

Role of Global Inhibition in Brain Criticality

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We investigate the brain criticality hypothesis and the diverse roles of global inhibition in neural circuits. Recently we showed that increasing global inhibitory feedback leads to gradual rounding of first-order transition between dynamical phases, turning it into second-order phase transition. Results are replicated across different models of neural dynamics, namely, the Wilson–Cowan model and a network of leaky integrate-and-fire neurons. Across all these systems, a critical point is always found as a function of a pair of parameters controlling local excitability and global inhibition strength, and a general explanation revealing the roles of the shape of the activation function and fluctuations versus the extinction time-scale is provided. It is speculated that the brain could use global inhibition as a versatile means of shifting between first- and second-order dynamics, addressing the conundrum regarding the coexistence in neural dynamics of phenomena stemming from both. Some reflections regarding the comparison with other physical systems and the possible physiological significance are offered, and a hypothetical setup for an optogenetics experiment on cultured neurons is put forward.

Psilocybin Accelerates EEG Microstate Transitions and Elevates Approximate Entropy

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Abstract

Although the therapeutic potential of psilocybin has been documented, its effects on brain function remain incompletely understood. The relaxed beliefs under psychedelics (REBUS) theory proposes that psychedelics work by relaxing prior beliefs and increasing neural entropy, but this has primarily been tested using fMRI rather than EEG, which offers superior temporal resolution. This study investigated how psilocybin affects the spatiotemporal dynamics of the brain on the millisecond scale, examining whether its effects are modulated by mindfulness training and different cognitive states. Using EEG microstate and approximate entropy analyzes, we compared people who completed an 8-week Mindfulness-Based Cognitive Therapy program (N = 33) with controls (N = 30) in four conditions: video watching, resting state, meditation and music listening. The results showed that the 19 mg dose of psilocybin significantly altered brain dynamics, decreasing the duration of the microstate while increasing the rates of occurrence and the complexity of the signal. Mindfulness training showed no significant effect on these changes. While brain activity patterns primarily distinguished between eyes-open and eyes-closed cognitive states, psilocybin notably diminished the typical neural differences between passive rest and attentional states (meditation and music). These findings support the prediction of the REBUS theory of increased and neural entropy and under psychedelics and suggest that psilocybin creates a more dynamic and less constrained brain state,

particularly when visual input is reduced. The combination of microstate and entropy analyses provides complementary insights into how psychedelics affect both the temporal organization and complexity of neural activity.

Data-inferred multiscale brain models

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Abstract:

Regional parameters of whole brain models are inferred from large-scale brain recordings to provide mechanistic insights into brain function. The interpretability and range of parameters are limited by the choice of neural mass model. As opposed to phenomenological models, mean-field models maintain a link between microscopic and mesoscopic parameters, but they are often subject to strong assumptions in their derivation. Here, we validate a data-driven method to upscale detailed microscopic dynamics to the whole brain and infer parameters that are not available in the mean field model. We generated (Fig. 1A) a dataset of spiking activity of a heterogeneous QIF network (Izhikevich, E. M. 2007) and estimated the population dynamics using machine learning. We found that the reconstructed dynamics captured all the core features of the ground-truth exact mean-field model (MPR model, Montbrió, E. 2015) as illustrated by the phase plane reconstructions (Fig. 1B). We then compared whole brain activity using the estimated model or the ground truth model as a neural mass model in The Virtual Brain. We found the fluidity of the dynamics to be similar and the relationship between excitability and global coupling to be preserved (Fig 1.C). Lastly, we inferred excitability, synaptic strength, and connectivity between neurons from BOLD fMRI data and revealed the inherent degeneracy between synaptic strength and neuron connectivity which is not accessible using the mean-field model (Fig 1.D). In conclusion, estimating microscopic dynamics using machine learning techniques can successfully capture and reproduce results obtained mathematically in mean-field models.

