *Drosophila melanogaster* the Protocerebral Bridge has nine glomeruli on each hemisphere instead of the eight glomeruli found in *Schistocerca gregaria*, the effective circuit has eight-fold symmetry as that of the locust *Schistocerca gregaria*. The ensemble of $\Delta 7$ neurons

provides global, uniform, inhibition in *Drosophila melanogaster* but non-uniform focused inhibition in the locust *Schistocerca gregaria*. In both species, the P-EN, E-PG and P-EG neurons form a ring with eight-fold symmetry in which the P-EG neurons form local feedback loops improving the stability of the activity 'bump'. These findings reveal that even though the neural anatomy differs significantly between these two evolutionary remote species the effective circuit is preserved.

References

1. S. S. Kim, H. Rouault, S. Druckmann, and V. Jayaraman. Ring attractor dynamics in the *Drosophila* central brain. *Science*, 356(6340):849– 853, 2017.
2. K. S. Kakaria and B. L. de Bivort. Ring Attractor Dynamics Emerge from a Spiking Model of the Entire Protocerebral Bridge. *Frontiers in Behavioral Neuroscience*, 11:8, 2017.
3. T. Wolff and G. M. Rubin. Neuroarchitecture of the *Drosophila* central complex: A catalog of nodulus and asymmetrical body neurons and a revision of the protocerebral bridge catalog. *Journal of Comparative Neurology*, 526(16):2585–2611, 2018.
4. I. Pisokas and B. Webb. Reverse Engineering of the Insect Heading Encoding Circuit. *Proceedings of the Workshop on Robust Artificial Intelligence for Neurorobotics*, 2019.

©(2019) Pisokas I

Cite as: Pisokas I (2019) The Symmetry Within: The Head Direction Circuit of Two Species. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0233](https://doi.org/10.12751/nncn.bc2019.0233)

[T 85] Vestibular and Visual Heading Perception in Parkinson's Disease Patients Treated with Subthalamic Deep Brain Stimulation

Sinem B Beylergil^{1,2}, Mikkel V Petersen¹, Angela M Noecker¹, Sarah Ozinga¹, Mark F Walker^{2,3}, Cameron C McIntyre¹, Aasef G Shaikh^{1,2,3,4}

1. Biomedical Engineering, Case Western Reserve University, Cleveland, 44106, OH, USA

2. Daroff-Dell'Osso Ocular Motor Laboratory, Louis Stokes Veterans Affairs Medical Center, Cleveland, 44106, OH, USA

3. Department of Neurology, Case Western Reserve University, Cleveland, 44106, OH, USA

4. Movement Disorders Center, University Hospitals, Cleveland, 44106, OH, USA

The deficits in perception of self-motion, i.e. heading, may contribute to postural instability, impaired gait, and falls in Parkinson's Disease (PD). Heading perception based on visual and vestibular input might be modulated by subthalamic deep brain stimulation (StnDBS) through basal ganglia output's influence on the neural activity in the cerebellum and thalamus. The aim of this study is to investigate the effect of PD on visual and vestibular heading perception. We also test the hypothesis that StnDBS influences the vestibular network responsible for heading perception by modulating the cerebello-thalamic pathway. 10 PD patients with bilateral StnDBS and 5 age-matched healthy participants participated in the study. All subjects performed a two-alternative, forced-choice heading discrimination task, while they were seated in a chair mounted on a motion platform, i.e. hexapod (MOOGTM, East Aurora, NY). A passive whole-body translation along linear horizontal trajectories to the right or left was applied to the subjects in complete darkness. In a consecutive experiment, the same population received optic flow stimuli simulating linear forward motion through a 3D virtual reality google while being seated on a stationary chair with a head fixation. In both tasks, subjects were asked to indicate whether the movement was rightward or leftward relative to straight-ahead. PD subjects performed the experiments with their StnDBS off and on at therapeutic settings. Sensitivity to subtle variations in heading direction was

derived for each subject using a Gaussian psychometric function. Additionally, patient-specific anatomical models were built based on brain imaging data. Percentages of stimulated axonal pathways were predicted using finite element electric field models of StnDBS. Compared to healthy subjects, the PD group had higher detection thresholds in both vestibular and visual heading perception tasks. However, PD patients were more sensitive to the variations in heading direction in the visual task than the vestibular task independent of StnDBS condition. When the StnDBS was turned on, both vestibular and visual heading perception performance changed in patients. The anatomical model of the StnDBS revealed that cerebello-thalamic tract fibers might be responsible for this change. These results provide insight into the vestibular system's role in spatial navigation deficits in PD while elucidating the neural structures involved in heading perception.

Acknowledgements

This work was supported by Dr. Aasef G. Shaikh's Career Development Grant from the Americal Academy of Neurology and George C. Cotzias Memorial Fellowship.

©(2019) Beylgeril SB, Petersen MV, Noecker AM, Ozinga S, Walker MF, McIntrye CC, Shaikh AG

Cite as: Beylgeril SB, Petersen MV, Noecker AM, Ozinga S, Walker MF, McIntrye CC, Shaikh AG (2019) Vestibular and Visual Heading Perception in Parkinson's Disease Patients Treated with Subthalamic Deep Brain Stimulation. Bernstein Conference 2019 Abstract. doi: 10.12751/nncn.bc2019.0234

[T 86] Neural basis of social behavior in fruit flies

Ines M.A. Ribeiro¹, Michael Drews¹, Alexander Borst¹

1. Circuits-Computations-Models, Max Planck Institute Neurobiology, Am Klopferspitz 18, 82152 Martinsried, Germany

Many social interactions, such as courtship or aggression, demand proximity between the interacting partners. *Drosophila melanogaster* males court very close to the female, to tap the female abdomen with their foreleg and to produce a species-specific song within the female hearing range. Fruit flies court on food substrates crowded with other flies, including other males eager to court. To beat competition and be successful, the courting male must remain close to the female and relies on vision to do so. Visual cues, sensed at the retina, are processed in the optic lobe neuropiles, which extract visual features from the initial percept, such as contrast or motion. Visual features reach the central brain via visual projection neurons in invertebrates. How visual features are processed in central neural circuits and used to ultimately guide behavior remains poorly understood. Recently, we identified LC10a lobula visual projection neurons as key players for the male to remain close to the female during courtship. LC10a neurons are crucial for tracking small visual objects, in contrast to wide field motion stimuli. In line with this, LC10a neurons are preferentially sensitive to small moving objects. LC10a neurons project to the anterior optic tubercle, the largest optic glomerulus in the fly brain, that retains retinotopic organization of LC10a terminals. Interestingly, the anterior optic tubercle receives inputs from other LC10 subtypes, called LC10b, LC10c and LC10d. However, LC10b, LC10c and LC10d neurons are dispensable for males to remain close to the female during courtship. The dendrites from LC10b, LC10c and LC10d neurons arborize in different layers of the lobula optic lobe neuropile, suggesting that they might receive diverse visual inputs. To test this, we monitored calcium transients in all LC10 subtypes while presenting a large set of visual stimuli and found that LC10 subtypes

sense different sets of visual features. The LC10 subtypes could thus encode visual features pertaining to the same visual object, implicating combination of visual features in the anterior optic tubercle. Alternatively, LC10 subtypes could provide positional information of diverse visual objects, which would run in parallel in the anterior optic tubercle. Our findings open the door to uncover how visual information is processed in the central brain to ultimately guide proximity between partners in social interactions.

©(2019) Ribeiro IM, Drews M, Borst A

Cite as: Ribeiro IM, Drews M, Borst A (2019) Neural basis of social behavior in fruit flies. *Bernstein Conference 2019*

Abstract. doi: [10.12751/nncn.bc2019.0235](https://doi.org/10.12751/nncn.bc2019.0235)

[T 87] The evolution and neural basis of escape responses to looming visual stimuli in ecologically divergent *Peromyscus* mice

Felix Baier¹, Hopi E. Hoekstra¹

1. Department of Organismic & Evolutionary Biology and Department of Molecular & Cellular Biology,
Harvard University, 16 Divinity Avenue, Cambridge, MA 02138, USA

Rapidly approaching, 'looming' objects signal imminent threat to many animals and typically elicit defensive behaviors, such as orienting, freezing, darting, and flight. The looming response has recently emerged as a model for visual behavior in laboratory mice, but whether species-specific differences exist in this innate behavior and how these arise from changes in the underlying neural circuitry remains unknown. Here we focus on two species of deer mice, which evolved in ecologically distinct habitats: *Peromyscus maniculatus* occupy prairie environments with abundant cover in the midwestern United States, while *P. polionotus* colonize open oldfield habitat in the southeastern US. We found that laboratory-raised mice of the two species respond similarly with deceleration and freezing to a laterally moving, sweeping stimulus. By contrast, the two species show opposing behavioral responses to a looming stimulus: *P. maniculatus* typically dart or flee to a refuge, while *P. polionotus* more often slow down and/or briefly freeze. This behavior is a predator-specific response and cannot be explained by differences in the response to visual novelty. We find that the responses in both species are not invariantly expressed, but instead scale with threat saliency, and demonstrate that *P. polionotus* has a higher escape threshold than *P. maniculatus*. Furthermore, similar opposing responses occur to an acoustic predator stimulus, suggesting that the underlying mechanisms are independent of sensory modality. To uncover the neural basis of these divergent behaviors, we are characterizing immediate early gene (IEG) neuronal activity in several brain regions implicated in the looming response. Our ultimate goal is to functionally perturb neuronal populations with optogenetic, *in vitro* electrophysiological, viral and chemogenetic approaches to identify the neural mechanisms underlying the evolution of ecologically relevant escape behavior.

©(2019) Baier F, Hoekstra HE

Cite as: Baier F, Hoekstra HE (2019) The evolution and neural basis of escape responses to looming visual stimuli in ecologically divergent *Peromyscus* mice. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0236](https://doi.org/10.12751/nncn.bc2019.0236)

Neurons, networks, dynamical systems

[T 88] Long-Range Neuronal Coordination Near the Breakdown of Linear Stability

Moritz Layer¹, David Dahmen¹, Lukas Deutz², Paulina Dabrowska¹, Nicole Voges³, Michael von Papen¹, Sonja Gruen^{1,4}, Markus Diesmann^{1,5,6}, Moritz Helias^{1,6}

1. Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA Institute Brain Structure-Function Relationships (INM-10), Forschungszentrum Juelich, Wilhelm-Johnen-Straße, 52428 Jülich, Germany

2. Institute for Artificial and Biological Computation, School of Computing, University of Leeds, E C Stoner Building, Leeds LS2 9JT, United Kingdom

3. INT UMR 7289, Aix-Marseille Université, 27, boulevard Jean Moulin 13005, Marseille, France

4. Theoretical Systems Neurobiology, Faculty 1, RWTH Aachen University, Worriingerweg 3, 52056 Aachen, Germany

5. Department of Psychiatry, Psychotherapy and Psychosomatics, Faculty 10, RWTH Aachen University, Pauwelsstraße 30, 52074 Aachen, Germany

6. Department of Physics, Faculty 1, RWTH Aachen University, Otto-Blumenthal-Straße, 52074 Aachen, Germany

Experimental findings suggest that cortical networks operate in a balanced state [1] in which strong recurrent inhibition suppresses single cell input correlations [2,3]. The balanced state, however, only restricts the average correlations in the network, the distribution of correlations between individual neurons is not constrained. We here investigate this distribution and establish a functional relation between the dynamical state of the system and the variance of correlations as a function of cortical distance. The former is characterized by the spectral radius, a measure for how strong a signal is damped while traversing the network. To this end, we develop a theory that captures the heterogeneity of correlations across neurons. Technically, we derive a mean-field theory that assumes the distribution of correlations to be self-averaging; i.e. the same in any realization of the random network. This is possible by taking advantage of the symmetry of the disorder-averaged [4] effective connectivity matrix. We here demonstrate that spatially organized, balanced network models predict rich pairwise correlation structures with spatial extent far beyond the range of direct connections [5]. Massively parallel spike recordings of macaque motor cortex quantitatively confirm this prediction. We show that the range of these correlations depends on the spectral radius, which offers a potential dynamical mechanism to control the spatial range on which neurons cooperatively perform computations.

Acknowledgements

Supported by HGF young investigator's group VH-NG-1028, European Union Horizon 2020 grant 785907 (Human Brain Project SGA2) and the Deutsche Forschungsgemeinschaft (Research Training Group 2416 MultiSenses-MultiScales)

References

- 1 Van Vreeswijk, C., & Sompolinsky, H. (1996). Chaos in neuronal networks with balanced excitatory and inhibitory activity. *Science*, 274(5293), 1724-1726. [10.1126/science.274.5293.1724](https://doi.org/10.1126/science.274.5293.1724)
- 2 Renart, A., De La Rocha, J., Bartho, P., Hollender, L., Parga, N., Reyes, A., & Harris, K. D. (2010). The asynchronous state in cortical circuits. *science*, 327(5965), 587-590. [10.1126/science.1179850](https://doi.org/10.1126/science.1179850)
- 3 Tetzlaff, T., Helias, M., Einevoll, G. T., & Diesmann, M. (2012). Decorrelation of neural-network activity by inhibitory feedback. *PLoS computational biology*, 8(8), e1002596. [10.1371/journal.pcbi.1002596](https://doi.org/10.1371/journal.pcbi.1002596)
- 4 Dahmen, D., Grün, S., Diesmann, M., & Helias, M. (2019). Second type of criticality in the brain uncovers rich multiple-neuron dynamics. *Proceedings of the National Academy of Sciences*, 116(26), 13051-13060. [10.1073/pnas.1818972116](https://doi.org/10.1073/pnas.1818972116)

- 5 Schnepel, P., Kumar, A., Zohar, M., Aertsen, A., & Boucsein, C. (2014). Physiology and impact of horizontal connections in rat neocortex. *Cerebral Cortex*, 25(10), 3818-3835. [10.1093/cercor/bhu265](https://doi.org/10.1093/cercor/bhu265)

©(2019) Layer M, Dahmen D, Deutz L, Dabrowska P, Voges N, von Papen M, Gruen S, Diesmann M, Helias M
Cite as: Layer M, Dahmen D, Deutz L, Dabrowska P, Voges N, von Papen M, Gruen S, Diesmann M, Helias M (2019)
Long-Range Neuronal Coordination Near the Breakdown of Linear Stability. *Bernstein Conference 2019 Abstract*.
doi: [10.12751/nncn.bc2019.0237](https://doi.org/10.12751/nncn.bc2019.0237)

[T 89] Low-dimensional dynamics of spiking neuron networks

Gianni Valerio Vinci^{1,2}, Andrea Galluzzi¹, Maurizio Mattia¹

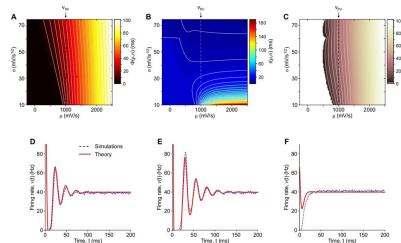
1. Istituto Superiore di Sanità, Rome 00169, Italy

2. Dipartimento di Fisica, Università di Roma "Tor Vergata", Rome 00133, Italy

The collective dynamics of neuronal networks can be complex even when simplified one-compartment spiking (integrate-and-fire, IF) neurons are considered for modeling. Complexity arises from the sparse-in-time nature of the inter-neuronal communication, the high-dimensionality of the system and the quenched randomness in the synaptic couplings. Reducing such complexity relying on mean-field approaches has a long history in theoretical neuroscience [1-6], although adopted approximations often limit the general applicability of the resulting simplified dynamics. Here, starting from the spectral expansion of the Fokker-Plank (FP) equation for the membrane potential density [7,8], a low-dimensional dynamics of the collective firing rate $\nu(t)$ (i.e., the network activity) is derived. The dimensionality of the resulting ordinary differential equation (ODE) for $\nu(t)$ is determined by the number n of slowest modes taken into account. This firing rate dynamics naturally incorporates the strength of the synaptic couplings provided that the changes of the membrane potential density are not too fast. By considering the two slowest modes, the firing rate dynamics is equivalent to the one of a damped oscillator in which the angular frequency $\omega(\nu)$ and the relaxation time $\tau(\nu)$ are state-dependent:

$$\ddot{\nu} + (2/\tau^2) \dot{\nu} = (1/\tau^2 + \omega^2)(\Phi - \nu)$$

where $\Phi(\nu)$ is the f-I curve (input-output gain function) and the explicit expression for the other coefficients can be found in [9]. The presented results apply to a wide class of networks of one-compartment neuron models and a Wilson-Cowan-like equation can be recovered under noise-dominated regimes, thus extending previous theoretical efforts [5,6]. The above dynamics is tested for two example neuron models: the standard leaky [10] and the simplified "VLSI" [11] IF neurons (i.e., LIF and VIF neuron, respectively). Besides the known spectrum of the FP operator for the VIF neurons [8], approximated expressions for the eigenvalues of the LIF neurons are derived relying on the eigenfunctions of the related FP operator [12,13]. The resulting τ and ω for the LIF neuron (Fig. 1) are qualitatively similar to those for the VIF neurons [14] and the exponential IF neurons numerically derived in [15]. The low-dimensional dynamics is found to be in good agreement with microscopic simulations both under fluctuation- and drift-dominate (supra-threshold) regimes (Fig. 1).



(A) f-I curve Φ in the plane of the mean (μ) and st.dev. (σ) of the input synaptic current. Decay time (B) and angular frequency (C) of the 2D dynamics of ν . Match between theory and simulation under drift- [uncoupled (D) and coupled (E)] and uncoupled noise-dominant (F) regime.

Acknowledgements

We thank L.F. Abbott, M. Augustin, R. Benzi, E. Hugues, G. Gigante and E.S. Schaffer for the stimulating discussions. Supported by EU Horizon 2020 R&I Programme under HBP SGA2 (grant no. 785907 to M.M.).

References

1. Wilson HR and Cowan JD (1972). Excitatory and inhibitory interactions in localized populations of model neurons. *Biophys J*, 12(1): 1–24. DOI: [10.1016/S0006-3495\(72\)86068-5](https://doi.org/10.1016/S0006-3495(72)86068-5)
2. Amit DJ and Tsodyks M (1991). Quantitative study of attractor neural network retrieving at low spike rates: I. substrate – spikes, rates and neuronal gain. *Network*, 2(3): 259–273. DOI: [10.1088/0954-898X/2/3/003](https://doi.org/10.1088/0954-898X/2/3/003)
3. Gerstner, W (1995). Time structure of the activity in neural network models. *Phys Rev E*, 51(1): 738–758. DOI: [10.1103/PhysRevE.51.738](https://doi.org/10.1103/PhysRevE.51.738)
4. Shriki O, Hansel D and Sompolinsky H (2013). Rate models for conductance-based cortical neuronal networks. *Neural Comput*, 15(8):1809–41. DOI: [10.1162/08997660360675053](https://doi.org/10.1162/08997660360675053)
5. Schaffer ES, Ostojic S and Abbott LF (2013). A complex-valued firing-rate model that approximates the dynamics of spiking networks. *PLoS Comput Biol*, 9(10): e1003301. DOI: [10.1371/journal.pcbi.1003301](https://doi.org/10.1371/journal.pcbi.1003301)
6. Montbrió E, Pazó D and Roxin A (2015). Macroscopic description for networks of spiking neurons. *Phys. Rev. X*, 5(2): 021028. DOI: [10.1103/PhysRevX.5.021028](https://doi.org/10.1103/PhysRevX.5.021028)
7. Knight BW (2000). Dynamics of encoding in neuron populations: some general mathematical features. *Neural Comput*, 12(3): 473–518. DOI: [10.1162/089976600300015673](https://doi.org/10.1162/089976600300015673)
8. Mattia M and Del Giudice P (2002). Population dynamics of interacting spiking neurons. *Phys Rev E*, 66: 051917. DOI: [10.1103/PhysRevE.66.051917](https://doi.org/10.1103/PhysRevE.66.051917)
9. Mattia M (2016). Low-dimensional firing rate dynamics of spiking neuron networks. *ArXiv*, 1609.08855.
10. Lapicque L (1907). Recherches quantitatives sur l'excitation électrique des nerfs traitée comme une polarisation. *J Physiol Pathol Gen*, 9: 620–35.
11. Fusi S and Mattia M (1999). Collective behavior of networks with linear (VLSI) integrate-and-fire neurons. *Neural Computation*, 11(3): 633–652. DOI: [10.1162/089976699300016601](https://doi.org/10.1162/089976699300016601)
12. Brunel N and Hakim V (1999). Fast global oscillations in networks of integrate-and-fire neurons with low firing rates. *Neural Comput*, 11(7), 1621–71. DOI: [10.1162/089976699300016179](https://doi.org/10.1162/089976699300016179)
13. Deniz T and Rotter S (2017). Solving the two-dimensional Fokker-Planck equation for strongly correlated neurons. *Phys Rev E*, 95: 012412. DOI: [10.1103/PhysRevE.95.012412](https://doi.org/10.1103/PhysRevE.95.012412)
14. Augustin M, Ladenbauer J, Baumann F and Obermayer K (2017). Low-dimensional spike rate models derived from networks of adaptive integrate-and-fire neurons: Comparison and implementation. *PLoS Comput Biol*, 13(6), e1005545. DOI: [10.1371/journal.pcbi.1005545](https://doi.org/10.1371/journal.pcbi.1005545)

©(2019) Vinci GV, Galluzzi A, Mattia M

Cite as: Vinci GV, Galluzzi A, Mattia M (2019) Low-dimensional dynamics of spiking neuron networks. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0238](https://doi.org/10.12751/nncn.bc2019.0238)

[T 90] **Low-rate firing limit for neurons with axon, soma and dendrites driven by spatially distributed stochastic synapses**

Robert Paul Gowers¹, Yulia Timofeeva^{2,3}, Magnus J E Richardson⁴

1. Mathematics for Real-World Systems Centre for Doctoral Training, University of Warwick, Zeeman Building, CV4 7AL, Coventry, United Kingdom

2. Department of Computer Science, University of Warwick, University of Warwick, Coventry, CV4 7AL, United Kingdom

3. Department of Clinical and Experimental Epilepsy, University College London, UCL Queen Square Institute of Neurology, London, WC1N 3BG, United Kingdom

4. Mathematics Institute, University of Warwick, Zeeman Building, CV4 7AL, Coventry, United Kingdom

Neurons *in vivo* are subject to synaptic input with highly variable pulse strength and arrival time. How this stochastic synaptic drive is integrated and ultimately triggers outgoing spikes has been modelled extensively since the late 1960s, with significant analytical progress made in how class-specific membrane and synaptic properties affect neuronal integration. Due to tractability, most analytical work approximates neurons as electrotonically compact or comprising a small number of discrete connected compartments.

We consider continuous models of neurons comprising dendrites, soma and axon with spatially-distributed fluctuating synaptic drive. We demonstrate that the fluctuation-driven firing rate can be approximated in the low-rate limit using an extension of Rice's level-crossing formula (Rice 1945), which has been previously utilised for point neuron models (Tchumatchenko 2010, Puelma-Touzel 2015). This low-rate firing limit is applicable to pyramidal neurons, for which average firing rates has been observed experimentally to be low compared to the reciprocal of the membrane time constant.

Applying this approach to even simple neuronal morphologies yields analytical approximations that demonstrate a surprising richness. First, certain dendritic morphologies have firing-rate functions of the input drive that are independent of the electrotonic length, yet distinct from the functions found for point-like models. Second, when an axon is added, we demonstrate that the firing rate varies non-monotonically with the axonal radius, with the peak firing rate corresponding to a radius similar to that found for pyramidal cells. Third, we observe that adding dendrites with fluctuating drive does not always increase the firing rate of the neuron, with the optimal number of dendrites for fluctuation-driven firing dependent on the axonal radius and the mean level of synaptic drive. Finally, we show that soma size and the position of spike-initiation in the axon alter these non-monotonic relationships, with a larger soma increasing the number of dendrites that maximises the firing rate, and a spike-initiation position further along the axon increasing the optimal axonal radius that maximises the firing rate.

The approach we introduce provides a general framework for going beyond point-like neuron models, demonstrating that it is possible to obtain analytical results in the low-rate limit that capture the effects of spatially-distributed synaptic drive.

References

- 1 Gowers, Timofeeva, Richardson 2019 [10.1101/669705](https://doi.org/10.1101/669705)
- 2 Rice 1945 [10.1002/j.1538-7305.1945.tb00453.x](https://doi.org/10.1002/j.1538-7305.1945.tb00453.x)
- 3 Tchumatchenko 2010 [10.1103/PhysRevLett.104.058102](https://doi.org/10.1103/PhysRevLett.104.058102)
- 4 Puelma-Touzel 2015 [10.1371/journal.pcbi.1004636](https://doi.org/10.1371/journal.pcbi.1004636)

©(2019) Gowers RP, Timofeeva Y, Richardson MJE

Cite as: Gowers RP, Timofeeva Y, Richardson MJE (2019) Low-rate firing limit for neurons with axon, soma and dendrites driven by spatially distributed stochastic synapses. *Bernstein Conference 2019* Abstract.
doi: [10.12751/nncn.bc2019.0239](https://doi.org/10.12751/nncn.bc2019.0239)

[T 91] Magnetic phenomena in ensembles of spiking neurons

Andreas Baumbach¹, Johannes Schemmel¹, Mihai Petrovici^{1,2}

1. Heidelberg University, Kirchhoff Institut für Physik, Im Neuenheimer Feld 227, 69115 Heidelberg, Deutschland

2. Uni Bern, Department of Physiology, Bühlpfplatz 5, 3012 Bern, Schweiz

In this work we go back to the original and arguably simplest model known to exhibit critical phenomena, the Ising model for ferromagnetism. Following the model of [Petrovici 2016], we implement an Ising-like spiking neural network that implements the same Boltzmann distribution using recent work on spiking neural networks under Poissonian noise. As such a description is widely used in neuroscience to effectively describe biological models and data one would expect that all the phenomena known from statistical physics can also be observed in these systems.

This work investigates a simplified model, the neural sampling framework introduced by [Buesing 2011], which we modify to include exponentially decaying interactions (resembling biological interactions), capturing the major dynamical difference to LIF sampling. While the global properties, like the unordered phase in the infinite temperature limit and the ordered phase in the zero temperature limit can still be observed. We show that the phase diagram of this model shows richer phenomena than the classical Ising model predicts. For example it allows such a system to converge non-monotonously to its final state even for a non-zero external field.

Acknowledgements

This work has received funding from the European Union 7th Framework Programme under grant agreement 604102 (HBP), the Horizon 2020 Framework Programme under grant agreement 720270 (HBP) and the Manfred Staerk Foundation.

References

- 1 Petrovici 2016 [10.1103/PhysRevE.94.042312](https://doi.org/10.1103/PhysRevE.94.042312)
- 2 Buesing 2011 [10.1371/journal.pcbi.1002211](https://doi.org/10.1371/journal.pcbi.1002211)

©(2019) Baumbach A, Schemmel J, Petrovici M

Cite as: Baumbach A, Schemmel J, Petrovici M (2019) Magnetic phenomena in ensembles of spiking neurons. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0240](https://doi.org/10.12751/nncn.bc2019.0240)

[T 92] Mathematical model order reduction of a Fokker-Planck mean-field model

Mikko Lehtimäki¹, Ippa Seppälä¹, Lassi Paunonen², Marja-Leena Linne¹

¹. Faculty of Medicine and Health Technology, Tampere University, Korkeakoulunkatu 10, Finland

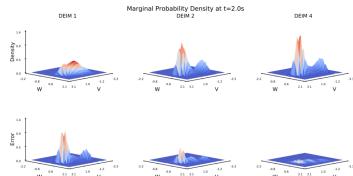
². Faculty of Information Technology and Communication Sciences, Tampere University, Korkeakoulunkatu 10, Finland

Development of large-scale models of neuronal network dynamics is important in order to increase understanding of the whole brain. Although mathematical analysis of these models is intractable and their numerical simulation is very resource intensive, mean-field approximation has been shown to be an effective tool for studying populations of biophysically detailed neurons [1]. Here we compare state-of-the-art methods for improving the simulation time of mathematical models and show that a nonlinear Fokker-Planck-McKean-Vlasov-type neuronal mean-field model can be accurately approximated in low-dimensional subspaces with these methods.

Using mean-field approximation, cells are grouped together into populations based on their statistical similarities, in order to represent the dynamics of the system in terms of the ensemble behaviour. These populations can then be described by a probability density function expressing the distribution of neuronal states at a given time. In this study we focus on a mean-field model of a network of FitzHugh-Nagumo neurons with chemical synapses using the Fokker-Planck formalism, which results in a nonlinear McKean-Vlasov partial differential equation (PDE) [1]. For numerical simulations the PDE is discretized in space over three variables and a high-dimensional system, whose domain is a cube, is obtained.

The dimensionality, and hence simulation time, of discretized PDE systems can be reduced using mathematical model order reduction (MOR) methods. MOR methods are well established in engineering sciences, such as control theory. However, in computational neuroscience MOR is underutilised, although the potential benefits in enabling large-scale simulations are obvious [3].

Here we use recently developed advanced variants of the Discrete Empirical Interpolation Method (DEIM) [2] to reduce a nonlinear mean-field model. The system can be reduced with minimal information loss by deriving subspaces where the entire system is approximated with a small number of dimensions during the simulation phase, and after simulation the original model can be fully reconstructed (see Figure 1). By applying these methods, the simulation time of the model is radically shortened, albeit not without dimension-dependent approximation error. This can be particularly useful when attempting to model whole-brain activity, for which there is an immediate demand in clinical and robotic applications.



The DEIM approximation of the mean-field model, where V is the voltage and W is the recovery variable of FitzHugh-Nagumo neurons. Upper row shows the state and lower row the approximation error. DEIM dimension grows to the right. Approximation improves as the dimension increases.

Acknowledgements

This work was supported by the Academy of Finland grant (297893) to M.-L.L. The support from the Graduate School of Tampere University M.L. is acknowledged.

References

- 1 Baladron J, Fasoli D, Faugeras O, Touboul J. Mean-field description and propagation of chaos in networks of Hodgkin-Huxley and FitzHugh-Nagumo neurons. *The Journal of Mathematical Neuroscience*. 2012 Dec 1;2(1):10. [10.1186/2190-8567-2-10](https://doi.org/10.1186/2190-8567-2-10)
- 2 Chaturantabut S, Sorensen DC. Nonlinear model reduction via discrete empirical interpolation. *SIAM Journal on Scientific Computing*. 2010 Sep 7;32(5):2737-64. [10.1137/090766498](https://doi.org/10.1137/090766498)
- 3 Lehtimäki M, Paunonen L, Pohjolainen S, Linne ML. Order reduction for a signaling pathway model of neuronal synaptic plasticity. *IFAC-PapersOnLine*. 2017 Jul 1;50(1):7687-92. [10.1016/j.ifacol.2017.08.1143](https://doi.org/10.1016/j.ifacol.2017.08.1143)

©(2019) Lehtimäki M, Seppälä I, Paunonen L, Linne M

Cite as: Lehtimäki M, Seppälä I, Paunonen L, Linne M (2019) Mathematical model order reduction of a Fokker-Planck mean-field model. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0241](https://doi.org/10.12751/nncn.bc2019.0241)

[T 93] Modular formations in a neural network with long and short-term plasticity.

Ewandson Luiz Lameu¹, Elbert E.N. Macau^{1,2}

1. *Laboratory of Computation and Applied Mathematics, National Institute for Space Research (INPE), São José dos Campos, Brazil*
2. *Federal University of São Paulo, São José dos Campos, Brazil*

Neuronal plasticity, also called brain plasticity, is the capability of the brain to change its function and structure. The plasticity occurs due to the external environment, recovery from brain injury, and modifications within the body. We study the effect of both spike-timing-dependent (STDP) and short-term (STP) plasticity in the synaptic strength between coupled excitatory Hodgkin-Huxley neurons as a function of their natural frequencies. The STDP rule changes the intensity of the synaptic coupling considering the time interval between the spikes of postsynaptic and presynaptic neurons. The STP is related to the release of neurotransmitters into the synaptic cleft and the recovery time. Previous works reported that the STDP rule induces the appearance of directed connections from the high to low-frequency neurons. In our simulations, we observe that the presence of STP with high recovery time allows the existence of connections only when the neurons have close spiking frequencies. We show that the system can form different size clusters, depending on the STP recovery time and also the neuronal frequencies distribution.

Acknowledgements

We wish to acknowledge the support: CNPq, CAPES and São Paulo Research Foundation (FAPESP processes 2016/23398-8, 2017/13502-5, 2015/50122-0)

©(2019) Lameu EL, Macau EE

Cite as: Lameu EL, Macau EE (2019) Modular formations in a neural network with long and short-term plasticity.. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0242](https://doi.org/10.12751/nncn.bc2019.0242)

[T 94] NEST Desktop: A web-based GUI for NEST Simulator

Sebastian Spreizer^{1,2}, Stefan Rotter¹, Markus Diesmann², Hans Ekkehard Plessner³, Benjamin Weyers⁴

1. Bernstein Center Freiburg, Faculty of Biology, University of Freiburg, Freiburg, Germany

2. Institute of Neuroscience and Medicine (INM-6), Jülich Research Center, Jülich, Germany

3. Faculty of Science and Technology, Norwegian University of Life Science, Ås, Norway

4. Department IV - Computer Science, Human-Computer Interaction, University of Trier, Trier, Germany

In the past few years, we have developed a web-based graphical user interface (GUI) for the NEST simulation code: NEST Desktop [1]. This GUI enables the rapid construction, parametrization, and instrumentation of neuronal network models typically used in computational neuroscience. The primary objective was to create a tool of classroom strength that allows users to rapidly explore neuroscience concepts without the need to learn a simulator control language at the same time. Currently, NEST Desktop requires a full NEST installation on the user's machine, limiting uptake by a non-expert audience, and limiting the networks studied to such that can be simulated on a laptop or desktop machine. To ease the use of the app and the range of simulations possible with NEST Desktop, we want to separate the GUI from the simulation kernel, rendering the GUI in the web browser of the user, while the simulation kernel is running on a centrally maintained server. NEST Desktop has a high potential to be successful as a widely used GUI for the NEST simulator. To achieve this goal, in a first step all tools have to agree on a communication scheme and data format (using JSON) used to interact with a server-side running NEST instance in a session management, e.g. Docker or Singularity containers. Next, previously developed tools, namely the NEST Instrumentation App [2] and VIOLA [3], will be integrated into the app to extend visual modeling and analysis functionalities. In the course of this work, the use of an in situ pipeline [4] developed for neuronal network simulators will be considered to also enable the app to receive larger data sets from NEST Simulator during a running simulation, enhancing the interactivity of the app also for large simulations on HPC facilities. We plan to develop and maintain NEST Desktop sustainably. Therefore, we intend to integrate NEST Desktop into the HBP infrastructure. Additionally, the open-source code of NEST Desktop will be published as a standalone distribution for teaching and training.

Acknowledgements

This project has received funding from the European Unions Horizon 2020 Research and Innovation Program under Grant Agreement No. 785907 (Human Brain Project SGA2).

References

1 Source code of NEST Desktop

2 Source code of NEST InstrumentationApp on Github

3 Senk J et al. (2018) VIOLA - A Multi-Purpose and Web-Based Visualization Tool for Neuronal-Network Simulation Output [10.3389/fninf.2018.00075](https://doi.org/10.3389/fninf.2018.00075)

4 Oerhl S et al. (2018) Streaming Live Neuronal Simulation Data into Visualization And Analysis [10.1007/978-3-030-02465-9_18](https://doi.org/10.1007/978-3-030-02465-9_18)

©(2019) Spreizer S, Rotter S, Diesmann M, Plessner HE, Weyers B

Cite as: Spreizer S, Rotter S, Diesmann M, Plessner HE, Weyers B (2019) NEST Desktop: A web-based GUI for NEST Simulator. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0243](https://doi.org/10.12751/nncn.bc2019.0243)

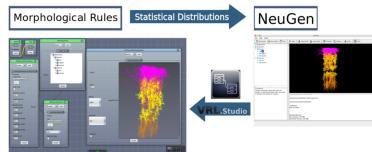
[T 95] NeuGen-VRL-Plugin: simultaneous generation of various realistic morphologies of neurons and neural networks in 3D and visual linking with neural simulators

Junxi Wang¹, Dr. Michael Hoffer¹, Prof. Dr. Gabriel Wittum^{1,2}

1. G-CSC, Goethe University Frankfurt, Kettenhofweg 139, Germany

2. CEMSE, King Abdullah University of Science and Technology (KAUST), 23955-6900 Thuwal, Saudi Arabia

NeuGen was implemented to efficiently generate realistic morphologies of neurons and neural networks in 3D. It is based on sets of descriptive and iterative rules that represent the axonal and dendritic geometry of neurons by inter-correlating morphological parameters. VRL-Studio is an intuitive, visual integrated development environment (IDE) based on the Visual Reflection Library (VRL). Due to the visual reflection of VRL-Studio, a lot of user interfaces can be created repeatedly by the same text-based programming. Therefore, with the NeuGen-VRL-Plugin, various realistic morphologies can be generated simultaneously. Otherwise, the neural generator interfaces can still be linked with simulator plugins using data-flow and control-flow in VRL-Studio. As a result, the morphologies generated by NeuGen can be more easily used by all kinds of simulators.



NeuGen-VRL-Plugin

Acknowledgements

Support by HBP, by BMBF, BMWi and by University of Frankfurt is gratefully acknowledged.

References

1. J. P. Eberhard, A. Wanner, G. Wittum, NeuGen: A tool for the generation of realistic morphology of cortical neurons and neural networks in 3D, Neurocomputing, Volume 70, Issues 1-3, December 2006, Pages 327-342 [10.1016/j.neucom.2006.01.028](https://doi.org/10.1016/j.neucom.2006.01.028)
2. S. Wolf, S. Grein, G. Queisser, Employing NeuGen 2.0 to Automatically Generate Realistic Morphologies of Hippocampal Neurons and Neural Networks in 3D, Neuroinformatics, Volume 11, Issue 2, April 2013, Pages 137-48 [10.1007/s12021-012-9170-1](https://doi.org/10.1007/s12021-012-9170-1)
3. M. Hoffer, C.Poliwoda, G.Wittum. Visual Reflection Library - A Framework for Declarative GUI Programming on the Java Platform. Computing and Visualization in Science, Journal Computing and Visualization in Science, Volume 16, Issue 4, August 2013, Pages 181-192 [10.1007/s00791-014-0230-y](https://doi.org/10.1007/s00791-014-0230-y)

©(2019) Wang J, Hoffer DM, Wittum PDG

Cite as: Wang J, Hoffer DM, Wittum PDG (2019) NeuGen-VRL-Plugin: simultaneous generation of various realistic morphologies of neurons and neural networks in 3D and visual linking with neural simulators. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0244](https://doi.org/10.12751/nncn.bc2019.0244)

[T 96] Neural adaptation in auditory cortex is a complex network phenomenon: preliminary results from simulations and intracortical measurements

Nina Härtwich¹, Jing Ma^{1,2}, Matthias Deliano², Reinhard König¹, Patrick J. C. May^{1,3}

1. Special Lab Non-Invasive Brain Imaging, Leibniz Institute for Neurobiology, Magdeburg, Germany

2. Department Systems Physiology of Learning, Leibniz Institute for Neurobiology, Magdeburg, Germany

3. Department of Psychology, Lancaster University, Lancaster, United Kingdom

An attenuation of cortical responses is observable in the auditory cortex (AC) when identical stimuli are presented in quick succession. This phenomenon, known as adaptation, is most likely caused by short-term synaptic depression (STSD), and it is thought to be a physiological expression of auditory sensory memory. To explore adaptation and its implications for memory, we constructed a computational model of the gerbil AC. The gerbil has a similar hearing range as humans, making it a good animal model of human hearing, and the functional anatomy of the gerbil AC is well established. Our gerbil AC model is based on the modelling approach for human and monkey AC introduced by May et al. (2015), where individual cortical columns represent the basic computational unit of the network. Further, the time scale of STSD is summarised in one central parameter τ , the time constant of recovery from synaptic depression. Both the time course of adaptation as well as the maximum time span over which temporally complex stimulation can be represented in the network depend on τ . We simulated adaptation in gerbil AC using a repetitive stimulation paradigm. Identical stimuli were presented at regular stimulus-onset intervals (SOIs) within a stimulus block, and SOI was varied across blocks. We also varied the audio frequency of the input by targeting different parts of the 16-column tonotopic map of the network's input field. For each input frequency and each column in the model we summarised the time span needed for recovery from adaptation in one value, τ_{SOI} . Our simulations indicate that, for each individual column, τ_{SOI} systematically varies as a function of stimulus audio frequency, and thus the time scale of adaptation does not directly reflect τ , the time scale of STSD. Instead, adaptation is a network effect resulting from a complex interplay of neural dynamics and cortical anatomy. This prediction is now being tested in intracortical measurements in the gerbil auditory cortex, and we present preliminary results from these analyses. We expect that the variations in the response dynamics and therefore the response strength lay the foundation for selective responses to more complex stimuli, for example the ability of individual columns to exhibit combination sensitivity. This would confirm that adaptation plays a central role in auditory memory tasks.

Acknowledgements

We thank our colleagues Michael Brunk, Max Happel, and Frank Ohl at the Leibniz Institute for their support. We are grateful for the financial support provided by the state of Saxony-Anhalt (PhD scholarship), the Chinese Scholarship Council, and the European Commission (Horizon 2020 grant 763959).

References

- 1 May, P. J., Westö, J., & Tiitinen, H. (2015). Computational modelling suggests that temporal integration results from synaptic adaptation in auditory cortex. *European Journal of Neuroscience*, 41(5), 615-630.

©(2019) Härtwich N, Ma J, Deliano M, König R, May PJC

Cite as: Härtwich N, Ma J, Deliano M, König R, May PJC (2019) Neural adaptation in auditory cortex is a complex network phenomenon: preliminary results from simulations and intracortical measurements. *Bernstein Conference 2019*
Abstract. doi: [10.12751/nncn.bc2019.0245](https://doi.org/10.12751/nncn.bc2019.0245)

[T 97] Neuronal avalanches in developing networks of Hawkes spiking neurons

Sven Goedeke¹, Felipe Yaroslav Kalle Kossio¹, Raoul-Martin Memmesheimer¹

1. Neural Network Dynamics and Computation, Institute of Genetics, University of Bonn, Bonn, Germany

Neuronal avalanches are activity bursts with approximately power-law distributed sizes and durations. They have been observed on different scales in various neural systems. A possible explanation for their generation is that the underlying dynamics operate close to a critical state in which responses to small perturbations (or inputs) occur on all scales. Experimental studies indicate that neuronal avalanches may emerge during network development [e.g. 1,2]. We present a simple model based on activity-dependent growth for developing networks of spiking neurons and demonstrate how these can “grow into” criticality [3]. Neurons spike stochastically with an instantaneous rate, which is excited by input spikes from other neurons as in a system of Hawkes processes. The growth mechanism is regulated homeostatically: If a neuron’s average spike rate is below a target rate, its neurites grow to increase the excitatory input. If its average spike rate is above the target rate, its neurites shrink.

Using mathematical analysis and simulations we show that our networks grow into a stationary state at which growth and shrinkage of neurites balance while the neurons are active at their target rates. The characteristics of the stationary state are determined by the ratio of the target spike rate to the neurons’ spontaneous spike rate. If this ratio is large, every spike in the network causes on average almost one additional spike, and the network self-organizes into a nearly critical state. Identifying the network’s total spiking dynamics with a self-exciting Hawkes process we analytically derive the size and duration distributions for nearly critical as well as subcritical states.

In neuroscientific experiments, avalanches may overlap and form complexes. The observer of an experiment will usually only have access to the latter. Using the duration distribution of single avalanches, we therefore determine the probability that avalanches overlap in our model as well as the distributions of avalanche complexes.

Acknowledgements

Supported by the German Federal Ministry of Education and Research (BMBF) via the Bernstein Network (Bernstein Award 2014, 01GQ1501 and 01GQ1710).

References

- 1 Pasquale, V, Massobrio, P, Bologna, LL, Chiappalone, M & Martinoia, S. Self-organization and neuronal avalanches in networks of dissociated cortical neurons. *Neuroscience* 153, 1354–1369 (2008) [10.1016/j.neuroscience.2008.03.050](https://doi.org/10.1016/j.neuroscience.2008.03.050)
- 2 Yada, Y, et al. Development of neural population activity toward self-organized criticality. *Neuroscience* 343, 55–65 (2017) [10.1016/j.neuroscience.2016.11.031](https://doi.org/10.1016/j.neuroscience.2016.11.031)
- 3 Kalle Kossio, FY, Goedeke, S, van den Akker, B, Ibarz, B & Memmesheimer, RM. Growing Critical: Self-Organized Criticality in a Developing Neural System. *Phys. Rev. Lett.* 121, 058301 (2018) [10.1103/PhysRevLett.121.058301](https://doi.org/10.1103/PhysRevLett.121.058301)

©(2019) Goedeke S, Kalle Kossio FY, Memmesheimer R

Cite as: Goedeke S, Kalle Kossio FY, Memmesheimer R (2019) Neuronal avalanches in developing networks of Hawkes spiking neurons. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0246](https://doi.org/10.12751/nncn.bc2019.0246)

[T 98] Neuronal dynamics related to figure-ground segregation in V1 of the macaque monkey

William H Barnes^{1,2}, Sylvia van Stijn^{1,2}, Miriam C Mueller^{1,2}, Johanna Klon-Lipok^{1,2}, Martin Vinck³, Sean H Lee⁴, Wolf Singer^{1,2}

1. Singer Lab, Ernst Strüngmann Institute, Deutschordenstraße 46, Frankfurt am Main, Germany

2. Singer Emeritus Group, Max Planck Institut for Brain Research, Max-von-Laue-Straße 4, Frankfurt am Main, Germany

3. Vinck Lab, Ernst Strüngmann Institute, Deutschordenstraße 46, Frankfurt am Main, Germany

4. Neuroscience, Max Planck Institute for Empirical Aesthetics, Grüneburgweg 14, Frankfurt am Main, Germany

An ongoing mystery of visual processing is how fragmented local visual information gets bound into a unified global percept. To interrogate this question, we developed a figure-ground stimulus composed of disjoined Gabor patches (GPs) that, when properly oriented, formed an apparent contour. We assessed macaque V1 neural dynamics (MUA and LFP) in response to contour onset. Electrophysiological recordings were made with semi-chronic electrode arrays (Gray Matter Research) which allowed us to simultaneously sample from a large number of cells with receptive fields (RFs) located over a dispersed visual area. The visual stimulus consisted of an array of randomly-placed, randomly-oriented GPs. Following a replotting of all GPs, a small number of GPs then changed their orientation to create a closed or open circular apparent contour (figure) which was situated in a field of randomly placed, randomly oriented GPs (background). Another subset of GPs (8) were placed at the location of selected electrode RFs. Across the full length of a trial, these Gabor patches did not change location or orientation. For any given trial, some unchanging GPs would be included in the figure and some in the background. Thus, the effect of a global perceptual change could be assessed while local stimulus features remain constant. To increase attention to the figure, the monkey reported whether the figure was open or closed. We found many signatures of figure-ground segregation in the spiking (MUA) and LFP activity. Starting at 100ms after figure onset and lasting for the duration of the figure, spike rates are enhanced for RFs on the contour (on RFs) and suppressed for RFs that are off (off RFs). Oscillations above 40Hz are enhanced and a 15-35Hz band is suppressed for on RFs vs. off RFs. The Fano factor is reduced during figure presentation for both on and off RFs with the strongest reduction occurring for on RFs. Importantly, spike-field coherence in the gamma range was enhanced during figure presentation. Coincident with the enhanced spike-field coherence, a naive Bayes classifier showed mild but significant positive classification performance for trials where the monkey correctly identified the figure as open or closed vs. trials where the opening was incorrectly identified. This suggests that the focusing of spike timing into gamma-rhythmic windows serves to bind the figure elements by synchronous firing in a behaviorally relevant way.

©(2019) Barnes WH, van Stijn S, Mueller MC, Klon-Lipok J, Vinck M, Lee SH, Singer W

Cite as: Barnes WH, van Stijn S, Mueller MC, Klon-Lipok J, Vinck M, Lee SH, Singer W (2019) Neuronal dynamics related to figure-ground segregation in V1 of the macaque monkey. Bernstein Conference 2019 Abstract.

doi: 10.12751/nncn.bc2019.0247

[T 99] **One step back, two steps forward: interference and learning in recurrent neural networks**

Chen Beer¹, Omri Barak²

1. Viterby Faculty of Electrical Engineering, Technion Israel Institute of Technology, Israel

2. Rappaport Faculty of Medicine, Technion Israel Institute of Technology, Israel

Artificial neural networks, trained to perform cognitive tasks, have recently been used as models for neural recordings from animals performing these tasks. While some progress has been made in performing such comparisons, the evolution of network dynamics throughout learning remains unexplored. This is paralleled by an experimental focus on recording from trained animals, with few studies following neural activity throughout training.

In this work, we address this gap in the realm of artificial networks by analyzing networks that are trained to perform memory and pattern generation tasks. The functional aspect of these tasks corresponds to dynamical objects in the fully trained network – a line attractor or a set of limit cycles for the two respective tasks. We use these dynamical objects as anchors to study the effect of learning on their emergence. We find that the sequential nature of learning – one trial at a time – has major consequences for the learning trajectory and its final outcome. Specifically, we show that Least Mean Squares (LMS), a simple gradient descent suggested as a biologically plausible version of the FORCE algorithm, is constantly obstructed by forgetting, which is manifested as the destruction of dynamical objects from previous trials. The degree of interference is determined by the correlation between different trials. We show which specific ingredients of FORCE avoid this phenomenon. Overall, this difference results in convergence that is orders of magnitude slower for LMS.

Learning implies accumulating information across multiple trials to form the overall concept of the task. Our results show that interference between trials can greatly affect learning, in a learning rule dependent manner. These insights can help design experimental protocols that minimize such interference, and possibly infer underlying learning rules by observing behavior and neural activity throughout learning.

©(2019) Beer C, Barak O

Cite as: Beer C, Barak O (2019) One step back, two steps forward: interference and learning in recurrent neural networks. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0248](https://doi.org/10.12751/nncn.bc2019.0248)

[T 100] Optical stimulation evokes sustained activity in the isolated medial septum

Karolína Korvasová^{1,2}, Felix Ludwig³, Sanja Bauer Mikulovic³, Liudmila Sosulina³, Stefan Remy^{3,4}, Tom Tetzlaff¹

1. Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA-Institute Brain Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany

2. RWTH Aachen University, Aachen, Germany

3. Neuronal Networks Group, German Center for Neurodegenerative Diseases, Bonn, Germany

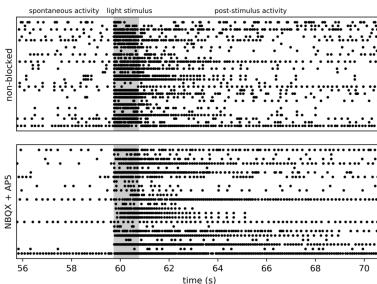
4. Department of Epileptology, University of Bonn Medical Center, Bonn, Germany

The processing of spatially related input during locomotion involves oscillatory hippocampal (HPC) activity in the theta band. It is known that the medial septum (MS) plays a central role in the generation of HPC theta activity, but the underlying mechanisms have not yet been described. Fuhrmann et al. [1] have shown that a brief stimulation of glutamatergic (VGluT2) neurons in the mouse MS *in vivo* evokes sustained theta activity in the HPC local-field potential (LFP), lasting for at least 10 seconds and preceding the onset of locomotion. Blocking of glutamatergic synapses in the MS suppresses sustained theta activity.

Here, we investigate to what extent the MS alone can generate sustained activity. To this end, we study responses of individual MS neurons to optical stimulation in acute mouse MS slices recorded by microelectrode arrays (MEAs). MS slices exhibit spontaneous activity, with a fraction of neurons being active at rates of 5-15 spikes/s. Brief 1-second optical stimulation of VGluT2 neurons consistently leads to a sustained increase in the activity in some of the MS neurons, lasting for several, sometimes more than 10 seconds. The same effect is observed in slices with blocked glutamatergic and/or GABAergic connections (see Figure 1). Irrespective of the blocking condition, we do not detect any signs of spike-train synchronization or spatial clustering of stimulus evoked sustained activity. Stimulation of parvalbumin-expressing (PV) neurons does not lead to any significant firing rate modulation after stimulus offset.

We conclude that the isolated MS is capable of generating sustained activity at time scales comparable to those found in the HPC [1]. The generation of this sustained activity seems to be the result of a bistable dynamics of individual VGluT2 neurons, and does not rely on synaptic interactions within the MS network. Single neurons exhibiting bistable dynamics have been described in earlier studies [2,3].

It remains to be shown how coherent HPC theta activity can emerge from asynchronous sustained activation of MS neurons, and to what extent the stimulus-evoked generation of sustained HPC theta activity relies on direct projections from VGluT2 neurons to the HPC. Future work is further dedicated to a systematic comparison between the characteristics (duration, stimulus efficiency) of sustained spiking activity in the MS, sustained theta activity in HPC LFPs, and behavioral responses.



Stimulus evoked sustained spiking activity in a medial-septal slice. Spiking activity of single units before, during (gray regions), and after continuous optical stimulation of VGlut2 neurons in the absence (top) and presence of NBQX+AP5 (bottom).

Acknowledgements

Funded by the European Union's Horizon 2020 Framework Programme for Research and Innovation under Specific Grant Agreement No. 720270, 785907 (Human Brain Project SGA1, SGA2), the German Research Foundation (DFG; grants DI 1721/3-1 [KFO219-TP9], SFB1089) and the Swedish Research Council (2018-06254)

References

- 1 Fuhrmann et al. (2015) Locomotion, Theta Oscillations, and the Speed-Correlated Firing of Hippocampal Neurons Are Controlled by a Medial Septal Glutamatergic Circuit, *Neuron* 86(5):1253-1264 [10.1016/j.neuro.2015.05.001](https://doi.org/10.1016/j.neuro.2015.05.001)
- 2 Turrigiano et al. (1995) Selective Regulation of Current Densities Underlies Spontaneous Changes in the Activity of Cultured Neurons, *Journal of Neuroscience* 15(5):3640-3652 [10.1523/JNEUROSCI.15-05-03640.1995](https://doi.org/10.1523/JNEUROSCI.15-05-03640.1995)
- 3 Izhikevich (2006) Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting, MIT Press

©(2019) Korvasová K, Ludwig F, Bauer Mikulovic S, Sosulina L, Remy S, Tetzlaff T

Cite as: Korvasová K, Ludwig F, Bauer Mikulovic S, Sosulina L, Remy S, Tetzlaff T (2019) Optical stimulation evokes sustained activity in the isolated medial septum. *Bernstein Conference 2019* Abstract.

doi: [10.12751/nncn.bc2019.0249](https://doi.org/10.12751/nncn.bc2019.0249)

[T 101] Persistent activity is prevented by interneuron heterogeneity

Joachim Hass^{1,2}, Salva Ardid³, Jason Sherfey³, Nancy Kopell³

1. Faculty of Applied Psychology, SRH University of Applied Sciences, Maria-Probst-Strasse 3, 69123 Heidelberg, Germany

2. Department of Theoretical Neuroscience, Central Institute of Mental Health, Medical Faculty Mannheim of Heidelberg University, J5, 68159 Mannheim, Germany

3. Department of Mathematics and Center for Biodynamics, Boston University, 111 Cummington Mall, Boston, MA 02215, USA

Persistent activity, the maintenance of neural activation over short periods of time in cortical networks, is widely thought to underlie the cognitive function of working memory. A large body of modeling studies has reproduced this kind of activity using cell assemblies with strengthened synaptic connections. However, almost all of these studies have considered persistent activity within networks with homogeneous neurons and synapses, making it difficult to judge the validity of such model results for cortical dynamics, which is based on highly heterogeneous neurons.

Here, we consider persistent activity in a detailed, strongly data-driven network model of the prefrontal cortex with heterogeneous neuron and synapse parameters [1]. Surprisingly,

persistent activity could not be reproduced in this model without incorporating further constraints. In particular, we found that the naturally occurring heterogeneity in the parameters governing inhibitory input to the cell assembly such as the interneuron rheobase constitutes a limiting factor for persistent activity [2]. We also identified a dynamic mechanism that may underlie this phenomenon: Heterogeneity in any kind of input to the cell assembly drags its members out of the bistable dynamic regime, eventually leaving too few pyramidal cells to maintain the positive feedback loop that constitutes bistability. We constructed a minimal model to illustrate this mechanism, showing that it is independent from the specifications of the original network model [1]. Importantly, this minimal model correctly predicts that interneuron heterogeneity is much more important to prevent persistent activity compared to pyramidal cell heterogeneity due to the much steeper input-output curve of the interneurons. Finally, we discuss effects of the network size and implications for the current state of persistence-based working memory models.

Acknowledgements

This work was supported by grants from the Army Research Office (ARO) of the American Department of Defense (W911NF-14-1-0374) and from the WIN-Kolleg of the Heidelberger Akademie der Wissenschaften. We thank Michelle McCarthy for valuable discussions and continuous support during this research.

References

- 1 Hass J, Hertag L, Durstewitz D (2016) A Detailed Data-Driven Network Model of Prefrontal Cortex Reproduces Key Features of In Vivo Activity. *PLoS Comput Biol* 12(5):e1004930. [10.1371/journal.pcbi.1004930](https://doi.org/10.1371/journal.pcbi.1004930)
- 2 Hass J, Ardid S, Sherfey J, Kopell N (2019) Constraints on Persistent Activity in a Biologically Detailed Network Model of the Prefrontal Cortex with Heterogeneities. *bioRxiv*, 645663.

©(2019) Hass J, Ardid S, Sherfey J, Kopell N

Cite as: Hass J, Ardid S, Sherfey J, Kopell N (2019) Persistent activity is prevented by interneuron heterogeneity. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0250](https://doi.org/10.12751/nncn.bc2019.0250)

[T 102] Phenomenological models for single-neuron energetics

Tanguy Fardet^{1,2}, Anna Levina^{1,2}

1. Computer Science Department, Tübingen University, Sand 14, 72076 Tübingen, Germany

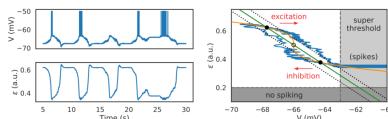
2. Max Planck Institute for Biological Cybernetics, Max-Planck-Ring 8, 72076 Tübingen, Germany

Despite representing only 2% of the body mass in humans, the brain requires up to 20% of the oxygen and 25% of the glucose supply to function, which is striking, yet remarkably little given the variety of tasks it has to tackle. Many models have been developed to account for neuronal behaviors but none of the standard implementations account for energy consumption. Despite the insights these models provided, they cannot faithfully characterize neuronal states involving high metabolic stress, for instance in epilepsy [1] or many neurodegenerative diseases [2].

This work aims at filling the gap by introducing new and augmented integrate-and-fire models which account for energy requirements associated to neuronal activity. These models reproduce qualitatively crucial behaviors such as depolarization blocks and bistability while remaining computationally efficient and analytically tractable, thus enabling the study of large neuronal ensembles. Therefore, they provide a bridge between the complexity of detailed conductance-based models [3], that can capture a large spectrum of the neuronal behaviours but become both intractable and computationally expensive, and simple models such as the leaky integrate-and-fire neuron, that are numerically

efficient but cannot reproduce important dynamical features such as depolarization block. As the new models phenomenologically reproduce the influence of ATP/ADP levels and ion concentrations on the membrane potential [4], they enabled us to propose straightforward and falsifiable mechanisms for several important phenomena.

The poster will detail some of these possible mechanisms, focusing on epilepsy, as well as up-and-down states [5]. Each case will be illustrated by both theoretical analysis and numerical simulations to show how the mechanisms captured by the models can provide an intuitive explanation to these behaviors.



Left: evolution of membrane potential (top) and energy level (bottom) for input-triggered up-and-down states. Right: phase space, with the nullclines (V -green, energy-orange), trajectory (blue), and fixed points (black, filled if stable). Dotted lines mark bifurcations towards a single fixed point.

References

- 1 Zsurka, Gábor, and Wolfram S Kunz. "Mitochondrial Dysfunction and Seizures: The Neuronal Energy Crisis." *The Lancet Neurology* 14, no. 9 (September 2015): 956–66. [10.1016/S1474-4422\(15\)00148-9](https://doi.org/10.1016/S1474-4422(15)00148-9)
- 2 Zilberman, Yuri, and Misha Zilberman. "The Vicious Circle of Hypometabolism in Neurodegenerative Diseases: Ways and Mechanisms of Metabolic Correction: Hypometabolism in Neurodegenerative Diseases." *Journal of Neuroscience Research* 95, no. 11 (November 2017): 2217–35. [10.1002/jnr.24064](https://doi.org/10.1002/jnr.24064)
- 3 Le Masson, Gwendal, Serge Przedborski, and L.F. Abbott. "A Computational Model of Motor Neuron Degeneration." *Neuron* 83, no. 4 (August 2014): 975–88. [10.1016/j.neuron.2014.07.001](https://doi.org/10.1016/j.neuron.2014.07.001)
- 4 Kann, Oliver, and Richard Kovács. "Mitochondria and Neuronal Activity." *American Journal of Physiology-Cell Physiology* 292, no. 2 (February 2007): C641–57. [10.1152/ajpcell.00222.2006](https://doi.org/10.1152/ajpcell.00222.2006)
- 5 Vyazovskiy, Vladyslav V., and Kenneth D. Harris. "Sleep and the Single Neuron: The Role of Global Slow Oscillations in Individual Cell Rest." *Nature Reviews Neuroscience* 14, no. 6 (June 2013): 443–51. [10.1038/nrn3494](https://doi.org/10.1038/nrn3494)

©(2019) Fardet T, Levina A

Cite as: Fardet T, Levina A (2019) Phenomenological models for single-neuron energetics. *Bernstein Conference 2019*
Abstract. doi: [10.12751/nncn.bc2019.0251](https://doi.org/10.12751/nncn.bc2019.0251)

[T 103] Plasticity rules for learning unreliable noisy inputs under energetic constraints

Dmytro Grytskyy¹, Renaud Blaise Jolivet^{1,2}

1. Département de Physique Nucléaire et Corpusculaire (DPNC), University of Geneva, Geneva, Switzerland

2. CERN, Geneva, Switzerland

Information measures are often used to assess the efficacy of neural networks, and learning rules can be derived through optimization procedures on such measures [3,6,7]. There has also been recent interest for sequence learning [2,5]. In biological neural networks, computation is restricted by the amount of available resources [4,7]. Considering energy restrictions, it is reasonable to balance information processing efficacy and energy consumption [1]. Here, we obtain such an energy-constrained learning rule for inputs evolving in time. There are several possible sources of unreliability for inputs processing and learning. We studied interaction between two of these sources, namely noisy synapses and finite presentation times, resulting in presentation of only partial sequences, and energetic constraints. To do so, we studied networks of non-linear Hawkes neurons and assessed information flow using mutual information. We then applied gradient descent for a combination of mutual information and energetic costs to obtain learning rules. Constraining energy consumption results in a rearrangement of the correspondence between inputs and respective output with more frequent input patterns being mapped to lower energy orbits. Taking into account the unreliability of neural transmission results in an additional negative term in the learning rule, proportional to the synaptic weight. As a result, rare events are not learned, while a maximal response is evoked in the network by seldom but still recognizable inputs. Because the learning rule we derived contains a global variable integrating over time, consecutive inputs can influence synaptic changes triggered by preceding events strengthening respective synapses for better inference. When strict sequences are presented and learned, the learning rule can lead to inhibiting the response to later segments of those sequences because of energetic limitations. Learning tends to maximize the diversity of output sequences and limits the noise in those. If feedback from the network to the environment is added, learning strengthens connections to neurons whose outputs mostly influence future inputs.

Acknowledgements

This work is supported by the Swiss National Science Foundation (31003A_170079) and by the Australian Research Council (DP180101494).

References

1. R. Bourdoukan et al (2012) Advances in Neural Information Processing Systems 25:2285-2293
2. J. Brea, W. Senn, J.-P Pfister. (2011) NIPS 2011:1422-1430.
3. G. Chechik (2003) Neural Computation, 15(7):1481-1510.
4. J. Harris, R. Jolivet, D. Attwell (2012) Neuron 75(5):762-777.
5. D. Kappel, B. Nessler, W. Maass (2014) PLOS Computational Biology, 10(3):e1003511
6. R. Linsker (1992) Neural Computation 4 (5): 691-702
7. L. Yu, Y. Yu (2017) J Neurosci Res. 95(11):2253-2266

©(2019) Grytskyy D, Jolivet RB

Cite as: Grytskyy D, Jolivet RB (2019) Plasticity rules for learning unreliable noisy inputs under energetic constraints. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0252](https://doi.org/10.12751/nncn.bc2019.0252)

[T 104] Power-law avalanches and all the synchronicity states emerging in a unified model of excitatory-inhibitory balanced network

Mauricio Girardi-Schappo¹, Ludmila Brochini², Tawan T. A. Carvalho³, Ariadne A. Costa⁴, Osame Kinouchi¹

1. Departamento de Física, FFCLRP/Universidade de São Paulo Campus de Ribeirão Preto, Ribeirão Preto, SP, 14040-901, Brazil

2. Instituto de Matemática e Estatística, Universidade de São Paulo, São Paulo, SP, 05508-090, Brazil

3. Departamento de Física, Universidade Federal de Pernambuco, Recife, PE, 50670-901, Brazil

4. Unidade Acadêmica Especial de Ciências Exatas, Universidade Federal de Goiás Campus Jataí, Jataí, GO, 75801-615, Brazil

Asynchronous irregular (AI) and critical states are two competing frameworks proposed to explain spontaneous neuronal activity. We introduce a mean-field model with stochastic neurons that generalizes the integrate-and-fire network of Brunel (2000). We show that the point with balanced inhibitory/excitatory synaptic weight ratio $g_c \approx 4$ corresponds to a second order absorbing phase transition usual in self-organized critical (SOC) models (Muñoz et al. 1999). At the synaptic balance point g_c , the network exhibits absorbing state power-law neuronal avalanches with the usual exponents and scaling laws (Bortolotto et al. 2016; Girardi-Schappo & Tragtenberg 2018), whereas for nonzero external field the system displays the four usual synchronicity states (AI, asynchronous regular, synchronous regular and synchronous irregular), as well as slow oscillations, of balanced networks. The inherent soft threshold of our model allow us to generalize the synaptic balance condition, obtaining

$$g_c = 4 - \frac{1}{0.2\Gamma J},$$

where Γ is the neuronal gain and J is the synaptic strength, showing that weaker synapses or small neuronal gains shift the balance towards a synaptic balance condition less than four (i.e. inhibition can be less than four times the excitation) for a fixed ratio of four excitatory to one inhibitory neuron in the network. Our model shows that both frameworks are in fact coexisting in the phase diagram of the model, allowing for the introduction of adaptation mechanisms that drive the system close to the critical (balanced) point.

Acknowledgements

This article was produced as part of the activities of FAPESP Research, Innovation and Dissemination Center for Neurorhythms, grants No. 2013/07699-0, 2016/24676-1 (L.B.), 2016/00430-3 (A.A.C.), and 2018/09150-9 (M.G.-S.). We acknowledge financial support from CNPq, FACEPE, and CNAIPS-USP.

References

- 1 N Brunel (2000). Dynamics of sparsely connected networks of excitatory and inhibitory spiking neurons. *J. Comput. Neurosci.*, 8(3):183-208.
- 2 MA Muñoz, R Dickman, A Vespignani, S Zapperi (1999). Avalanche and spreading exponents in systems with absorbing states. *Phys. Rev. E*, 59(5):6175
- 3 M Girardi-Schappo, MHR Tragtenberg (2018). Measuring neuronal avalanches in disordered systems with absorbing states. *Phys. Rev. E*, 97:042415 [10.1103/PhysRevE.97.042415](https://doi.org/10.1103/PhysRevE.97.042415)
- 4 GS Bortolotto, M Girardi-Schappo, JJ Gonsalves, LT Pinto, MHR Tragtenberg (2016). Information processing occurs via critical avalanches in a model of the primary visual cortex. *J. Phys. Conf. Ser.*, 686(1):012008 [10.1088/1742-6596/686/1/012008](https://doi.org/10.1088/1742-6596/686/1/012008)

[T 105] Reliable spike propagation in local cortical circuits of strong and dense connectivity

Juan Luis Riquelme¹, Mike Hemberger¹, Gilles Laurent¹, Julijana Gjorgjieva¹

1. Max Planck Institute for Brain Research, Germany

Circuits of neurons in the brain simultaneously transform and transmit information in order to generate perception and action. How activity propagates locally within cortical circuitry remains poorly understood. Many theoretical studies have focused on the propagation of firing rate signals in networks of sparsely and weakly connected neurons. However, experimental evidence shows us that local cortical networks can present very high connection probabilities and a heavy-tailed distribution of synaptic strengths. In addition, recent experiments in the turtle visual cortex revealed that the induction of single spikes in pyramidal cells evokes sequential patterns of spiking activity with fine temporal structure in the surrounding cortex. Subsets of the activated neurons display high precision in the timing of their first spike across trials, resulting in repeatable multi-neuron sequences that spread away from the source. We are attempting to understand the mechanistic underpinnings of such responses and their reliability. We studied the propagation of single spikes under experimentally derived connectivity rules, using a computational approach. We developed a network model of one hundred thousand spiking point neurons with cellular, synaptic and network parameters fitted to experimental measurements. Accordingly, the resulting dense connectivity was composed of a majority of weak conductance-based synapses and a few strong ones. Our numerical simulations show how reliable single-spike transmission can be mediated by such network connectivity. The repeated induction of single spikes in single excitatory units allowed us to assess response reliability. The spatial features of the model's connectivity were able to capture the spatio-temporal signature of elicited activity in experiments. Through analysis of the paths taken by activity in the model, we highlight how stochastic connectivity patterns can nevertheless underlie precise spike transfer. Our work explains how single spikes may, under certain conditions of activity and connectivity, trigger reliable response patterns in local cortical networks.

Acknowledgements

JLR, JG, MH and GL thank the Max Planck Society for funding

©(2019) Riquelme JL, Hemberger M, Laurent G, Gjorgjieva J

Cite as: Riquelme JL, Hemberger M, Laurent G, Gjorgjieva J (2019) Reliable spike propagation in local cortical circuits of strong and dense connectivity. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0254](https://doi.org/10.12751/nncn.bc2019.0254)

[T 106] Renormalization Group for Spatially Extended Neuronal Networks

Jonas Stapmanns^{1,2}, Tobias Kühn^{1,3}, David Dahmen¹, Thomas Luu⁴, Carsten Honerkamp², Moritz Helias^{1,3}

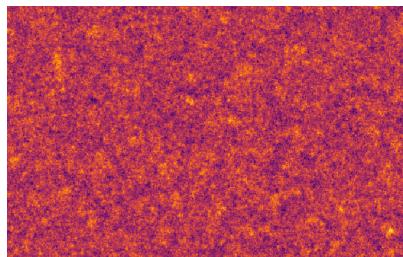
1. Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA Institute Brain Structure-Function Relationships (INM-10), Forschungszentrum Juelich, Germany

2. Institute for Theoretical Solid State Physics, RWTH Aachen, Germany

3. Department of Physics, Faculty 1, RWTH Aachen, Germany

4. Institut für Kernphysik (IKP-3) and Institute for Advanced Simulation (IAS-4) and Jülich Center for Hadron Physics, Forschungszentrum Juelich, Germany

Many phenomena observed in biological neural networks can only be explained by assuming nonlinear interactions. Due to effects like synaptic failure and channel noise, neuronal dynamics is also inherently stochastic. The investigation of the interaction of both of these properties is challenging because due to the nonlinearity, correlations of higher order influence those of lower order. Nonlinear, stochastic systems exhibit a plethora of dynamical states. The cortex, especially, is often suggested to operate close to a critical point at which linear response theory fails since the neural dynamics is dominated by large fluctuations on all length scales [1]. This is the realm of the Renormalization Group (RG), stemming from statistical and particle physics. We use this technique in the form introduced by Kenneth G. Wilson [2] to study a two-dimensional stochastic neural field model. Its connectivity is composed of two Gaussian kernels, one mimicking the excitatory and the other the inhibitory input. Its dynamics is given by a nonlinear gain and intrinsic nonlinear neuron dynamics. Gaussian white noise accounting for unspecified external input and intrinsic stochasticity drives our system. In its long-distance approximation, this model is similar to that proposed by Kardar, Parisi, and Zhang (KPZ) [3]. Along the lines taken in their approach, we derive RG-flow equations describing the couplings in our neural field model on different length scales. From this, one finds the upper critical dimension $d_c = 2$, which corresponds to the dimension of networks in cortex. Above d_c , mean-field theory is exact as the Gaussian fixed point is attractive for small interactions, whereas below d_c , the interaction dominates the behavior. For $d = d_c$, however, we find that the Gaussian fixed point becomes unstable and the interaction parameter flows into a strong coupling regime – similar to the KPZ model. A strong coupling fixed point may be present, which would indicate self-similarity – the signature of a critical state. Our analysis therefore implies certain constraints on the architecture of the neural network (within our model) if it is supposed to work at a critical point. For example, we conclude that we get stable dynamics only if the excitatory inputs extend wider than the inhibitory ones.



Snapshot of a simulation of the neural field activity. Bright spots correspond to high and dark spots to low activity.

Acknowledgements

Partly supported by seed funds MSCALE and CLS002 of the RWTH University; the JARA Center for Doctoral studies within the graduate School for Simulation and Data Science (SSD); the Helmholtz association: Young investigator's grant VH-NG-1028; EU-Grant 785907 (HBP).

References

- 1 Beggs, J. M., Plenz, D. (2003), Neuronal avalanches in neocortical circuits, *Journal of Neuroscience*, 23, 35, 11167–11177. [10.1523/JNEUROSCI.23-35-11167.2003](https://doi.org/10.1523/JNEUROSCI.23-35-11167.2003)
- 2 Wilson, K. G., Kogut, J. (1974), The renormalization group and the expansion, *Physics Reports*, 12, 2 , 75 - 199.
- 3 Kardar, M., Parisi, G., Zhang, Y.(1986), Dynamic Scaling of Growing Interfaces, *Phys. Rev. Lett.* 56, 889–892. [10.1103/PhysRevLett.56.88](https://doi.org/10.1103/PhysRevLett.56.88)

©(2019) Stapmanns J, Kühn T, Dahmen D, Luu T, Honerkamp C, Helias M

Cite as: Stapmanns J, Kühn T, Dahmen D, Luu T, Honerkamp C, Helias M (2019) Renormalization Group for Spatially Extended Neuronal Networks. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0255](https://doi.org/10.12751/nncn.bc2019.0255)

[T 107] Slow rhythmic activity arising from an interplay of the membrane voltage dynamics and extracellular potassium

Mahraz Behbood^{1,2}, Jan-Hendrik Schleimer^{1,2}, Susanne Schreiber^{1,2}

1. Institute for Theoretical Biology, Humboldt-Universität zu Berlin, Philippstr. 13, Haus 4, 10115 Berlin, Germany

2. Bernstein Center for Computational Neuroscience, Philippstr. 13, Haus 6, 10115 Berlin, Germany

Single-cell bursting has been associated with the physiological and pathophysiological rhythmic activity of the brain. Cellular dynamics can arise from very different mechanisms. They can, for example, be network-driven or caused by the dynamics of ionic conductances. Here, we focus on a cellular mechanism that relies on an interplay with the dynamics in extracellular potassium concentrations. Experiments show that the concentration of extracellular potassium change during neural activity and can even exhibit oscillations. On the one hand side, these oscillations in concentration may be a direct consequence of the spiking dynamics of bursting cells. On the other hand, as the concentration of extracellular K^+ influences the reversal potential E_K , an externally driven rhythmicity of extracellular K^+ concentration may also enforce bursting in neurons that would otherwise be regularly firing. So do we have to solve a hen-or-egg problem between the dynamics of the neuronal membrane potential and extracellular potassium to uncover the mechanism underlying the oscillatory phenomenon? Here, we propose that the experimentally observed bursting and rhythmicity in potassium concentration can arise from an interplay between both variables, none of which need

to show the burst-rhythm on their own. To this end, we use a minimal model, comprising conductance-based membrane-potential dynamics of a regularly firing neuron, yet combined with an ionic pump and variable extracellular potassium concentrations in a confined extracellular space. We show that for lower pump rates, a transient accumulation in extracellular K^+ provides positive feedback onto the voltage dynamics, finally resulting in a depolarization block and hence a firing pause. During this spiking pause, however, the pump dynamics can restore lower K^+ concentrations, leading to a state where spiking is re-initiated by intrinsic conductances. These cycles repeat, resulting in the bursting spiking activity as well as the oscillations in extracellular K^+ . We show that, mathematically, the observed rhythmicity is based on a hysteresis-loop in the K^+ dynamics. Taken together, we demonstrate a mechanism that requires both hen and egg and whose bursting rhythmicity would not show up in either hen or egg in isolation. We propose to use the model for further investigations on how dynamic changes of extracellular K^+ affect phenomena like spreading depolarization and epilepsy.

References

- 1 J. M. Ramirez, H. Koch, A. J. Garcia, A. Doi, and S. Zanella. The role of spiking and bursting pacemakers in the neuronal control of breathing. *Journal of Biological Physics*, 37(3):241–261, jun 2011. [10.1007/s10867-011-9214-z](https://doi.org/10.1007/s10867-011-9214-z)
- 2 Gyorgy Buzsaki. *Rhythms of the Brain*. Oxford University Press, 2006. [10.1093/acprof:oso/9780195301069.001.0001](https://doi.org/10.1093/acprof:oso/9780195301069.001.0001)
- 3 L. Gilles and N. Mohammad. Odorant-induced in the Mushroom Bodies of the Locust. *The Journal of Neuroscience*, 14(May):2993–3004, 1994. [10.1523/JNEUROSCI.14-05-02993.1994](https://doi.org/10.1523/JNEUROSCI.14-05-02993.1994)
- 4 C. M. Gray and W. Singer. Stimulus-Specific Neuronal Oscillations in Orientation Columns of Cat Visual Cortex. *Proceedings of the National Academy of Sciences*, 86(5):1698–1702, 1989. [10.1073/pnas.86.5.1698](https://doi.org/10.1073/pnas.86.5.1698)
- 5 N. Brunel. Dynamics of Sparsely Connected Networks of Excitatory and Inhibitory Spiking Neurons. *Journal of Computational Neuroscience*, 8:183–208, 2000. [10.1023/A:1008925309027](https://doi.org/10.1023/A:1008925309027)
- 6 E. D. Lumer, G. M. Edelman, and G. Tononi. Neural Dynamics in a Model of the Thalamo- cortical System. I. Layers, Loops and the Emergence of Fast Synchronous Rhythms. *Cerebral cortex*, (May):207–227, 1997. [10.1093/cercor/7.3.207](https://doi.org/10.1093/cercor/7.3.207)
- 7 E. M. Izhikevich. *Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting*. MIT Press, 2007.
- 8 F. Ding, J. O'donnell, Q. Xu, N. Kang, N. Goldman, and M. Nedergaard. Changes in the composition of brain interstitial ions control the sleep-wake cycle. *Science*, 352(6285):550–555, apr 2016. [10.1126/science.aad4821](https://doi.org/10.1126/science.aad4821)
- 9 F. Amzica, S. Dufour, R. Vallée, O. Chever, and P. Dufour. In vivo simultaneous intra- and extracellular potassium recordings using a micro-optrode. *Journal of Neuroscience Methods*, 194(2):206–217, 2010. [10.1016/j.jneumeth.2010.10.004](https://doi.org/10.1016/j.jneumeth.2010.10.004)

©(2019) Behbood M, Schleimer J, Schreiber S

Cite as: Behbood M, Schleimer J, Schreiber S (2019) Slow rhythmic activity arising from an interplay of the membrane voltage dynamics and extracellular potassium. *Bernstein Conference 2019 Abstract*. doi: [10.12751/ncnc.bn2019.0256](https://doi.org/10.12751/ncnc.bn2019.0256)

[T 108] Spectral decomposition of refractory density equation for neural population dynamics

Bastian Pietras^{1,2}, Noé Gallice³, Wulfram Gerstner³, Tilo Schwalger^{1,2}

1. Bernstein Center for Computational Neuroscience Berlin, 10115 Berlin, Germany

2. Institute of Mathematics, TU Berlin, 10623 Berlin, Germany

3. Brain Mind Institute, École polytechnique fédérale de Lausanne (EPFL), Station 15, CH-1015 Lausanne, Switzerland

A standard approach to describe the activity of cortical neural populations dwells on heuristic firing rate equations such as the Wilson-Cowan model [1]. Despite their success in explaining a variety of macroscopic neural data and various cortical computations, these models cannot account for the correct transient dynamics of the activity of a large group of neurons. Alternatively, one can derive the population activity from the properties of its individual neurons [2]. Many attempts, however, turn out to be computationally inefficient and mathematically intractable. Here, we present a novel approach that is based on the refractory density of neurons modeled as time-dependent renewal processes. The resulting firing rate model is low-dimensional, and, at the same time, it is able to capture the transient dynamics of the neural population.

Given a homogeneous population of neurons, we describe the individual firing activity as a renewal process subject to time-varying inputs, which can also be the recurrent input from the population. Due to the large number of neurons within such a population, we can simplify the analysis and group all those neurons together that have the same “age”, that is, their respective last spikes occurred at the same instant in time. This refractory density approach [3] results in an infinite-dimensional evolution equation, which we aim to simplify through an eigenfunction expansion akin to [4,5].

Remarkably, the population activity can sufficiently well be reproduced already by a first-mode approximation of the refractory density. The corresponding three-dimensional firing rate model is able to capture (transient) network effects that are due to partial spike synchronization. We explicitly demonstrate the validity of our model for a large homogeneous populations of Poisson neurons with absolute refractoriness. Moreover, we note that the theoretical framework is general and can be applied to all renewal processes.

References

- 1 H.R. Wilson and J.D. Cowan. Excitatory and inhibitory interactions in localized populations of model neurons. *Biophys. J.*, 12(1):1, 1972 [10.1016/S0006-3495\(72\)86068-5](https://doi.org/10.1016/S0006-3495(72)86068-5)
- 2 T. Schwalger, M. Deger, and W. Gerstner. Towards a theory of cortical columns: From spiking neurons to interacting neural populations of finite size. *PLoS Comput. Biol.*, 13(4), 2017 [10.1371/journal.pcbi.1005507](https://doi.org/10.1371/journal.pcbi.1005507)
- 3 W. Gerstner. Population dynamics of spiking neurons: Fast transients, asynchronous states, and locking. *Neural Comput.*, 12:43, 2000 [10.1162/089976600300015899](https://doi.org/10.1162/089976600300015899)
- 4 B.W. Knight. Dynamics of Encoding in Neuron Populations: Some General Mathematical Features. *Neural Comput.*, 12:473, 2000 [10.1162/089976600300015673](https://doi.org/10.1162/089976600300015673)
- 5 M. Mattia, P. Del Giudice. Population dynamics of interacting spiking neurons. *Phys. Rev. E* 66: 051917, 2002 [10.1103/PhysRevE.66.051917](https://doi.org/10.1103/PhysRevE.66.051917)

©(2019) Pietras B, Gallice N, Gerstner W, Schwalger T

Cite as: Pietras B, Gallice N, Gerstner W, Schwalger T (2019) Spectral decomposition of refractory density equation for neural population dynamics. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0257](https://doi.org/10.12751/nncn.bc2019.0257)

[T 109] Stability of bump attractor dynamics in the model of parametric working memory with synaptic heterogeneities

Pavel Esir¹, Ivan Lazarevich^{1,2}, Misha Tsodyks^{1,3}

1. Department of Neurotechnology, Lobachevsky University, Nizhny Novgorod, Russia

2. Group for Neural Theory, Ecole Normale Supérieure, Paris, France

3. Department of Neurobiology, Weizmann Institute, Rehovot, Israel

Attractor networks provide a plausible theoretical framework for understanding the basis of spatial working memory. Information about the external stimuli in attractor networks is stored in the form of localized activity bumps. This kind of networks is known to be structurally unstable and even small parameter perturbations lead to a break of symmetry and cause the activity bump to drift away from the stored state. Theoretical estimates show that robust storage of parametric information requires the fine-tuning of connection weights in the network.

It has been shown that synaptic facilitation can dramatically slow down the drift of the activity bump. This result is in agreement with the observation that connections between neurons in the prefrontal cortex (PFC) exhibit increased level of short-term synaptic facilitation compared to primary sensory areas.

In this work we show that in case when activity in the attractor network is stored in form of population spikes (PS) drift of the activity bump can slow down even more compared to the case of sustained activity. This happens because there is no synaptic activity between PSs and the bump drifts away from the stored state only during PSs themselves. We show that these results are in accordance with the recently proposed hypothesis of "activity-silent" working memory.

Acknowledgements

This work was supported by The Russian Science Foundation (Grant No. 18-11-00294).

©(2019) Esir P, Lazarevich I, Tsodyks M

Cite as: Esir P, Lazarevich I, Tsodyks M (2019) Stability of bump attractor dynamics in the model of parametric working memory with synaptic heterogeneities. *Bernstein Conference 2019 Abstract.* doi: [10.12751/nncn.bc2019.0258](https://doi.org/10.12751/nncn.bc2019.0258)

[T 110] Electrical synapses regulate both subthreshold integration and population activity of principal cells in response to transient inputs within canonical feedforward circuits

Tuan Pham^{1,2}, Julie S Haas¹

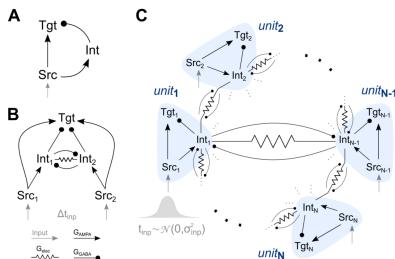
1. Department of Biological Sciences, Lehigh University, Bethlehem, PA, USA

2. Committee on Computational Neuroscience, The University of Chicago, Chicago, IL, USA

As information about the world traverses the brain, the signals exchanged between neurons are passed and modulated by synapses, or specialized contacts between neurons. While neurotransmitter-based synapses tend to exert either excitatory or inhibitory pulses of influence on the postsynaptic neuron, electrical synapses, composed of plaques of gap junction channels, continuously transmit signals that can either excite or inhibit a coupled neighbor. A growing body of evidence indicates that electrical synapses, similar to their chemical counterparts, are modified in strength during physiological neuronal activity. The synchronizing role of electrical synapses in neuronal oscillations has been well established, but their impact on transient signal processing in the brain is much less understood.

To investigate the impact of electrical synapses on transient signals, we constructed computational models based on the canonical feedforward neuronal circuit (Fig. 1A) of disynaptic inhibition with the inclusion of electrical synapses between inhibitory interneurons. Using Izhikevich type neurons, we progressively expanded models and analysis from a single circuit (Fig. 1A) to a pair of coupled circuits (Fig. 1B), and finally to a network composed of canonical circuits (Fig. 1C). We provided discrete closely-timed inputs to the circuits, and characterize the influence of electrical synapse strength on both subthreshold integration and spiking statistics at the output stage of the model.

Our simulations highlight the diverse and powerful roles that electrical synapses play even in simple circuits. At a local scale (Fig. 1B), the modeling results suggest that electrical coupling sharpens subthreshold integration window at the target principal neurons for closely-timed inputs of source neurons, while inhibitory coupling widens such window especially for disparately-timed inputs. At a network scale (Fig. 1C), depending on connection strength, both interneuronal coupling mechanisms together can delay or accelerate, and sharpen spiking of output principal neurons, affecting the information transmission from the source population to target population. Because these canonical circuits are represented widely throughout the brain, we expect that these are general principles for the influence of electrical synapses on transient signal processing across the brain.



Feedforward canonical circuit of disynaptic inhibition (A) embedded in a local circuit (B) to investigate subthreshold summation, and in a coupled network (C) to investigate spiking statistics in a network due to electrical and reciprocal inhibitory coupling between inhibitory interneurons

Acknowledgements

Brains for Brains Award 2019 (Bernstein Network Computational Neuroscience) and Undergraduate Research Grant 2017 – 2018 (Dept of Biol Sci, College of Arts and Sciences, Lehigh University) to TP. Whitehall Foundation and NSF IOS 1557474 to JSH. Parv Venkatasubramaniam for helpful discussion.

©(2019) Pham T, Haas JS

Cite as: Pham T, Haas JS (2019) Electrical synapses regulate both subthreshold integration and population activity of principal cells in response to transient inputs within canonical feedforward circuits. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0259](https://doi.org/10.12751/nncn.bc2019.0259)

[T 111] Synopsis of Statistics and Dynamics of Binary and Rate Neuronal Networks

Christian Keup^{1,2}, Tobias Kühn^{1,2}, David Dahmen¹, Moritz Helias^{1,2}

1. INM-6 / IAS-6 /INM-10, Research Centre Juelich, Jülich, Germany

2. Department of Physics, RWTH Aachen, Germany

Recent years have shown a renaissance of field theoretic methods applied to neural systems. Following this line of research, we here demonstrate a mapping between networks of binary neurons and networks of rate neurons. We show how by replacing binary neurons with appropriately chosen rate units and additional external white noise, the resulting rate network exhibits the same mean activity and time-lagged autocorrelation function as the original network of binary neurons in dynamical-mean-field approximation.

Next, we asked whether or not the network dynamics is chaotic, which has important consequences for the representation of information by neuronal activity. In networks that show chaotic dynamics on a microscopic level, a robust representation of information can only be achieved on the level of coarse-grained measures.

Considering the special case of SCS-connectivity [Sompolinsky et al. 1988], the dependence of the transition to chaos is known for rate networks also in the presence of white noise input [Schuecker et al. 2018]. Using our mapping, we work on transferring this knowledge to the chaos transition in the corresponding binary network. Because the resulting prediction is partially at odds with simulations, we compare both to another calculation extending the classical result of [van Vreeswijk & Sompolinsky 1998] and a third inspired by [Touzel & Wolf 2017], discussing the assumptions inherent in each approach. Our work therefore unifies the treatment of autocorrelations in [van Vreeswijk

and Sompolinsky 1998] and [Sompolinsky et al. 1988], and aims towards a more unified picture of chaos in neuronal networks.

Acknowledgements

Partly supported by the Helmholtz association: Young Investigator's grant VH-NG-1028, and EU-Grant 785907 (HBP)

References

- 1 Sompolinsky et al. (1988) Chaos in Random Neural Networks. *Phys.Rev.Lett.* 61:259
- 2 van Vreeswijk & Sompolinsky (1998) Chaotic Balanced State in a Model of Cortical Circuits. *Neural Comp.* 10(6), 1321-71
- 3 Touzel & Wolf (2017) Statistical mechanics of phase-space partitioning in large-scale neuronal circuits. *arXiv:1703.05205v1*
- 4 Schuecker et al. (2018) Optimal sequence memory in driven random networks. *Phys.Rev.X* 8,041029

©(2019) Keup C, Kühn T, Dahmen D, Helias M

Cite as: Keup C, Kühn T, Dahmen D, Helias M (2019) Synopsis of Statistics and Dynamics of Binary and Rate Neuronal Networks. *Bernstein Conference 2019 Abstract.* doi: [10.12751/nncn.bc2019.0260](https://doi.org/10.12751/nncn.bc2019.0260)

[T 112] Tailored ensembles of neural networks optimize sensitivity to stimulus statistics

Johannes Zierenberg^{1,2}, Jens Wilting¹, Viola Priesemann^{1,2}, Anna Levina^{3,4}

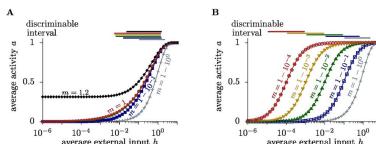
1. Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, 37077 Göttingen, Germany

2. Bernstein Center for Computational Neuroscience, Am Fassberg 17, 37077 Göttingen, Germany

3. University of Tübingen, Max Planck Ring 8, 72076 Tübingen, Germany

4. Max Planck Institute for Biological Cybernetics, Max Planck Ring 8, 72076 Tübingen, Germany

Living organisms are constantly exposed to sensory stimuli with complex, high-dimensional statistics. Properly reacting to these stimuli is essential for the organism to survive. However, already the encoding of stimulus intensity bears problems, as intensities are often distributed over multiple orders of magnitude. The capability to process these broad distributions can be quantified by the dynamic range. For recurrent neural networks, it was shown that the dynamic range of the neural response is maximized at criticality [1,2]. Here, we note that an optimal neural response to real complex stimulus statistics does not only require a sufficiently large dynamic range, but also requires to cover those intensities that are relevant. We quantify the intensities covered by the dynamic range with what we call the discriminable interval. For a single network near criticality, we show analytically that this discriminable interval cannot be tuned to cover all possible stimulus intensities. As a result, some intensities cannot be encoded – although they are potentially essential for the organism to survive. To resolve this problem, we derive a rule for activity-dependent synaptic adaptation that allows the network to fine-tune the discriminable interval. We demonstrate that an ensemble of such networks with specifically fine-tuned discriminable intervals can generate an optimal response to complex stimulus statistics.



Response curves and discriminable intervals for different control parameters (m). (A) Classical branching network with non-equilibrium phase transition at $m = 1$. (B) Modified network where the discriminable interval becomes a function of m .

References

- 1 O. Kinouchi and M. Copelli, "Optimal dynamical range of excitable networks at criticality", *Nat. Phys.* 2, 348 (2006).
- 2 W. L. Shew et al., "Neuronal Avalanches Imply Maximum Dynamic Range in Cortical Networks at Criticality", *J. Neurosci.* 9, 29 (2009).

©(2019) Zierenberg J, Wilting J, Priesemann V, Levina A

Cite as: Zierenberg J, Wilting J, Priesemann V, Levina A (2019) Tailored ensembles of neural networks optimize sensitivity to stimulus statistics. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0261](https://doi.org/10.12751/nncn.bc2019.0261)

[T 113] Thalamic influence on cortical dynamics: a computational study.

Enrico Cataldo¹, Matteo Saponati², Jordi Garcia-Ojalvo³, Alberto Mazzoni⁴

1. *Department of Physics, University of Pisa, Largo Bruno Pontecorvo 3, Pisa, Italy*
2. *Institut de Neurosciences des Systèmes, Faculté de Médecine – Aix-Marseille Université, 27, Boulevard Jean Moulin, 13005 Marseille, France*
3. *Department of Experimental and Health Science, Universitat Pompeu Fabra, Doctor Aiguader, 88 08003-Barcelona, Spain*
4. *The Biorobotics Institute, Sant'Anna School of Advanced Studies, Viale Rinaldo Piaggio 34, 56025, Pontedera (Pi), Italy*

Almost all sensory inputs, before reaching the cortex, pass through the thalamus, which processes, selects and relays them to the cortex. At the same time, inputs coming from the cortex modulate thalamic activity, which, thereby, plays a key role in cognitive processes [1, 2]. Numerous computational models have been built to shed light on some specific aspects of thalamocortical dynamics [3-5].

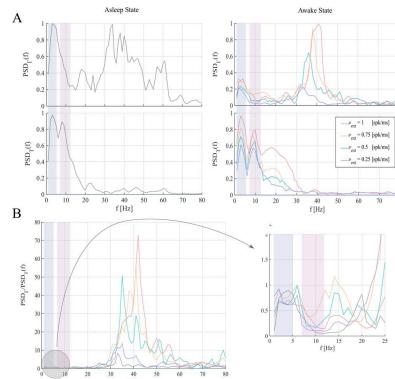
Our aim is to investigate, by means of a thalamocortical computational model, the propagation of thalamic activity to the cortex. Our model, which extends previously developed models [6] and [7] of cortical and thalamic network, respectively, consists of a network of excitatory and inhibitory neurons connected to each other according to known experimental anatomical constraints. Each neuron of the network is described with an adaptive exponential integrate and fire model [8]. The summed synaptic currents allow us to estimate the thalamic and cortical Local Field Potentials (LFPs) [9]. For full details see [10].

It is known the thalamic gating and selection of sensory inputs happen through a modulation of its internal activity, in which spindle oscillations play a fundamental role, but the mechanisms underlying this process are not completely understood. Among the mechanisms worthwhile to clarify there is the issue of how thalamocortical connections convey selectively stimulus-driven information over the background of thalamic internally generated activity as spindle oscillations (see Figure 1).

Our model is able to reproduce many aspects of the thalamocortical dynamics. Among them, it reproduces rhythms in the cortical LFP in response to external stimuli and to low-frequency rhythms in thalamic LFP, with and without sensory inputs (see Figure 1).

We found two possible mechanisms underlying the filtering out of spindle oscillations. One of this is that spindle oscillations are weaker in neurons projecting to the cortex. The other one is the resonance dynamics of cortical networks, which selectively blocks frequency in the range encompassing spindle oscillations. This latter mechanism depends on the balance of the strength of thalamocortical connections toward excitatory and inhibitory neurons in the cortex. These results are robust and stable to several tests

such as parameter variation and pave the way toward an integrated simulation from periphery to cortex of the sensory streams and back from cortex to thalamus.



LFPs spectrum. A) Estimated power spectral densities of thalamic and cortical LFPs without (left) and with (right) external inputs (Poisson spike-train). Blue and purple stripes represent delta and theta frequency range. B) Ratio of cortical to thalamic power spectrum as a function of input rate.

Acknowledgements

Department of Physics, University of Pisa, Italy

References

- 1 [1] Rikhye RV, Wimmer RD, Halassa MM (2018) Toward an integrative theory of thalamic function. *Annu Rev Neurosci* 41: 163–83.
- 2 [2] Crunelli V, Connolly WM, Usrey WM, eds. (2016) Thalamic function – beyond a simple relay. Lausanne: Frontiers Media. Doi: 10.3389/978-2-88919-842-9.
- 3 [3] Li G, Henriquez CS, Froehlich F (2008) Unified thalamic model generates multiple distinct oscillations with state-dependent entrainment by stimulation. *PLoS Comput Biol* 13(10): e1005797.
- 4 [4] Krishnan GP, Chauvette S, Shamie I, Soltani S, Timofeev I, Cash SS, Halgren E, Bazhenov M (2016) Cellular and neurochemical basis of sleep stages in the thalamocortical network. *eLife* 5:e18607.
- 5 [5] Krishnan GP, Rosen BQ, Chen JY, Muller L, Sejnowski TJ, Cash SS, Halgren E, Bazhenov M (2018) Thalamocortical and intracortical laminar connectivity determines sleep spindle properties. *PLoS Comput Biol* 14(6): e1006171.
- 6 [6] Mazzoni A, Panzeri S, Logothetis NK, Brunel N (2008) Encoding of naturalistic stimuli by local field potential spectra in networks of excitatory and inhibitory neurons. *PLoS Comput Biol* 4(12) e1000239.
- 7 [7] Barardi A, Garcia-Ojalvo J, Mazzoni M (2016) Transition between functional regimes in an integrate-and-fire network model of the thalamus. *PLoS one* 11(9) e0161934.
- 8 [8] Brette R, Gerstner W (2005) Adaptive exponential integrate-and-fire model as an effective description of neuronal activity. *J Neurophysiol* 94(5) 3637–3642.
- 9 [9] Mazzoni A, Linden H, Cuntz H, Lansner A, Panzeri S, Einevoll GT (2015) Computing the local field potential (lfp) from integrate-and-fire network models, *PLoS Comput Biol* 11(12) e1004584.
- 10 [10] Saponati M, Garcia-Ojalvo J, Cataldo E, Mazzoni A (2019) Integrate-and-fire network model of activity propagation from thalamus to cortex. *Biosystems*, 183: 103978.

©(2019) Cataldo E, Saponati M, Garcia-Ojalvo J, Mazzoni A

Cite as: Cataldo E, Saponati M, Garcia-Ojalvo J, Mazzoni A (2019) Thalamic influence on cortical dynamics: a computational study.. *Bernstein Conference 2019 Abstract*. doi: 10.12751/ncnbc2019.0262

[T 114] The Interplay between Randomness and Low-rank Structure in Recurrent Neural Networks

Friedrich Schuessler^{1,2}, Alexis Dubreuil³, Francesca Mastrogiosepppe⁴, Srdjan Ostojic³, Omri Barak^{1,2}

1. Faculty of Medicine, Technion, Haifa, Israel

2. Network Biology Research Labs, Technion, Haifa, Israel

3. Laboratoire de Neurosciences Cognitives, ENS, Paris, France

4. Gatsby Computational Neuroscience Unit, UCL, London, Great Britain

A given network in the brain is determined by many factors, from development and homeostasis to the tasks the network is involved in. Thus, when considering a specific task, the connectivity contains both structurally related and unrelated – in a sense random – components. Understanding the interplay between the structured and random components, and their effect on network dynamics and functionality, is an important open question. Connectivity structures that were hand-designed to solve specific tasks are often low-rank. Similarly, trained networks have shown to involve low-rank structures. Finally, experimental recordings show both low-dimensional activity as well as large heterogeneity, consistent both with low-rank structures and random connectivity. Previous work addressed the coexistence of low-rank structures and random connectivity, but without correlation between them. This limits the dynamics and leaves the random connectivity non-functional. We characterize the effect of such correlations in nonlinear networks by studying the emerging fixed points and their stability analytically. We determine the spectrum of the stability matrix and find that the correlations may induce multiple outliers. Finally, we apply our formalism to investigate learning. We explain the formation of low-rank structures and show how correlations to the initial random component can facilitate learning.

©(2019) Schuessler F, Dubreuil A, Mastrogiosepppe F, Ostojic S, Barak O

Cite as: Schuessler F, Dubreuil A, Mastrogiosepppe F, Ostojic S, Barak O (2019) The Interplay between Randomness and

Low-rank Structure in Recurrent Neural Networks. Bernstein Conference 2019 Abstract.

doi: [10.12751/nncn.bc2019.0263](https://doi.org/10.12751/nncn.bc2019.0263)

[T 115] The optimal number of release sites in synapses with neurotransmitter spillover

Mehrdad Salmasi^{1,2,3}, Stefan Glasauer^{2,3,4}, Martin Stemmler^{2,5}

1. Graduate School of Systemic Neurosciences, Ludwig-Maximilians-Universität, Munich, Germany

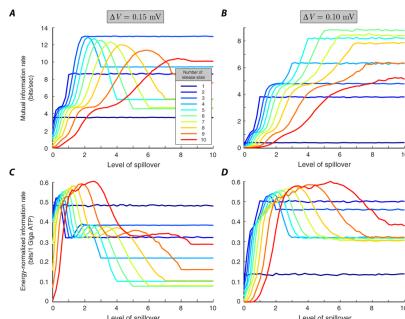
2. Bernstein Center for Computational Neuroscience, Munich, Germany

3. German Center for Vertigo and Balance Disorders, Ludwig-Maximilians-Universität, Munich, Germany

4. Chair of Computational Neuroscience, Brandenburg University of Technology Cottbus-Senftenberg, Senftenberg, Germany

5. Department of Biology II, Ludwig-Maximilians-Universität, Munich, Germany

Synapses span a large spectrum—from the calyx of Held, a specialized synapse with hundreds of release sites, to synapses in central nervous system with one or two release sites. The greater the number of release sites, the stronger the synaptic signal is amplified, as neurotransmitters spill over to activate neighboring receptors [1]. At the same time, the release probability is inversely correlated with the number of release sites [2]. The consequences of this trade-off are still not completely understood, even in theory. We, therefore, set out to study the relationship between the clustering topology of release sites and the rate of information transmission between neurons. In particular, we ask how much information the spike train of a postsynaptic neuron conveys about a single presynaptic neuron's spike train. Binary asymmetric channels are used to model short-term depression/facilitation as well as synchronous and asynchronous release modes of the release sites [3,4]. The number of neighboring postsynaptic sites activated by the release of a single vesicle sets the model's level of spillover. We first derive a closed form equation for the postsynaptic potential as a function of the number of released vesicles and the level of spillover. We assume that the activation of a postsynaptic site generates a fixed voltage change, ΔV , in the postsynaptic potential at the soma, regardless of the location of the synapse [5]—increasing the membrane potential by 20 mV will generate a spike. The total number of release sites is fixed, but the number of synaptic contacts varies. We calculate the mutual information rate between the spike trains of an input neuron and the target neuron using the context tree weighting algorithm. Interestingly, the optimal number of release sites in a synapse depends strongly on ΔV . For a neuron with $\Delta V = 0.15$ mV, synapses with 3 release sites are best (Fig. 1A). However, if ΔV drops to 0.1 mV, then 6 release sites per synapse are optimal for neuronal communication (Fig. 1B). Information transmission comes at an energetic cost [6]. We analyze the energy-normalized information rate and show that this measure depends on the level of spillover and is enhanced by condensing more release sites in a synapse. In contrast to the result for maximizing information transmission, the ideal clustering of release sites, measured in bits/ATP, is no longer sensitive to the magnitude of ΔV (Fig. 1C,D).



Mutual information rate (A,B) and energy-normalized information rate (C,D) between the spike trains of an input neuron and the target neuron against the level of spillover for various numbers of release sites in the synapse. In A and C, $\Delta V = 0.15 \text{ mV}$ and in B and D, $\Delta V = 0.1 \text{ mV}$.

Acknowledgements

This work was supported by the BMBF grant 01EO1401 (German Center for Vertigo and Balance Disorders).

References

- 1 DiGregorio DA, Nusser Z, Silver RA, Spillover of glutamate onto synaptic AMPA receptors enhances fast transmission at a cerebellar synapse, *Neuron*, 2002 [10.1016/S0896-6273\(02\)00787-0](https://doi.org/10.1016/S0896-6273(02)00787-0)
- 2 Hardingham NR, Read JC, Trevelyan AJ, Nelson JC, Jack JJ, Bannister NJ, Quantal analysis reveals a functional correlation between presynaptic and postsynaptic efficacy in excitatory connections from rat neocortex, *Journal of Neuroscience*, 2010 [10.1523/JNEUROSCI.3244-09.2010](https://doi.org/10.1523/JNEUROSCI.3244-09.2010)
- 3 Salmasi M, Stemmler M, Glasauer S, Loebel A, Information rate analysis of a synaptic release site using a two-state model of short-term depression, *Neural computation*, 2017 [10.1162/NECO_a_00962](https://doi.org/10.1162/NECO_a_00962)
- 4 Salmasi M, Loebel A, Glasauer S, Stemmler M, Short-term synaptic depression can increase the rate of information transfer at a release site, *PLoS Computational Biology*, 2019 [10.1371/journal.pcbi.1006666](https://doi.org/10.1371/journal.pcbi.1006666)
- 5 Magee JC, Dendritic integration of excitatory synaptic input, *Nature Reviews Neuroscience*, 2000 [10.1038/35044552](https://doi.org/10.1038/35044552)
- 6 Harris J., Jolivet R, Attwell D, Synaptic energy use and supply, *Neuron*, 2012 [10.1016/j.neuron.2012.08.019](https://doi.org/10.1016/j.neuron.2012.08.019)

©(2019) Salmasi M, Glasauer S, Stemmler M

Cite as: Salmasi M, Glasauer S, Stemmler M (2019) The optimal number of release sites in synapses with neurotransmitter spillover. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0264](https://doi.org/10.12751/nncn.bc2019.0264)

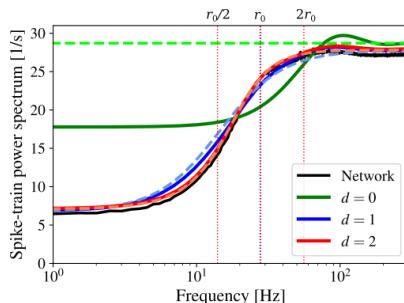
[T 116] **Theory of large and sparse recurrent networks including self-consistent temporal correlations of spike trains**

Sebastian Vellmer^{1,2}, Benjamin Lindner^{1,2}

1. Physics Department, Humboldt Universität zu Berlin, 12489, Berlin, Germany

2. Bernstein Center for Computational Neuroscience, 10115 Berlin, Germany

The dynamics of large and sparse recurrent networks of spiking neurons have been studied by mean-field theories. These theories exploit that neural input for a representative neuron is generated by other neurons. Since in a homogeneous network all neurons share the same properties, the statistics of neural input and output have to coincide which yields a condition of self consistency. In Brunel (2000) neural input is approximated as a temporally uncorrelated (white) noise process with Gaussian statistics that only depends on the input firing rate. Assuming self-consistent firing rates in the network, the firing rates can be estimated and different firing regimes can be localized by the solution of the corresponding Fokker-Planck equation (FPE) [1]. However, neural spike trains are temporally correlated and neural input, as the sum of many spike trains, maintains these correlations [2] that can be represented by the power spectrum. Also these temporal correlations are self consistent in networks and can be determined by an iterative scheme [3,4]. Here we introduce a mean-field theory that considers the self consistency of the power spectrum by approximating neural input as temporally correlated (colored) noise generated by a multidimensional Ornstein-Uhlenbeck process (OUP). We derive an analytical set of equations to calculate the spike-train power spectrum of a generalized integrate-and-fire neuron driven by the OUP from the corresponding multidimensional FPE. We use this developed framework to establish the mean-field theory in which the spectrum of the OUP has to coincide with the resulting spike-train power spectrum. Since a finite-dimensional OUP cannot exhibit arbitrary spectra, the condition of self consistency can only approximately be fulfilled at certain frequencies. The power spectrum of a d-dimensional OUP is given by a rational function with $2d+1$ variables, hence, the number of frequencies at which self consistency can be achieved is $2d+1$. In our example (see figure) we use the high-frequency limit that represents the self consistency of the firing rate r in all cases. We recover the theory in [1] for $d=0$. For $d=1$ we additionally achieve self-consistency at the low frequency limit $f=0$ and at $f=r$, for $d=2$ also at $f=r/2$ and $f=2r$. The higher dimensionality increases the spectrum's degree of freedom, and thus, yields a better approximation on the self-consistent power spectrum observed in the network simulation.



Self-consistent power spectrum: observed in network simulation (black) line and as the solution of the mean-field theory (colored). Input (dashed) and spike-train spectrum (solid) coincide at infinity (all), zero ($d > 0$) and vertical lines.

Acknowledgements

This paper was developed within the scope of the IRTG 1740 / TRP 2015/50122-0, funded by the DFG / FAPESP.

References

1. N. Brunel. Dynamics of sparsely connected networks of excitatory and inhibitory spiking neurons. *J. Comput. Neurosci.*, 8:183, 2000.
2. B. Lindner. Superposition of many independent spike trains is generally not a Poisson process. *Phys. Rev. E.*, 73:022901, 2006.
3. A. Lerchner, C. Ursta, J. Hertz, M. Ahmadi, P. Ruffiot and S. Enemark. Response variability in balanced cortical networks. *Neural Comput.*, 18:634, 2006.
4. B. Dummer, S. Wieland and B. Lindner. Self-consistent determination of the spike-train power spectrum in a neural network with sparse connectivity. *Front. Comp. Neurosci.*, 8:104, 2014.

©(2019) Vellmer S, Lindner B

Cite as: Vellmer S, Lindner B (2019) Theory of large and sparse recurrent networks including self-consistent temporal correlations of spike trains. Bernstein Conference 2019 Abstract. doi: 10.12751/nncn.bc2019.0265

[T 117] Timescales of spontaneous cortical dynamics reflect the underlying spatial network structure

Roxana Zeraati^{1,2}, Nicholas Steinmetz³, Tirin Moore⁴, Tatiana Engel⁵, Anna Levina^{2,6,7}

1. International Max Planck Research School, University of Tübingen, Tübingen, Germany

2. Max Planck Institute for Biological Cybernetics, Tübingen, Germany

3. Department of Biological Structure, University of Washington, Seattle, USA

4. Department of Neurobiology, Stanford University, California, USA

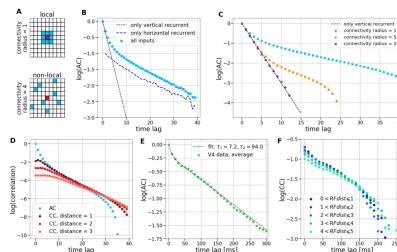
5. Cold Spring Harbor Laboratory, New York, USA

6. University of Tübingen, Tübingen, Germany

7. Bernstein Center for Computational Neuroscience, Tübingen, Germany

Spontaneous cortical activity unfolds across different spatial scales. On a local scale of individual columns, activity spontaneously transitions between episodes of vigorous (On) and faint (Off) spiking synchronously across cortical layers [1]. On a wider spatial scale, activity propagates as cascades of elevated firing across many columns, characterized by a branching ratio defined as the average number of units activated by each active unit [2]. Timescales of these intrinsic fluctuations were suggested to reflect the network's specialization for task-relevant computations, but how they arise from the spatial structure of the network is unknown. To find out to what extent these timescales reflect the dynamics on different spatial scales and the underlying network

structure, we developed a branching network model capable of capturing both local On-Off dynamics and global activity propagation. Our model consists of bistable units representing cortical columns with spatially structured connections to other columns (Fig 1A). We found that the timescales of local dynamics reflect the spatial network structure. In the model, activity of single columns exhibits two distinct timescales: one induced by the recurrent excitation within the column and another induced by interactions between the columns (Fig 1B). The first timescale dominates dynamics in networks with more dispersed connectivity, whereas the second timescale is prominent in networks with more local connectivity (Fig 1C). The second timescale is also evident in cross-correlations (CC) between columns because of their shared recurrent inputs and becomes longer with increasing distance between columns (Fig 1D). To test model predictions, we analyzed multi-electrode recordings of spiking activity from single columns in the area V4 and observed two timescales in both local On-Off fluctuations and CCs of neural activity on different channels within the same column (Fig 1E, F). We examined the dependency of these timescales on horizontal cortical distance, by leveraging the slight horizontal shifts in columnar recordings and using the distances between centers of receptive fields (RF) across different channels as a surrogate for horizontal displacement. As predicted by the model, the second timescale in CCs became longer with increasing RF-center distance. Our results suggest that timescales of local fluctuations in single cortical columns provide information about the underlying spatial network structure.



A) Model connectivity. B) Representation of different timescales in single columns autocorrelation (AC). C) Average AC of individual columns for different network structures. D) Dependency of CC on distance between the columns. E) Average AC of V4 data. F) V4 data CC averaged over same RF-distances.

Acknowledgements

The research was funded by SMARTSTART 2 program and the Sofja Kovalevskaja Award from the Alexander von Humboldt Foundation, endowed by the Federal Ministry of Education and Research. The simulations were performed on the BlackNBlue computer cluster at Cold Spring Harbor Laboratory.

References

- Engel, Tatiana A., et al. "Selective modulation of cortical state during spatial attention." *Science* 354.6316 (2016): 1140-1144. [10.1126/science.aag1420](https://doi.org/10.1126/science.aag1420)
- Wilting, Jens, and Viola Priesemann. "Inferring collective dynamical states from widely unobserved systems." *Nature communications* 9.1 (2018): 2325.

©(2019) Zeraati R, Steinmetz N, Moore T, Engel T, Levina A

Cite as: Zeraati R, Steinmetz N, Moore T, Engel T, Levina A (2019) Timescales of spontaneous cortical dynamics reflect the underlying spatial network structure. *Bernstein Conference 2019* Abstract. doi: [10.12751/ncnbc2019.0266](https://doi.org/10.12751/ncnbc2019.0266)

[T 118] Towards a reduced model of ripple oscillations in recurrent inhibitory networks

Natalie Schieberstein^{1,2}, Richard Kempter^{1,2,3}

1. Institute for Theoretical Biology, Humboldt University Berlin, Philippstr. 13, Haus 4, 10115 Berlin, Germany

2. Bernstein Center for Computational Neuroscience, Humboldt University Berlin, Philippstr. 13, Haus 6, 10115 Berlin, Germany

3. Einstein Center for Neurosciences Berlin, Charité, Charitéplatz 1, 10117 Berlin, Germany

Hippocampal ripple oscillations have long been implicated in important cognitive functions such as memory consolidation [1]. The mechanisms underlying ripple generation however are still under debate. Modeling studies [2,3] have shown that a network of recurrently coupled inhibitory interneurons (INT-INT) can produce oscillations in the ripple band (140-220 Hz) and even exhibit intra-ripple frequency accommodation (IFA) — an asymmetry in the instantaneous network frequency in response to transient, sharp-wave like stimulation [3,4]. Here we develop a minimal model that reflects the core features of INT-INT networks required for both ripple oscillations and IFA. We hypothesize that there is a link between IFA and a network's steady-state profile, i.e., its response to excitatory feedforward input of constant intensity. The steady-state profile of the network in [3] shows a regime of sparse synchrony, where the population activity oscillates at a ripple-range frequency, which is much higher than the mean unit rate and only has a weak, non-linear dependence on the input level. We propose that, given such a steady-state profile, IFA emerges as the result of a speed-dependent hysteresis effect in the population synchrony. Our model reduction points to the importance of noise: We can reproduce sparse synchrony and IFA in fully coupled networks of either leaky integrate-and-fire units or more abstract pulse-coupled oscillators, given that the inhibitory coupling is delayed and that each unit receives independent noise. Such reduced models might be the basis for deriving the network frequency, and hence the regime of sparse synchrony, in an analytical fashion. Understanding the range of INT-INT-type networks that reproduce sparse synchrony and IFA is crucial to derive testable predictions and assess the plausibility of interneuron networks as the main pacemaker of ripple oscillations. Unraveling the ripple generating mechanism(s) is essential for the development of experimental protocols that can selectively test the role of ripple oscillations in memory consolidation.

[1] G. Buzsáki, Neuroscience 31: 551-570, 1989 [2] N. Brunel, X.-J. Wang, J Neurophysiol 90: 415-30, 2003 [3] J. Donoso, D. Schmitz, N. Maier, R. Kempter, J Neurosci 38: 3124 –3146, 2018 [4] Sullivan et al., J Neurosci, 31: 8605-8616, 2011

References

- 1 Buzsáki [10.1016/0306-4522\(89\)90423-5](https://doi.org/10.1016/0306-4522(89)90423-5)
- 2 Brunel, Wang [10.1152/jn.01095.2002](https://doi.org/10.1152/jn.01095.2002)
- 3 Donoso et al. [10.1523/JNEUROSCI.0188-17.2018](https://doi.org/10.1523/JNEUROSCI.0188-17.2018)
- 4 Sullivan et al. [10.1523/JNEUROSCI.0294-11.2011](https://doi.org/10.1523/JNEUROSCI.0294-11.2011)

©(2019) Schieberstein N, Kempter R

Cite as: Schieberstein N, Kempter R (2019) Towards a reduced model of ripple oscillations in recurrent inhibitory networks. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0267](https://doi.org/10.12751/nncn.bc2019.0267)

[T 119] Training spiking networks to decode single spikes and bursts gives rise to interneuron diversity

Joram Keijser^{1,2}, Henning Sprekeler^{1,3}

1. Modelling of Cognitive Processes,, Berlin Institute of Technology, Marchstr. 23 10587 Berlin, Germany

2. Einstein Center for Neurosciences, Charitéplatz 1, 10117, Berlin, Germany

3. Bernstein Center for Computational Neuroscience Berlin, Philippstraße 13/Haus 6, 10115, Germany

Inhibitory interneurons play a fundamental role in cortical information processing despite being outnumbered by excitatory cells [1]. In recent years, it has been shown that these interneurons exhibit a broad diversity with respect to their morphology, firing patterns, connectivity and short term plasticity [2]. However, the origin and computational role of this diversity is not well understood.

We hypothesize that interneuron diversity is the result of an optimisation for particular neuronal functions during development. To test this hypothesis, we optimise a previously proposed network model [3], in which excitatory neurons use both spikes and bursts to separately communicate input signals targeting their somatic and dendritic compartments, respectively. Downstream interneuron populations can decode the two signals using appropriately tuned synaptic weights and short-term plasticity. In [3], these parameters were tuned manually. Here, we show that these properties can be tuned automatically by building on recent advances in training spiking networks using surrogate gradient learning [4]. Before optimisation, the interneuron population is not diversified and does not separate somatic and dendritic inputs. After optimisation, the interneurons either receive short term depressing or short term facilitating inputs which make them selective for either single spikes or bursts.

This shows that surrogate-gradient learning can be used to optimise both network and neuron properties in spiking networks, opening the possibility to understand how interneuron diversity emerges from functional requirements.

Acknowledgements

This work was funded by the Einstein Center for Neurosciences Berlin

References

- 1 Isaacson, J. S., & Scanziani, M. (2011). How inhibition shapes cortical activity. *Neuron*, 72(2), 231-243. [10.1016/j.neuron.2011.09.027](https://doi.org/10.1016/j.neuron.2011.09.027)
- 2 Tremblay, R., Lee, S., & Rudy, B. (2016). GABAergic interneurons in the neocortex: from cellular properties to circuits. *Neuron*, 91(2), 260-292. [10.1016/j.neuron.2016.06.033](https://doi.org/10.1016/j.neuron.2016.06.033)
- 3 Naud, R., & Sprekeler, H. (2018). Sparse bursts optimize information transmission in a multiplexed neural code. *Proceedings of the National Academy of Sciences*, 115(27), E6329-E6338. [10.1073/pnas.1720995115](https://doi.org/10.1073/pnas.1720995115)
- 4 Neftci, E. O., Mostafa, H., & Zenke, F. (2019). Surrogate gradient learning in spiking neural networks. arXiv preprint arXiv:1901.09948.

©(2019) Keijser J, Sprekeler H

Cite as: Keijser J, Sprekeler H (2019) Training spiking networks to decode single spikes and bursts gives rise to interneuron diversity. *Bernstein Conference 2019* Abstract. doi: [10.12751/nncn.bc2019.0268](https://doi.org/10.12751/nncn.bc2019.0268)

[T 120] **Tuft dendrites of pyramidal neurons operate as feedback-modulated functional subunits**

Florian Eberhardt^{1,2}, Andreas V.M. Herz^{1,2}, Stefan Häusler^{1,2}

1. *Biology II, LMU München, Munich, Germany*

2. *BCCN Munich, Munich, Germany*

Dendrites of pyramidal cells exhibit complex morphologies and contain a variety of ionic conductances, which generate non-trivial integrative properties. Basal and proximal apical dendrites have been shown to function as independent computational subunits within a two-layer feedforward processing scheme. The outputs of the subunits are linearly summed and passed through a final non-linearity. It is an open question whether this mathematical abstraction can be applied to apical tuft dendrites as well. Using a detailed compartmental model of CA1 pyramidal neurons and a novel theoretical framework based on iso-response methods, we first show that somatic sub-threshold responses to brief synaptic inputs cannot be described by a two-layer feedforward model. Then, we relax the core assumption of subunit independence and introduce non-linear feedback from the output layer to the subunit inputs. We find that additive feedback alone explains the somatic responses to synaptic inputs to most of the branches in the apical tuft. Individual dendritic branches bidirectionally modulate the thresholds of their input-output curves without significantly changing the gains. In contrast to these findings for precisely timed inputs, we show that neuronal computations based on firing rates can be accurately described by purely feedforward two-layer models. Our findings support the view that dendrites of pyramidal neurons possess non-linear analog processing capabilities that critically depend on the location of synaptic inputs. The iso-response framework proposed in this computational study is highly efficient and could be directly applied to biological neurons.

©(2019) Eberhardt F, Herz AV, Häusler S

Cite as: Eberhardt F, Herz AV, Häusler S (2019) Tuft dendrites of pyramidal neurons operate as feedback-modulated functional subunits. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0269](https://doi.org/10.12751/nncn.bc2019.0269)

[T 121] Tuned cellular and network properties maximize information transmission in rodent somatosensory cortex

Andreas Neef^{1,2}, Ricardo Martins Merino^{1,2}, Omer Revah³, Carolina Leon Pinzon², Michael J Gutnick³, Ilya Fleidervish⁴, Fred Wolf^{1,2}

1. Campus Institut for Dynamics of Biological Networks, Göttingen, Germany

2. BCCN Göttingen, Germany

3. Koret School of Veterinary Medicine, Hebrew University, Rehovot, Israel

4. Department of Physiology and Cell Biology, Ben Gurion University, Be'er Sheva, Israel

Populations of cortical neurons often encode sensory information in the time dependent population firing rate. Here we studied the quality of population encoding in a prototypical system in somatosensory cortex. Spiny stellate (SpSt) neurons are the prevalent excitatory cells of Layer 4 of rodent somatosensory cortex and are organized in 'barrels'. Each barrel receives nearly all of its excitatory input from neurons in the same barrel, with the majority originating from within layer 4 while the remained represents sensory feed-forward input from thalamus. Because it is a primary thalamocortical target, the Layer 4 circuit comprises a key gateway into the cortical circuit. We used whole-cell patch clamp to measure the temporal properties of the background input that SpSt receive from their local network and compared it with the input received by the much larger Layer 5 pyramidal cells. SpSt cells receive much more slowly fluctuating input with a correlation time of around 7 ms as opposed to only 2 ms for pyramidal cells. These correlation times tightly correlate with the EPSC decay times observed in the respective cells. We then characterized the capabilities of both cell types to encode rapid signals under an input resembling a synaptically active environment. When we use a background input with 5 ms correlation time, we find that indeed SpSt cells have a smaller encoding bandwidth than pyramidal neurons. However, when using a longer correlation time of 10 ms, the encoding bandwidth of SpSt broadens strongly, approaching that of a pyramidal cell. This improvement in encoding bandwidth of sensory input depends on activation of potassium conductance, as it disappears when Kv1 or Kv7.2/3 channels are pharmacologically blocked. In summary, in SpSt cells, synaptic properties and axonal potassium conductances seem to be matched to achieve a wide bandwidth of information encoding.

©(2019) Neef A, Martins Merino R, Revah O, Leon Pinzon C, Gutnick MJ, Fleidervish I, Wolf F

Cite as: Neef A, Martins Merino R, Revah O, Leon Pinzon C, Gutnick MJ, Fleidervish I, Wolf F (2019) Tuned cellular and network properties maximize information transmission in rodent somatosensory cortex. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0270](https://doi.org/10.12751/nncn.bc2019.0270)

[T 122] Understanding computations and information representation in a multistage recurrent neural network

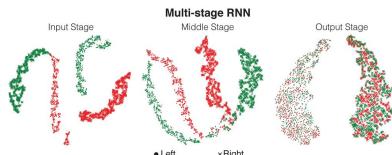
Michael Kleinman¹, Chandramouli Chandrasekaran², Jonathan Kao¹

1. Electrical and Computer Engineering, University of California, Los Angeles, USA

2. Anatomy and Neurobiology, Boston University, USA

Decision-making and other cognitive behaviors are solved in a distributed fashion with the coordination of multiple brain regions. However, elucidating the computations in each brain region is especially challenging since recordings of the neural population are sparse and knowledge of within and between region connectivity is either sparse or unknown. Here, our goal was to understand how distributed networks solve cognitive tasks by leveraging recurrent neural network (RNN) models [1]. To that end, we investigated the dynamics of a fully observable multistage RNN trained to discriminate the dominant color of a checkerboard and provide a corresponding color-dependent motor output [2]. We found that the last stage of the multistage RNN retained direction related information, but not color information – a phenomenon observed in neurons in the dorsal premotor cortex. We next investigated how the RNN preserved the direction related information across stages, while filtering the color information. This amounted to finding how each stage recurrently processed the external inputs so that it could produce useful outputs for subsequent stages. We identified interpretable task-relevant axes [3] and found that in the input stage, the color inputs were integrated along a color axis and readout along a direction axis. The amount of information that propagated to the subsequent layer (i.e., between layer 1 and 2 or layer 2 and 3) depended on the orientation of these axes with respect to the null and range space of the feedforward connectivity matrix between stages. The direction axis was predominantly aligned with the range space, while the color axis was predominantly aligned with the null space. This separation represents a possible mechanism that allows information to be locally processed, with relevant information for subsequent stages preferentially propagated. In the output stage, neural population activity separated based on the resulting decision. By analyzing the output stage recurrent weight matrix, we found that the last stage was a standard winner-take-all circuit.

Overall, our results show how distributed computation can be understood in terms of how individual stages process inputs to produce suitable outputs for the subsequent stages. Our analyses provide both a framework for understanding distributed computation in neural systems and offer experimentally testable hypotheses for the computations that occur in various brain regions.



tSNE embedding of RNN rates near movement onset, labelled with the selected target color and reach direction. The output stage largely encodes direction information, consistent with PMd data.

Acknowledgements

MK was supported by the National Sciences and Engineering Research Council (NSERC). CC was supported

by an NIH/NINDS R00 Grant 4R00NS092972-03.

References

- 1 Barak, O. Recurrent neural networks as versatile tools of neuroscience research. *Curr. Opin. Neurobiol.* 46, 1–6 (2017).
- 2 Chandrasekaran, C., Peixoto, D., Newsome, W. T. & Shenoy, K. V. Laminar differences in decision-related neural activity in dorsal premotor cortex. *Nat. Commun.* 8, (2017).
- 3 Mante, V., Sussillo, D., Shenoy, K. V. & Newsome, W. T. Context-dependent computation by recurrent dynamics in prefrontal cortex. *Nature* 503, 78–84 (2013).

©(2019) Kleinman M, Chandrasekaran C, Kao J

Cite as: Kleinman M, Chandrasekaran C, Kao J (2019) Understanding computations and information representation in a multistage recurrent neural network. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0271](https://doi.org/10.12751/nncn.bc2019.0271)

[T 123] Facilitating the propagation of spiking activity in feedforward networks by including feedback

Hedyeh Rezaei¹, Alireza Valizadeh¹, Ad Aertsen², Arvind Kumar³

1. Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran

2. Faculty of Biology, and Bernstein Center Freiburg, University of Freiburg, Freiburg, Germany

3. Dept. of Computational Science and Technology, School of Computer Science and Communication, KTH Royal Institute of Technology, Stockholm, Sweden

Transient oscillations in network activity upon sensory stimulation have been reported in different sensory areas. These evoked oscillations are the generic response of networks of excitatory and inhibitory neurons (EI-networks) to a transient external input (Mehring et al., 2003; Ledoux and Brunel, 2011). Recently, it has been shown that this resonance property of EI-networks can be exploited for communication in modular neuronal networks by enabling the transmission of sequences of synchronous spike volleys ('pulse packets'), despite the sparse and weak connectivity between the modules (Hahn et al., 2014; 2018). The condition for successful transmission is that the pulse packet (PP) intervals match the period of the modules' resonance frequency. Hence, the mechanism was termed "communication through resonance" (CTR). This mechanism has three severe constraints, though. First, it needs periodic trains of PPs, whereas single PPs fail to propagate. Second, the inter-PP interval needs to match the network resonance. Third, transmission is very slow, because in each module, the network resonance needs to build-up over multiple oscillation cycles. Here, we show that, by adding appropriate feedback connections to the network, the CTR-mechanism can be improved and the aforementioned constraints relaxed. Specifically, we show that adding feedback connect ions between two upstream modules, called the resonance pair (Figure 1), in an otherwise feedforward modular network can support successful propagation of a single PP throughout the entire network. The key condition for successful transmission is that the sum of the forward and backward delays in the resonance pair matches the resonance frequency of the network modules. The transmission is much faster, by more than a factor of two, than in the original CTR mechanism. Moreover, it distinctly lowers the threshold for successful communication by synchronous spiking in modular networks of weakly coupled networks. Thus, our results suggest a new functional role of bidirectional connectivity for the communication in cortical area networks.

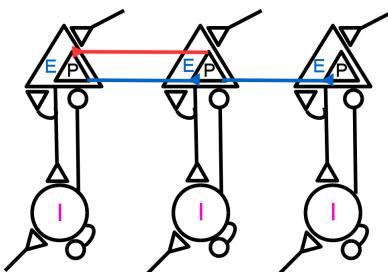


Figure 1. Schematic representation of a feedforward modular network of EI-networks with a resonance pair.

Acknowledgements

Funding by the German Federal Ministry of Education and Research grant to the Bernstein Focus Neurotechnology Freiburg/Tuebingen, the Carl Zeiss Foundation, and the MSRT of Iran is acknowledged. We acknowledge support by the State of Baden-Wuerttemberg through and the German Research Foundation.

References

- 1 Hahn G, Bujan A F, Fregnac Y, Aertsen A, Kumar A. Communication through resonance in spiking neuronal networks. *PLOS Comp Biol* 10(8), e1003811, (2014). [10.1371/journal.pcbi.1003811](https://doi.org/10.1371/journal.pcbi.1003811)
- 2 Hahn, G, Ponce-Alvarez, A, Deco, G, Aertsen, A, Kumar, A. Portraits of communication in neuronal networks. *Nature Reviews Neuroscience* 20:117-127, (2018). [10.1038/s41583-018-0094-0](https://doi.org/10.1038/s41583-018-0094-0)
- 3 Ledoux E, Brunel N, Dynamics of networks of excitatory and inhibitory neurons in response to time-dependent inputs. *Front Comput Neurosci* 5:25, (2011). [10.3389/fncom.2011.00025](https://doi.org/10.3389/fncom.2011.00025)
- 4 Mehring C, Hehl U, Kubo M, Diesmann M, Aertsen A, Activity dynamics and propagation of synchronous spiking in locally connected random networks, *Biol Cybern* 88:395-408, (2003). [10.1007/s00422-002-0384-4](https://doi.org/10.1007/s00422-002-0384-4)

©(2019) Rezaei H, Valizadeh A, Aertsen A, Kumar A

Cite as: Rezaei H, Valizadeh A, Aertsen A, Kumar A (2019) Facilitating the propagation of spiking activity in feedforward networks by including feedback. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0272](https://doi.org/10.12751/nncn.bc2019.0272)

Motor control, movement, navigation

[T 124] Anatomical origin of space-coding features in the hippocampal LFP signal

Carlo De Donno^{1,2}, Jakob Macke¹, Anton Sirota²

1. Professorship for Computational Neuroengineering, Technical University of Munich, Germany

2. Cognition and Neural Plasticity, Ludwig Maximilian University of Munich, Germany

Spiking activity of neural populations across the entorhino-hippocampal system is known to encode the position of the animal at the level of single cell firing rates as well as its phase of firing within the theta oscillation cycle. Theta-rhythmic population activity gives rise to laminae-specific synaptic current dipoles that linearly sum up to the theta oscillation LFP signal. Theta-cycle waveshapes measured across the CA1 pyramidal layer have recently been shown to contain spatial information which allows decoding of animal position, comparably to that of spiking activity. However, the link of decoding ability of such localized LFP signal to the afferent translaminar LFP generators dynamics remains elusive.

Here, we reproduce results from [1], using LFP signals sampled over the entire hippocampal transverse plain in freely-moving rat running on a linear track [2]. We identified a low-rank high-variance subspace of the LFP signal, consistent with superposition of laminae-limited dipoles driven by multiple theta rhythmic afferent inputs. In contrast, spatial information resided in a lower-variance subspace of the theta-limited LFP signal. Spatially-tuned independent components in this subspace had a sparse but widely distributed anatomical profile in the hippocampus. We consider several possible models for spatial tuning in the LFP and examine their agreement with the data. We hypothesize that these sparse space-coding patterns represent mean-field output of globally coordinated continuous attractor dynamics across entorhino-hippocampal circuits coding for the position of the animal. In addition, this work is paving the way for anatomically and biophysically grounded neuroprosthesis methodology based on the LFP signals.

Acknowledgements

Funding from European Union Horizon 2020 FETPROACT program via grant agreement no. 723032 (BrainCom) to A.S.

References

- 1 Agarwal, Gautam, et al. "Spatially distributed local fields in the hippocampus encode rat position." *Science* 344.6184 (2014): 626-630. [10.1126/science.1250444](https://doi.org/10.1126/science.1250444)
- 2 Montgomery, Sean M., Anton Sirota, and György Buzsáki. "Theta and gamma coordination of hippocampal networks during waking and rapid eye movement sleep." *Journal of Neuroscience* 28.26 (2008): 6731-6741. [10.1523/JNEUROSCI.1227-08.2008](https://doi.org/10.1523/JNEUROSCI.1227-08.2008)

©(2019) De Donno C, Macke J, Sirota A

Cite as: De Donno C, Macke J, Sirota A (2019) Anatomical origin of space-coding features in the hippocampal LFP signal. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0273](https://doi.org/10.12751/nncn.bc2019.0273)

[T 125] A neural circuit model for exploration in Drosophila larva

Marina Wosniack^{1,2}, Jimena Berni³, Julijana Gjorgjieva^{1,2}

1. Computation in Neural Circuits, Max Planck Institute for Brain Research, Germany

2. School of Life Sciences Weihenstephan, Technical University of Munich, Germany

3. Department of Zoology, University of Cambridge, UK

In the absence of sensory cues to guide behavior, animals execute spontaneous sequences of movements to explore their environment. Drosophila larvae perform sequences of crawls, pauses and turns to navigate in the substrate. The movement is achieved by waves of muscle contraction that propagate along the larval body. Symmetric contraction of the left and right sides of the larval body results in crawls, while the asymmetric contraction of the most anterior segments generates a turn. The isolated central nervous system of the larva generates spontaneous activity waves that alternate between symmetric and asymmetric propagation – the same motifs found in crawls and turns. Coordinated waves have been observed even when the brain and part of the subesophageal zone were acutely silenced (Berni 2015), suggesting that the neural substrate for generating crawls and turns resides in central pattern generators distributed in the ventral nerve cord (VNC). In fact, an intersegmental chain of excitatory and inhibitory neurons in the VNC was recently implicated in the propagation of spontaneous activity waves (Fushiki et al. 2016). This inspired us to design a neural circuit model based on central pattern generators (Gjorgjieva et al. 2013) to explore the key elements that are necessary for a functional navigation circuit. Based on available information regarding the connectivity among neurons implicated in the propagation of symmetric waves, we investigated possible mechanisms that can generate asymmetrical activity. Our network model suggests that the connectivity across the midline is critical for generating asymmetric waves. Moreover, the same network can generate both the crawling and turning motifs observed in the isolated central nervous system. Thus, our model provides a general framework for investigating the neural substrates of the larval spontaneous navigation routine and can be extended to study goal-directed behavior by including identified descending neurons that can modulate the temporal dynamics of motor patterns in the VNC.

Acknowledgements

Thanks to the Max Planck Society (MW, JG), the Alexander von Humboldt Foundation (MW) and WT105568AIA Sir Henry Dale Fellowship, Wellcome Trust and Royal Society (JB).

References

- 1 Berni 2015 [10.1016/j.cub.2015.03.023](https://doi.org/10.1016/j.cub.2015.03.023)
- 2 Fushiki et al. 2016 [10.7554/eLife.13253](https://doi.org/10.7554/eLife.13253)
- 3 Gjorgjieva et al. 2013 [10.3389/fncom.2013.00024](https://doi.org/10.3389/fncom.2013.00024)

©(2019) Wosniack M, Berni J, Gjorgjieva J

Cite as: Wosniack M, Berni J, Gjorgjieva J (2019) A neural circuit model for exploration in Drosophila larva. Bernstein Conference 2019 Abstract. doi: [10.12751/nncn.bc2019.0274](https://doi.org/10.12751/nncn.bc2019.0274)

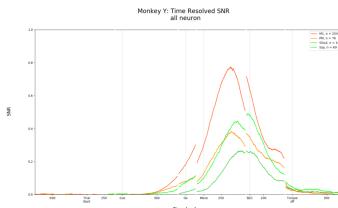
[T 126] Directional Tuning and dynamic variability changes in motor and somatosensory cortex during movement planning and execution.

Marita Metzler¹, Nasima Sophia Razizadeh¹, Yifat Prut², Martin Paul Nawrot¹

1. Computational Systems Neuroscience, Institute of Zoology, Zülpicherstr. 47b, 50674 Köln, Germany

2. Department of Medical Neurobiology, IMRIC, Hadassah Medical School, Jerusalem 91120, Israel

To facilitate accurate motor control, a dynamic interplay between participating brain regions is indispensable. Although many studies investigated the integration of sensory information within the motor cortex (MC) [1,2,3] only few studies focused on representation of movement kinematics in the somatosensory cortex (SS) [4]. In this project we want to compare representation of movement direction in both cortical areas in the monkey (*Maccaca fascicularis*) with respect to movement planning and execution. Therefore single unit activity (SUA) was recorded simultaneously in MC and SS while the animal performed a center out 2D wrist task [5]. The experimental paradigm facilitates a separation between preparatory period and movement by a delayed cue protocol. For quantification of directional tuning strength we used the signal-to-noise ratio [6]. Results indicate that beside M1 tuning activity already occurs in SS during the preparatory phase with a delay relative to M1. Additionally, we analysed dynamic changes of [i] spike time irregularity and [ii] trial-by-trial variability, computed by the [i] local coefficient of variation (CV2) and [ii] fano factor [7, 8]. Results are compared between MC and SS for different task epochs. While replicating published results for the fano factor [8, 9], which dropped during planning and more strongly during execution of movement, the CV2 doesn't exhibit significant trends during the different task epochs.



Time Resolved Signal-to-Noise Ratio (SNR) of motor and sensorimotor areas in one monkey

Acknowledgements

Funding was received from the Israel Science Foundation (ISF-1787/13 to YP), the German Science Foundation (DFG-ZUK 81/1 to MN) and the joint training program SmartStart 2 (to MM)

References

- Rizzolatti G, Fadiga L, Gallese V, Fogassi L. (1996) Premotor cortex and the recognition of motor actions. *Brain Res Cogn Brain Res.* 3:131–141. [10.1016/0926-6410\(95\)00038-0](https://doi.org/10.1016/0926-6410(95)00038-0)
- Hatsopoulos, N. G., & Suminski, A. J. (2011). Sensing with the motor cortex. *Neuron*, 72(3), 477–487. [10.1016/j.neuron.2011.10.020](https://doi.org/10.1016/j.neuron.2011.10.020)
- Pruszynski, J. A., Kurtzer, I., Nashed, J. Y., Omrani, M., Brouwer, B., & Scott, S. H. (2011). Primary motor cortex underlies multi-joint integration for fast feedback control. *Nature*, 478(7369), 387–390. [10.1038/nature10436](https://doi.org/10.1038/nature10436).
- Lee S., Kruglikov I., Huang Z.J., Fishell G. & Rudy B (2013) disinhibitory circuit mediates motor integration in the somatosensory cortex. *Nature Neuroscience* 16: 1662–1670 [10.1038/nn.3544](https://doi.org/10.1038/nn.3544).
- Yanai Y, Adamit N, Harel R, Israel Z, Prut Y (2007) Connected corticospinal sites show enhanced tuning similarity at the onset of voluntary action. *J Neurosci* 27:12349–57. [10.1523/JNEUROSCI.3127-07.2007](https://doi.org/10.1523/JNEUROSCI.3127-07.2007)
- Rickert J, Riehle A., Aertsen A., Rotter S., Nawrot MP (2009) Dynamic encoding of movement direction in motor cortical neurons. *J Neurosci* 29:13870–13882. [10.1523/JNEUROSCI.5441-08.2009](https://doi.org/10.1523/JNEUROSCI.5441-08.2009)
- Nawrot MP, Boucsein C, Molina VR, Riehle A, Aertsen A, Rotter S (2008) Measurement of variability dynamics in cortical spike trains. *J Neurosci Meth* 169:374–390. [10.1016/j.jneumeth.2007.10.013](https://doi.org/10.1016/j.jneumeth.2007.10.013)

- 8 Riehle A., Brochier T., Nawrot M., Grün S. (2018) Behavioral Context Determines Network State and Variability Dynamics in Monkey Motor Cortex. *Front. Neural Circuits* 12:52 [10.3389/fncir.2018.00052](https://doi.org/10.3389/fncir.2018.00052)
9 Churchland, MM, Yu, BM., Cunningham, ..., Shenoy, KV (2010) Stimulus onset quenches neural variability: a widespread cortical phenomenon. *Nat Neurosci* 13(3):369-78. [10.1016/j.jneurosci.2007.10.013](https://doi.org/10.1016/j.jneurosci.2007.10.013)

©(2019) Metzler M, Razizadeh NS, Prut Y, Nawrot MP

Cite as: Metzler M, Razizadeh NS, Prut Y, Nawrot MP (2019) Directional Tuning and dynamic variability changes in motor and somatosensory cortex during movement planning and execution.. *Bernstein Conference 2019 Abstract.*

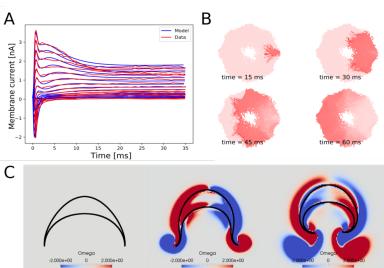
doi: [10.12751/nncn.bc2019.0275](https://doi.org/10.12751/nncn.bc2019.0275)

[T 127] From Single Neurons to Behavior in the Jellyfish *Aurelia aurita*

Fabian Pallasdies¹, Sven Goedeke¹, Wilhelm Braun¹, Raoul-Martin Memmesheimer¹

1. *Neural Network Dynamics and Computation, Institute for Genetics, University of Bonn, 53115 Bonn, Germany*

Understanding how biophysical properties of single neurons give rise to emergent network behavior is an important goal in theoretical neuroscience. Such a link between single neuron dynamics and functional biological networks is often hard to establish, yet crucial to understand how nervous systems enable organisms to survive in their natural environment and ultimately shape behavior and cognition. Here, we present a biophysically realistic bottom-up computational model of the nervous system of a scyphozoan jellyfish. We use voltage-clamp data [1] to fit Hodgkin-Huxley type neurons. Based on key structural features [2] we further build a model of the two nerve nets in charge of motor control. From simulations of the resulting nerve nets we can extract the muscle activity during swimming with high spatial and temporal resolution. We then use the immersed boundary method to simulate the fluid interactions of the jellyfish swimming motion in 2D. We find that the distribution of neurons in the scyphozoan nerve net is optimized to conduct excitation waves across the jellyfish bell and prove that upon stimulation, the excitation travels through the nerve net such that every neuron fires exactly once. After coupling the muscle model to the spiking activity, experimentally observed features of the swimming motion emerge simply from the structure of the nerve net. In addition to the first nerve net-based simulation of the jellyfish turning mechanism, we find a potential alternative turning mechanism that increases the level of control on the swimming motion of the animal. This suggests that the jellyfish is able to fine-tune its swimming motion by precisely timed activation of its two nerve nets. Since the nervous system of jellyfish likely represents an evolutionary ancestral state, our model can not only be used to further investigate the nervous system of one of the simplest neuron-bearing animals but also to advance our understanding of the evolutionary origins of nervous systems.



A: Biophysical neuron model fitted to the voltage-clamp data. The model (blue) follows the data (red) described in [1]. B: Time series of a nerve net activation wave. Color levels indicate neuron voltages. C: Swimming stroke after an activation wave. Color indicates vorticity.

Acknowledgements

We thank Peter A.V. Anderson and Alexander P. Hoover for fruitful discussions and the German Federal Ministry of Education and Research (BMBF) for support via the Bernstein Network (Bernstein Award 2014, 01GQ1710).

References

- 1 P.A.V. Anderson. Ionic currents of the Scyphozoan In: Evolution of the First Nervous Systems, Springer pp. 267-280, 1989
- 2 A. Horridge. Observations on the nerve fibres of *Aurelia aurita*. Journal of Cell Science 3.29: 85-92, 1954

©(2019) Pallasdies F, Goedeke S, Braun W, Memmesheimer R

Cite as: Pallasdies F, Goedeke S, Braun W, Memmesheimer R (2019) From Single Neurons to Behavior in the Jellyfish *Aurelia aurita*. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0276](https://doi.org/10.12751/nncn.bc2019.0276)

[T 128] Learning within and outside of the neural manifold

Barbara Feulner¹, Claudia Clopath¹

1. Bioengineering, Imperial College London, SW7 2AZ, UK

How the brain controls complex behaviour is still an open question in neuroscience. Foremost, the ability to flexibly adapt movements to new conditions or goals is puzzling. Recent experimental evidence supports the idea of a fixed set of neural covariation patterns called neural modes, which is flexibly used to create different kinds of movements [1]. The space these neural modes span is called neural manifold. Another set of studies suggest that fast motor adaptation is happening through changes within the original neural manifold, but new covariation patterns can be acquired over longer time-scales [2,3,4].

By using computational modelling, we explore the underlying constraints for within- and outside-manifold learning from a network perspective. Firstly, we test whether a generic optimization algorithm which acts on the recurrent weights is enough to explain the experimental discrepancy between within- and outside-manifold learning. Interestingly, we find that there is no intrinsic limitation preferring within-manifold learning. We don't find evidence that the change in recurrent connections is bigger for outside-manifold learning than for within-manifold learning. In a next step, we dismiss the assumption of a perfect teacher signal which is biologically implausible. Instead, we train a feedback model which infers the error signal on the single neuron level. This error signal is

used by the generic algorithm to adapt the recurrent weights accordingly. We find that the feedback model of the within-manifold perturbation can be learned to some extent, whereas it is not possible to infer any meaningful error information on the single neuron level for the outside-manifold perturbation. By using the learned, imperfect teacher signals, our results are consistent with the experimental findings of Sadler et al. [2], where monkeys can learn to rearrange their neural activity to within-manifold perturbations, but not to outside-manifold ones.

Our results suggest that the limitation for within- and outside-manifold learning is not the relearning of the recurrent dynamics itself, but the learning of the error feedback model. Though, one of the main assumptions of our work is that the neural manifold is mainly constrained by the recurrent connectivity. It remains to be investigated whether the same holds true if the manifold is predominantly shaped by external drive.

References

- 1 Gallego, J. A., Perich, M. G., Naufel, S. N., Ethier, C., Solla, S. A., & Miller, L. E. (2018). Cortical population activity within a preserved neural manifold underlies multiple motor behaviors. *Nature communications*, 9(1), 4233. [10.1038/s41467-018-06560-z](https://doi.org/10.1038/s41467-018-06560-z)
- 2 Sadler, P. T., Quick, K. M., Golub, M. D., Chase, S. M., Ryu, S. I., Tyler-Kabara, E. C., Yu, B. M. & Batista, A. P. (2014). Neural constraints on learning. *Nature*, 512(7515), 423. [10.1038/nature13665](https://doi.org/10.1038/nature13665)
- 3 Golub, M. D., Sadler, P. T., Oby, E. R., Quick, K. M., Ryu, S. I., Tyler-Kabara, E. C., Batista, A., Chase, S. M. & Yu, B. M. (2018). Learning by neural reassociation. *Nature neuroscience*, 21(4), 607-616. [10.1038/s41593-018-0095-3](https://doi.org/10.1038/s41593-018-0095-3)
- 4 Oby, E. R., Golub, M. D., Hennig, J. A., Degenhart, A. D., Tyler-Kabara, E. C., Yu, B. M., Chase, S. M. & Batista, A. P. (2019). New neural activity patterns emerge with long-term learning. *Proceedings of the National Academy of Sciences*, 201820296. [10.1073/pnas.1820296116](https://doi.org/10.1073/pnas.1820296116)

©(2019) Feulner B, Clopath C

Cite as: Feulner B, Clopath C (2019) Learning within and outside of the neural manifold. *Bernstein Conference 2019*
Abstract. doi: [10.12751/nncn.bc2019.0277](https://doi.org/10.12751/nncn.bc2019.0277)

[T 129] Paw coupling of neurons in rodent sensorimotor cortex during unconstrained locomotion behavior

Svenja Melbaum^{1,2}, David Eriksson³, Thomas Brox^{1,2}, Ilka Diester^{2,3,4}

1. Computer Vision Group, Dept. of Computer Science, University of Freiburg, 79110 Freiburg, Germany

2. BrainLinks-BrainTools Cluster of Excellence, University of Freiburg, 79110 Freiburg, Germany

3. Optophysiology Lab, Center for Neuroscience, University of Freiburg, 79110 Freiburg, Germany

4. Bernstein Center Freiburg, University of Freiburg, 79104 Freiburg, Germany

Most of the knowledge of the sensorimotor cortex of rodents stems from experiments with stereotyped, well-controlled movements. While this facilitates data analysis, it is unknown how results can be carried over to less constrained, self-paced behavior. For locomotion, it has been hypothesized that motor cortex involvement might be decreased for treadmill compared to runway walking [1]. We developed a novel behavioral paradigm combining locomotion with goal-directed behavior. Rats moved unconstrained on a grid, following a robot arm which delivered water drops at random points from underneath. Rats showed diverse locomotion patterns, often moving only the front paws, at times also backwards, while refraining from lifting up. The neuronal activity was recorded via electrodes from the output layer of the sensorimotor cortex. Simultaneous behavioral recordings were carried out via 3D tracking of markers on the four paws of the rats. To facilitate analysis, gait movements of the paws were binarized to either stance (not moving) or swing (moving). We then quantized the coupling of single units to individual

paws by computing spike-triggered averages [2] in the period ± 1 s around the spikes of each neuron (spike-triggered average paw swing-stance status, STAPSSS). Paw couplings were considered significant when the standard deviation of the STAPSSS exceeded the .99 quantile standard deviation of the STAPSSS of 1000 randomly shifted control spike trains. More than half of all neurons showed coupling to at least one paw. The ratios of significant neurons increased from anterior to posterior areas, with the highest ratios of significant neurons found in S1. While laterality for the front right and front left paw was significant, we also found neurons reacting to movements of the ipsilateral paw. One third of all neurons was coupled to at least two paws. We also used simple feed-forward neural networks to decode the swing-stance status of the right front paw from the Gaussian-smoothed spike trains of all neurons in the time period ± 400 ms. Accuracies were well above chance level, varying across rats and sessions, and significantly correlated to the ratios of significant neurons w.r.t. STAPSSS. Our results show for the first time behavioral coupling of neurons across the whole sensorimotor cortex of rodents during unconstrained behavior with inter-areal differences and laterality.

Acknowledgements

This work was supported by BrainLinks-BrainTools, Cluster of Excellence funded by the German Research Foundation (DFG, grant number EXC 1086) and Bernstein Award 2012.

References

- 1 DiGiovanna, J., Dominici, N., Friedli, L., Rigosa, J., Duis, S., Kreider, J., ... & Courtine, G. (2016). Engagement of the rat hindlimb motor cortex across natural locomotor behaviors. *Journal of Neuroscience*, 36(40), 10440-10455.
- 2 Kells, P. A., Gautam, S. H., Fakhraei, L., Li, J., & Shew, W. L. (2019). Strong neuron-to-body coupling implies weak neuron-to-neuron coupling in motor cortex. *Nature communications*, 10(1), 1575.

©(2019) Melbaum S, Eriksson D, Brox T, Diester I

Cite as: Melbaum S, Eriksson D, Brox T, Diester I (2019) Paw coupling of neurons in rodent sensorimotor cortex during unconstrained locomotion behavior. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0278](https://doi.org/10.12751/nncn.bc2019.0278)

[T 130] Pose estimation and map formation in a self-calibrating spiking neural network, realized on neuromorphic hardware

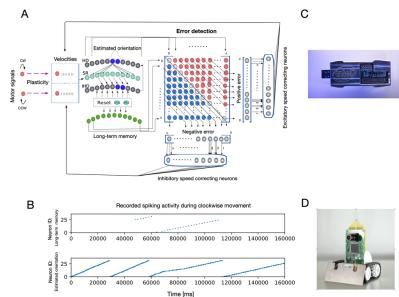
Raphaela Kreiser¹, Alpha Renner¹, Gabriel Waibel², Nuria Armengol², Yulia Sandamirskaya¹

1. Institute of Neuroinformatics, University of Zurich and ETH Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

2. Departement Informationstechnologie und Elektrotechnik, ETH Zurich, Switzerland

Foraging in potentially unknown, dynamically changing environments is a crucial skill for both animals and mobile robots. Solving this task requires an agent to integrate external sensory cues in order to build a map of the environment and to estimate its position on the map. Internally generated motor signals and interoceptive cues about executed movements can assist the task of pose estimation in a process called path integration. In order to use the motor signals to update the pose estimate, they need to be integrated. Moreover, the integration process needs to be calibrated, i.e. aligned with the actually performed movement. Inspired by the hippocampal navigation system of rats, we develop a spiking neural network architecture that can (1) integrate motor signals in order to update the internal representation of the pose in a 2D environment of the agent; (2) update and re-calibrate this path integration system based on intermittent external sensory cues (visually perceived landmarks), and (3) learn a representation of

the environment, i.e. the map and update it when necessary. In this work, we present an error-estimating network, in which the error, accumulated in the path integration process between two encounters with the same landmark, is estimated using the population code. A gain-field network effectively subtracts the pose estimation, stored in the long-term memory of the map, from the estimation based on the current path integration process, and stored in a working-memory representation of an activity bump of a neural field. The estimated error is used to adjust the path-integration speed in a simple Hebbian learning process using spike-timing-dependent plasticity (STDP). Synapses that shift the activity bump in the working-memory representation of the current orientation increase or decrease their weights according to the sign of the error until convergence. Moreover, if the error amplitude is large, a map update is triggered according to a three-factor (error-gated) learning rule of the long-term memory which associates locations and landmarks. We implement the developed neuronal architectures on the neuromorphic processor Loihi, a low-power, highly parallel, and event-based (spiking) neuronally-inspired computing hardware recently introduced by Intel. Evaluation and embodiment of the neuronal architecture are achieved in closed sensory-motor loop experiments using robotic agents.



- (A) SNN architecture for path integration, error detection and recalibration, and associative map learning.
- (B) Neural activity during clockwise movement. When sensory input activates the long-term memory, path integration speed is adjusted.
- (C) The neuromorphic processor Loihi.
- (D) The robotic agent.

Acknowledgements

This work was financially supported by Grant UZH-FK-16-106, ZNZ Fellowship, SNF grant PZOOP2_168183_1 "Ambizione".

©(2019) Kreiser R, Renner A, Waibel G, Armengol N, Sandamirskaya Y

Cite as: Kreiser R, Renner A, Waibel G, Armengol N, Sandamirskaya Y (2019) Pose estimation and map formation in a self-calibrating spiking neural network, realized on neuromorphic hardware. *Bernstein Conference 2019 Abstract*. doi: [10.12751/mncn.bc2019.0279](https://doi.org/10.12751/mncn.bc2019.0279)

[T 131] Postural adjustments for mobility and balance

Charlotte Le Mouel¹

1. Dynamic Locomotion Group, Max Planck Institute for Intelligent Systems, Heisenbergstr. 3 70569 Stuttgart, Germany

I will present the theory that efficient motor coordination relies on the nervous system finding the appropriate body mechanical properties to perform a motor task, through postural adjustments. Thus, when standing in challenging balance conditions, young adults stiffen their ankle through ankle muscle co-contraction to improve their stability [1]. In contrast, when they want to start walking, they relax their ankle, allowing them to fall forwards and fluidly initiate their first step [2]. Efficient gait initiation thus requires a combined decrease in ankle stiffness and a forwards acceleration of the body centre of mass. The amplitude and timing of these postural adjustments must be adjusted to the body height and mass, thus requiring postural learning throughout the lifespan. Finally, I suggest that impaired postural adjustments may lead to balance and mobility impairments, such as those which occur during ageing, and may have a dramatic impact on health and quality of life [3].

References

- 1 Le Mouel, C., and Brette, R. (2019). Anticipatory coadaptation of ankle stiffness and neural feedback for standing balance [10.1101/506493](https://doi.org/10.1101/506493)
- 2 Le Mouel, C., and Brette, R. (2017). Mobility as the Purpose of Postural Control. *Front Comput Neurosci* 11, 67 [10.3389/fncom.2017.00067](https://doi.org/10.3389/fncom.2017.00067)
- 3 Le Mouel, C., Tisserand, R., Robert, T., and Brette, R. (2019). Postural adjustments in anticipation of predictable perturbations allow elderly fallers to achieve a balance recovery performance equivalent to elderly non-fallers. *Gait & Posture* 71, 131–137 [10.1016/j.gaitpost.2019.04.025](https://doi.org/10.1016/j.gaitpost.2019.04.025)

©(2019) Le Mouel C

Cite as: Le Mouel C (2019) Postural adjustments for mobility and balance. *Bernstein Conference 2019 Abstract*. doi: [10.12751/nncn.bc2019.0280](https://doi.org/10.12751/nncn.bc2019.0280)

[T 132] Uncovering muscle population dynamics of locomotion using deep learning

Jonas F. Braun^{1,2}, Lahiru N. Wimalasena¹, Cristiano Alessandro³, Lee E. Miller^{3,4,5}, Matthew C. Tresch^{3,4,5}, Chethan Pandarinath^{1,6}

1. *Systems Neural Engineering Lab, Wallace H. Coulter Department of Biomedical Engineering, Georgia Tech and Emory University, Atlanta, GA, USA*

2. *Department for Electrical and Computer Engineering, Technical University of Munich, Munich, Germany*

3. *Department of Physiology, Northwestern University, Chicago, IL, USA*

4. *Department of Biomedical Engineering, Northwestern University, Chicago, IL, USA*

5. *Department of Physical Medicine and Rehabilitation, Northwestern University, Chicago, IL, USA*

6. *Department of Neurosurgery, Emory University, Atlanta, GA, USA*

In order to produce reliable, precise movements, the brain must coordinate the sequential activation of multiple muscles on a fine timescale. Understanding this coordination requires interpreting complex, dynamic muscle activation patterns recorded via electromyography (EMG). However, EMG signals contain the summed spiking activity of multiple motor units, making them a noisy reflection of muscle activation and difficult to interpret. Furthermore, the standard approach to processing EMG (i.e., rectification and smoothing) treats any temporal precision above 5-10 Hz as high frequency noise. Here we describe an alternate method to de-noise EMG signals that have been recorded

simultaneously from multiple muscles, by modeling their activity as the output of a low-dimensional dynamical system. We hypothesize that accurately modeling muscle population dynamics might substantially de-noise the recorded EMG. We use a variant of Latent Factor Analysis via Dynamical Systems (LFADS), a sequential auto-encoder previously developed to uncover dynamics from neural population spiking activity [1]. LFADS creates a generative model of observed data using a recurrent neural network, allowing it to capture nonlinear dynamics. We adapted the original approach to use a Gaussian emissions model, rather than Poisson, in order to account for the different statistics of EMG relative to spiking activity. We tested this approach on data collected from a rat walking on a treadmill. EMG was recorded from 12 hindlimb muscles using intramuscular electrodes. We found that LFADS uncovered moment-to-moment estimates of underlying muscle population dynamics, while preserving higher-frequency features not evident with standard processing methods. By modeling muscle population dynamics, we could more accurately predict the timing of gait events, such as the time the foot leaves the ground, compared to predictions from standard EMG estimates. Furthermore, the estimated dynamics also improved the prediction of single-trial gait kinematics, including joint angles. We conclude that LFADS provides an estimate of EMG activity that is more informative about behaviour than standard approaches. We hypothesize that this representation more accurately reflects underlying neural motor commands, and future work will apply LFADS to EMG collected simultaneously with recordings from motor cortex, to precisely probe the role of motor cortex in driving activation of the dynamics underlying muscle activity.

Acknowledgements

German Academic Scholarship Foundation Grant to JFB, National Science Foundation NCS 1835364 to CP, Burroughs Wellcome Fund Collaborative Travel Grant to CP, National Institute of Health NINDS NS086973 to MCT

References

- 1 C. Pandarinath, et al., Inferring single-trial neural population dynamics using sequential auto-encoders, *Nature Methods* 15, p805–815 (2018) [10.1038/s41592-018-0109-9](https://doi.org/10.1038/s41592-018-0109-9)

©(2019) Braun JF, Wimalasena LN, Alessandro C, Miller LE, Tresch MC, Pandarinath C

Cite as: Braun JF, Wimalasena LN, Alessandro C, Miller LE, Tresch MC, Pandarinath C (2019) Uncovering muscle population dynamics of locomotion using deep learning. *Bernstein Conference 2019* Abstract.
doi: [10.12751/nncn.bc2019.0281](https://doi.org/10.12751/nncn.bc2019.0281)

Index

Authors

- Abbott LF, 38
 Abdullah T, 168
 Abedi Khozani P, 255
 Aertsen A, 312
 Agarwal G, 25
 Aggleton JP, 237
 Aghvami SS, 140
 Aiple F, 59
 Aksamaz S, 187
 Aleshin S, 39, 120, 210
 Alessandro C, 322
 Alevi D, 203
 Aliyari Shoorehdeli M, 49
 Aljadef J, 194
 Amakhin DV, 169
 Amaro D, 112
 Amunts K, 91
 Amvrosiadis T, 223
 Andalibi V, 149
 Andrade de Carvalho TT, 155
 Angelaki DE, 4
 Ansarinia M, 208
 Antonietti A, 129
 Antrobus AD, 24
 Apkarian AV, 98, 168
 Ardid S, 285
 Arkhipov A, 139
 Armengol N, 320
 Armeni K, 33
 Asari H, 118
 Aschauer D, 177
 Aschner A, 100
 Ashida G, 207
 Ashwin P, 150
 Atayi M, 67
 Aurelien W, 176
 Babushkin V, 153
 Baden T, 239
 Bahl A, 20
 Baier F, 270
 Baladron J, 57
 Baliki MN, 98, 168
 Barahona M, 26
 Barak O, 283, 301
 Barbosa J, 153, 172
 Baria A, 168
 Barnes W, 256
 Barnes WH, 282
 Barthélémy F, 75
 Bassereh H, 242
 Bassetto G, 69, 80
 Bastien R, 15
 Batulin D, 167
 Bauer Mikulovic S, 284
 Bauer S, 76
 Bauer Y, 89
 Baumbach A, 275
 Becker M, 180
 Becker S, 45
 Beer C, 283
 Behbood M, 292
 Bellec G, 10
 Benjamin AS, 253
 Berens P, 121, 230
 Berger DR, 94
 Berger S, 61
 Berger SE, 168
 Bergomi M, 25
 Berling D, 137
 Bernaerts Y, 230
 Berni J, 315
 Berry II M, 19
 Berthet P, 86
 Bethge M, 3, 82, 121
 Betterton R, 176
 Betzel RF, 97
 Beylgeril SB, 268
 Billeh YN, 139
 Binder S, 187
 Bittner SR, 151
 Blohm G, 55, 192, 255
 Blumberg J, 59
 Boahen K, 158
 Böhm C, 213
 Boelts J, 88
 Bohnenkamp L, 52
 Bohté SM, 35
 Borges FdS, 136
 Bormuth V, 235
 Born G, 58, 89, 256
 Borst A, 269
 Botvinick M, 6
 bouhadjar Y, 192
 Brands AM, 161
 Brandt A, 59
 Braun J, 39, 120, 210
 Braun JF, 322
 Braun W, 317
 Brea J, 190
 Brette R, 16
 Brochier T, 75, 126
 Brochini L, 155, 289
 Brody CD, 214
 Brovkin A, 91
 Brox T, 319
 Brunel N, 2
 Buice MA, 23
 Busse L, 58, 89, 256, 263
 Cabral J, 92
 Cadena SA, 82
 Callahan-Flintoft C, 60
 Capone C, 42
 Cappelloni MS, 108
 Cardoso-Leite P, 208
 Carhart-Harris R, 92
 Carr CE, 110
 Carvalheiro J, 216
 Carvalho TTA, 289
 Casali A, 248
 Casarotto S, 248

AUTHORS

- Castro J, 230
Cataldo E, 299
Catania A, 54
Chalk M, 261
Chandrasekaran C, 311
Chattoraj A, 131
Chen W, 79
Chen X, 52
Cheng S, 221
Chintaluri C, 69
Chizhov AV, 169
Chrzanowska A, 217
Churgin M, 215
Clementz B, 173
Clopath C, 3, 11, 26, 48, 194, 318
Coen-Cagli R, 100
Compte A, 153, 172
Contantidinis C, 236
Costa AA, 289
Costa AdA, 155
Costard LS, 76
Cottreau B, 114
Couzin ID, 15
Cox DD, 115
Crombie D, 256, 263
Cruz B, 189
Cruzat J, 92
Csordas DE, 231
Cunningham JP, 151
Cuthbert B, 192
- D'Albis T, 181
D'amour J, 194
Dabrowska P, 126, 271
Dahmen D, 200, 271, 291, 297
Dai K, 139
Dale AM, 243
Dalmau J, 172
Dasilva M, 228
Dau T, 54
Davey N, 46
de Bivort B, 215
De Bonis G, 228
de Candia A, 19
de Cheveigné A, 54
De Donno C, 314
de la Rocha J, 63
Debrégeas G, 235
Deco G, 92
Dehning J, 72, 160
Deistler M, 233
Delano M, 280
Demirel Ç, 87
Denfield GH, 82
Deny S, 111, 226, 265
Despotović D, 261
Deutz L, 271
DiCarlo JJ, 101
Dickscheid T, 91
Diesmann M, 126, 137, 192, 271, 278
Diester I, 319
Dold D, 182, 196
Donoso JR, 221
Dotson NM, 160
- Drebitz E, 66
Drews M, 269
Dubreuil A, 301
Dudziak MJ, 228, 240
Dupuy N, 223
- Eberhardt F, 309
Echavarria C, 115
Ecker AS, 82
Eckert A, 211
Egerl U, 165
Egger V, 140
Egumenovska K, 217
Einevoll GT, 78, 86, 139, 243
Ekelmans P, 159
Endres D, 50, 211, 255
Engel T, 305
Engelken R, 38
Engert F, 20
Englitz B, 235
Eppler B, 177
Eriksson D, 319
Ernst U, 52, 66
Ernst UA, 252
Erő C, 129
Esghaei M, 184
Esir P, 85, 295
Essink S, 75
Euler T, 121, 256
Evangelista R, 205
- Falahi M, 65
Fardet T, 286
Farrow K, 217
Felsenberg J, 178
Fernandes H, 253
Ferrarese L, 118
Ferrari U, 226
Ferrario A, 103
Festa D, 100
Feulner B, 318
Fiehler K, 255
Field R, 194
Fischer C, 231
Fitz H, 33
Fleidervish I, 310
Franke K, 121
Franz J, 132
Freeman NW, 214
FRIEDRICH R, 32
Fries P, 256
Froemke R, 194
Frost BE, 237
Fyhn M, 139
- Gallice N, 294
Gallinaro JV, 185
Galluzzi A, 272
Ganguli S, 111, 158, 265
Garbers C, 83
Garcia-Ojalvo J, 299
Gastaldi C, 141
Gatys LA, 82
Gauthier JL, 214

AUTHORS

- Gehr C, 118
Geirhos R, 105
Geminiani A, 40
Gerber B, 37
Gershon ES, 173
Gerstner W, 141, 179, 190, 294
Gewaltig M, 128, 129
Ghantous M, 168
Giannakakis E, 30
Gilra A, 201
Gilon M, 200
Girardi-Schappo M, 155, 289
Girgin U, 87
Gjorgjieva J, 19, 43, 204, 266, 290, 315
Glasauer S, 242, 302
Goedeke S, 201, 281, 317
Goethals S, 16
Gollisch T, 138
Golosio B, 42
Goncalves PJ, 69, 80, 233
Goodfellow M, 150
Goulas A, 91, 97
Gov NS, 15
Gowers RP, 274
Gozel O, 179
Graham D, 96
Gray CM, 160
Greenberg DS, 233
Gregoriou GG, 126
Grewe J, 83
Griffith J, 168
Gros C, 31
Groß S, 249
Gruen S, 271
Grytskyy D, 288
Grün S, 75, 126, 137
Günthner MF, 82
Güntürkün O, 221
Guiomar G, 189
Gutkin B, 85
Gutnick MJ, 310
- Haas CA, 165
Haas JS, 113, 296
Hadaeghi F, 232
Haefner R, 131
Haefner RM, 108
Härtwich N, 280
Haeusler S, 212
Häusler S, 309
Häussler U, 165
Hafting T, 139
Hagemann A, 166
Hagen E, 78, 139, 243
Haghparast A, 49
Hagler D, 243
Hajek E, 10
Hajizadeh A, 127
Halnes G, 243
Hamker F, 34, 57
Hao Y, 96
Harnack D, 66
Harth P, 88
Harvey CD, 74, 258
- Hass J, 251, 285
Hayashi Y, 44
Hechler T, 211
Hege H, 88
Heining K, 165
Heinke D, 55
Helias M, 122, 200, 271, 291, 297
Hemberger M, 290
Hennig J, 227
Hennig M, 30
Hermoso-Mendizabal A, 63
Hernandez-Garcia A, 238
Herrera K, 20
Herz A, 212, 231
Herz AV, 309
Hilgetag CC, 91, 97
Hiratani N, 9
Hjortkjær J, 54
Höfling L, 121
Hoekstra HE, 5, 270
Hoffer DM, 279
Hoffman SJ, 160
Hofmann D, 147
Hokkanen H, 149
Homann J, 19
Honerkamp C, 291
Honneger K, 215
Hosseinzadeh Z, 247
Huang L, 168
- Iglesias S, 119
Illing B, 190
Indiveri G, 259
Insabato A, 200
Ioffe ML, 214
Iskander DR, 73
Ito J, 75
- Jabakhanji R, 168
Janz P, 165
Jedlicka P, 167
Jiang H, 123
Jocham G, 56
Joffrois C, 261
Jolivet RB, 288
Jürgensen A, 37, 259
- Kadir S, 46
Kadmon J, 158
Kaiser LF, 56
Kakaei E, 39, 120
Kalle Kossio FY, 281
Kalle Kossio YF, 201
Kao J, 311
Kaschube M, 177
Katakura O, 46
Katzner S, 58
Kautzky M, 256
Kaya Z, 219
Keedy SK, 173
Keemink SW, 161
Keijser J, 308
Kellner C, 83
Kempter R, 110, 181, 203, 205, 307

AUTHORS

- Kern M, 59
Keshavan MS, 173
Keup C, 297
Khalili A, 259
Khanal S, 58
Khezri Y, 184
Kihara AH, 136
Kilavik B, 126
Kilias A, 165
Kinouchi O, 155, 289
Kleinjohann A, 75, 137
Kleinman M, 311
Klon-Lipok J, 256, 282
Klos C, 201
Knight JC, 244
Knudsen GM, 92
Knösche TR, 125
Koay SA, 214
Kobak D, 230
Koch C, 139
König P, 238
König R, 73, 127, 280
Köppel C, 110
Köse H, 87
Kohn A, 100
Koo-Poeggel PC, 186
Kopell N, 285
Korcsak-Gorzo A, 27
Kording KP, 253
Korvasová K, 284
Kotkat AH, 89
Kouhpeimay Jahromi Z, 144
Koutsou A, 83
Kovács I, 210
Kraemer A, 110
Kraynyukova N, 89, 159
Kreiser R, 320
Kreiter A, 66
Kremkow J, 118
Kretzberg J, 207
Kringelback ML, 92
Kühn T, 122, 291, 297
Kudryashova N, 223
Kumar A, 165, 312
Kumar GM, 29
Kungl AF, 182, 196
Kuokkanen PT, 110
Kuras I, 128
Kuśmierz Ł, 145
- Lagzi F, 167
Lameu EL, 277
Lange R, 131
Larisch R, 34
Latham PE, 9, 24, 163
Laurent G, 7, 290
Layer M, 271
Lazar A, 256
Lazarevich I, 85, 295
Le Goc G, 235
Le Mouel C, 322
Lederer Z, 221
Lee AK, 213
Lee SH, 282
- Leers T, 71
Legenstein R, 10
Lehtimäki M, 276
Leibold C, 249, 263
Leon Pinzon C, 310
Levina A, 286, 298, 305
Li D, 236
Li HL, 14
Lichtman JW, 94
Lindner B, 304
Lindsey J, 111, 265
Linne M, 276
Lio' P, 224
Logothetis NK, 92
Loidolt M, 199
Loske P, 171
Lu D, 76
Ludwig F, 284
Lueckmann J, 69, 80
Luettgau L, 56
Luo Y, 217
Luu T, 291
- Ma J, 280
Ma O, 218
Maass W, 10, 27
Macau EE, 277
Machens C, 189, 241
Machens CK, 61, 161
Maclver MA, 13
Macke J, 314
Macke JH, 67, 69, 70, 80, 88, 233
Mackwood O, 21
Maddah A, 56
Maddox RK, 108
Märcher-Rørsted J, 54
Maes A, 26
Maex R, 46
Maier N, 205
Mainen Z, 25, 134
Maith O, 57
Makara JK, 157
Makarov R, 265
Mancoo A, 241
Marder E, 2
Marinov T, 60
Markram H, 128, 129
Marques de Melo T, 227
Marques T, 101
Marre O, 226, 261
Marshall L, 186, 187
Martin SK, 237
Martins Merino R, 310
Masis J, 115
Masquelier T, 114
Massimini M, 248
Mastrogiovanni F, 301
Mattia M, 228, 272
Matysiak A, 73, 127
May PJ, 127
May PJC, 280
Mazzoni A, 299
Mazzucato L, 134
McIntyre CC, 268

AUTHORS

- Meibodi N, 50
Meirovitch Y, 94
Meiser S, 207
MEISSNER-BERNARD C, 32
Melbaum S, 319
Memmesheimer R, 201, 281, 317
Menendez JA, 163
Mesquita A, 216
Metzler M, 316
Meyniel F, 53
Michaelos M, 260
Michel J, 91
Miehl C, 204
Migault G, 235
Mikulasch F, 198
Miller E, 62
Miller LE, 322
Mizuta K, 44
Mölle M, 186, 187
Molano-Mazon M, 63
Montaldo G, 217
Montlibert A, 114
Moore T, 305
Morales-Gregorio A, 126
Moreno-Bote R, 200
Mormann F, 166
Morozova O, 94
Morrison A, 170
Motiwala A, 189
Mueller M, 140
Mueller MC, 282
Müller S, 50
Müller TT, 224
Mugan U, 13
Mulle C, 176
Murakami M, 134
Murray A, 171
Murray JD, 236
- N. Araabi B, 140
Næss S, 243
Nagele J, 231
Najafiani E, 49
Nasretdinov A, 265
Naud R, 193
Naumann LB, 262
Nawrot MP, 37, 154, 178, 209, 259, 316
Neef A, 147, 310
Ness TV, 78, 86, 139, 243
Neubert V, 76
Nieh EH, 214
Nieuw T, 248
Nili Ahmadabadi M, 162
Noecker AM, 268
Nold A, 45
Nonnenmacher M, 80
Nowotny T, 244
- O'Mara SM, 237
Oberlaender M, 88
Ocker GK, 23
Ocko SA, 111, 265
Öcal K, 233
Ofner A, 81
- Ogawa S, 145
Okuneye VT, 173
Olsen SR, 139
Onken A, 223
Op de Beeck H, 71
Orza V, 40
Ostojic S, 301
Ozaki M, 152
Ozinga S, 268
- Pachitariu M, 260
Packheiser J, 221
Pallasdies F, 317
Pandarinath C, 322
Panzeri S, 74, 258
Paolucci PS, 42, 228
Paré M, 192
Pastorelli E, 42
Paton J, 189
Pauli R, 170
Paunonen L, 276
Pavarino E, 94
Pazienti A, 228
Pearlson GD, 173
Pecka M, 112
Pedrocchi A, 40
Pedrosa V, 48
Pereira U, 134
Peter A, 256
Petersen MV, 268
Peterson EJ, 185
Petre B, 168
Petrovici M, 275
Petrovici MA, 182, 196
Pfeiffer P, 146
Pham T, 113, 296
Pica G, 258
Pietras B, 294
Pinheiro Neto J, 143
Pinotsis D, 62
Pinto L, 214
Pisokas I, 267
Plesser HE, 278
Podlaski WF, 69
Poeppel D, 117
Ponzi A, 120
Pozzi I, 35
Preuschoff K, 65
Priesemann V, 72, 143, 160, 166, 198, 199, 246, 298
Proell M, 212
Prokin I, 85
Protachevicz PR, 136
Prut Y, 316
Pusch R, 221
- Qiu Y, 256
Quendera T, 25
- Rabiee B, 49
Ramesh P, 67
Ramkumar P, 253
Rankin J, 103
Rashid Shomali S, 162

AUTHORS

- Rasuli SN, 162
Rathbun D, 247
Rattay F, 242
Rausch L, 66
Ravichandran P, 251
Razizadeh NS, 316
Recanatesi S, 134
Reckziegel D, 168
Reinacher P, 59
Remy S, 284
Renner A, 152, 320
Renner S, 89
Revah O, 310
Rezaei H, 312
Rhee JY, 115
Ribeiro IM, 269
Richardson MJE, 274
Riedler O, 196
Riehle A, 75, 154
Rimehaug AE, 139
Riquelme JL, 290
Ritter P, 91
Roberts PA, 239
Rochefort N, 223
Rodarie D, 129
Roelfsema PR, 35
Roese R, 256
Rose P, 250
Rosenow F, 76
Rost T, 154
rostami V, 154
Rotter S, 185, 278
Rozenblit F, 138
Rudelt L, 198, 199, 246
Rumpel S, 177
Röth K, 266
Røe MB, 139
- Sacramento J, 182
Sadeghi M, 247
Safaaï H, 74
Sahani M, 107
Sakagiannis PP, 209
Salaj D, 10
Salmasi M, 302
Samengo I, 254
Samimizad B, 166
Sanchez-Vives MV, 228
Sandamirskaya Y, 152, 320
Sans Dublanc A, 217
Saponati M, 299
Sarker A, 60
Sbandati C, 40
Scala F, 230
Scarpetta S, 19
Schemmel J, 275
Scherr F, 10, 27
Schieferstein N, 307
Schleimer J, 146, 250, 292
Schleyer M, 37
Schmidt A, 44
Schmidt H, 125
Schmidt NB, 222
Schmitz D, 205
- Schnitzer TJ, 168
Schottdorf M, 132, 214
Schrader F, 104
Schrater P, 208, 255
Schreiber S, 146, 250, 292
Schubert F, 31
Schubö A, 50
Schuessler F, 301
Schulz A, 19
Schulze-Bonhage A, 59
Schumann M, 187
Schwalger T, 141, 294
Schöbi D, 119
Schünemann M, 66, 252
Seara-Cardoso A, 216
Seifert M, 239
Senk J, 126
Senn W, 182, 196
Seppälä I, 276
Shabani H, 247
Shahidi N, 138
Shaikh AG, 268
Shao S, 266
Sherfey J, 285
Shimazaki H, 162
Shivkumar S, 108
Shoham S, 132
Sibile J, 118
Siegel M, 62
Siegle JH, 139
Sielużycki C, 73
Singer W, 256, 282
Sintsov M, 265
Sirota A, 79, 314
Skaar JW, 78
Smith M, 253
Smith MA, 215
Soltanipour M, 219
Sompolinsky H, 5
Sonntag M, 83
Sorochynskyi O, 226
Sosulina L, 284
Spacek M, 89, 256, 263
Speiser A, 70
Spitzner FP, 72, 143
Spreizer S, 278
Sprekeler H, 21, 193, 203, 262, 308
Springer MA, 178
Sreenivasan K, 153
Sridhar VH, 15
Standage D, 55, 192
Stapmanns J, 291
Stasik AJ, 78, 139
Stein H, 172
Steinmetz N, 305
Stella A, 137
Stemmler M, 231, 302
Stephan KE, 119
Steuber V, 46
Stimberg M, 133
Stober S, 81
Stringer C, 260
Stühmer W, 132
Suarez P, 193

AUTHORS

- Subramoney A, 27
Sweeney JA, 173
Szatko K, 121
Szyszka P, 15

Tammenga CA, 173
Tan A, 29
Tan C, 29
Tank DW, 214
Tchumatchenko T, 45, 89, 159
Teichmann M, 34
Temudo A, 153
Teng X, 117
Teska A, 133
Tétreault P, 168
Tetzlaff C, 180
Tetzlaff T, 137, 170, 192, 284
Thiele N, 110
Thorwart A, 211
Thurley K, 222
Tian X, 218
Timcheck JP, 158
Timofeeva Y, 274
Tkačík G, 6
Tolias AS, 82, 230
Tomen N, 252
Tomiello S, 119
Tomás FJB, 146
Tortora M, 40
Toyoizumi T, 145
Tresch MC, 322
Treves A, 219
Triesch J, 76, 167
Tsodyks M, 295
Tubiana J, 235
Turaga SC, 70
Turner G, 215

Ujfalussy BB, 157
Ulanovsky N, 4
Uran C, 256
Urban A, 217

Vachon-Pressau E, 168
Valeeva G, 265
Valente M, 258
Valizadeh A, 144, 312
Van Albada Sj, 154
van Albada SJ, 27, 123, 126
van den Broek D, 33
van der Plas TL, 235
van Meegen A, 27, 122
van Rossum MC, 14
van Stijn S, 256, 282
Vanni S, 149
Vaněk J, 83
Vasilevskaya A, 58
Vattuone N, 254
Vellmer S, 304
Vercruyse F, 193
Verstynen T, 185
Vida I, 146
Vigotsky AD, 98
Vinci GV, 272

Vinck M, 256, 282
Vogel J, 132
Vogels TP, 69
Vogelsang L, 119
Voges N, 271
von Papen M, 271
Vuksanovic V, 171

Wachtler T, 58, 83, 104, 254
Waibel G, 320
Wakaizumi K, 168
Walker EY, 82
Walker MF, 268
Walther T, 221
Wang A, 74
Wang J, 279
Weber L, 119
Wegener D, 52
Wellstein KV, 119
Wenliang LK, 107
Werner R, 91
Weyers B, 278
Whybrow PC, 92
Wibral M, 246
Wichmann FA, 105
Wilmes KA, 11
Wilting J, 72, 298
Wimalasena LN, 322
Wischik C, 171
Wittum PDG, 279
Wolf F, 44, 132, 147, 310
Wolfrum M, 127
Wong DD, 54
Wosniack M, 43, 315
Wouters DJ, 192
Wu J, 146
Wu S, 105, 131
Wyble B, 60

Yanez F, 88
Yang GR, 63
Yavuz C, 40
Yen S, 29

Zaitsev AV, 169
Zeman A, 71
ZENKE F, 32
Zeraati R, 305
Zerenner T, 150
Zhang C, 147
Zhao Z, 256
Zierenberg J, 298
Ziman G, 210
Zrenner E, 247
Zwaka H, 20

Bernstein Conference 2020

**Berlin,
Sept 29 - Oct 2**

Satellite Workshops,
Sept 29-30

Main Conference,
Sept 30 - Oct 2