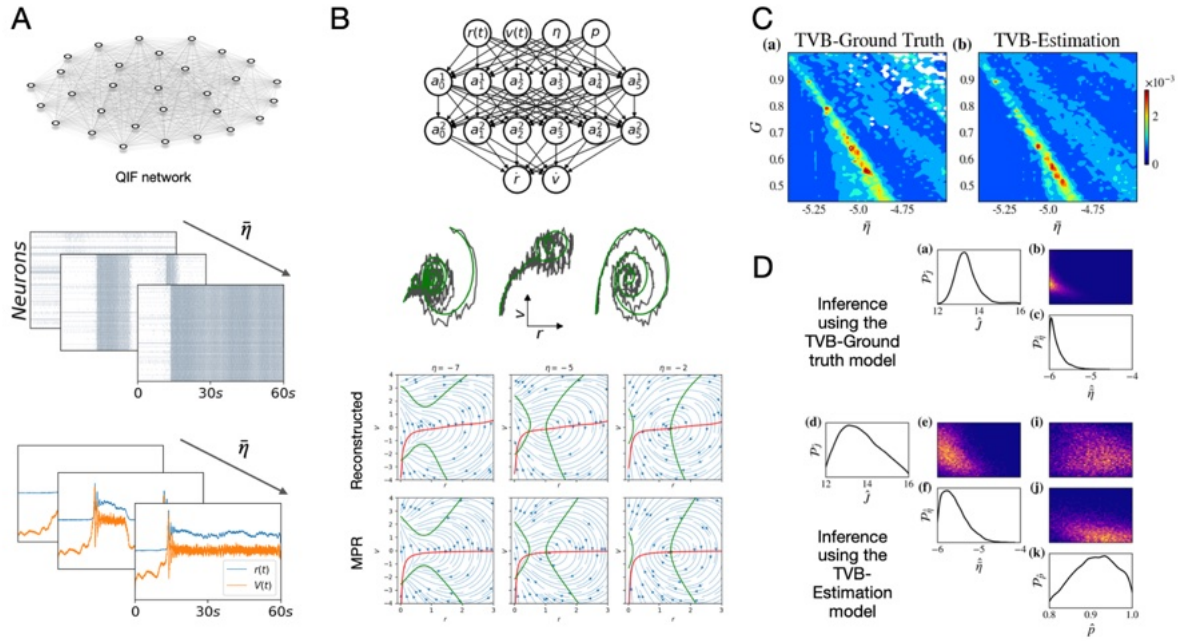


Fig 1. Graphical abstract. (A) from top to bottom: network of QIF neurons, data generated by sweeping for network parameters (here, the mode of excitability $\bar{\eta}$), extracted features (average firing rate and membrane potential). (B) Multilayer perceptron and example fitting of data trajectory in state space, reconstructed phase planes based of QIF data and MPR phase planes for different excitability. (C) Fluidity of the dynamics (variance of the functional connectivity dynamics) in a whole brain using the MPR model as neural mass (left) or the reconstructed model (right). (D) Posterior distributions from real BOLD fMRI data, using either the MPR as neural mass (top) or the reconstructed model (bottom).

Tuning to criticality in newborn brain activity induced by language prenatal experience

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Abstract

Several studies have shown that human newborns have sophisticated speech perception abilities allowing them to acquire any language. For instance, due to the rhythms and melodies that babies experience in their mother's womb during the last trimester of pregnancy, they can develop the ability to discriminate between their mother's language and other languages that are rhythmically different (but not rhythmically similar), even if these are unfamiliar to them. However, it remains unclear which neural mechanisms characterize such auditory ability. Here, using electroencephalography we investigate the newborn's brain activity analyzing the critical behavior of avalanches, their persistence, and their temporal structure during an auditory pre- and post-stimulus paradigm. Our results show a differentiation in the criticality signatures between familiar and unfamiliar languages. In the first case exponents and scaling relationships characterizing avalanche sizes and durations adjust better to the prediction of the mean-field directed percolation universality class than for the second case. Importantly, tuning to criticality induced by familiar language stimulation gets even more evident when we analyze additional dynamical properties of the cascading process. In particular, we observe that after the exposure to a familiar and rhythmically similar language the baby's neural activity presents an increase in the range of avalanche correlations, with the branching parameter getting closer to the critical value, and shows a peculiar temporal organization of avalanches that has been observed in the (critical) resting-state of adults. These findings may contribute to the understanding of underlying neural mechanisms governing language learning at the early stage.

State-dependent modulation of sensory populations by cortical feedback

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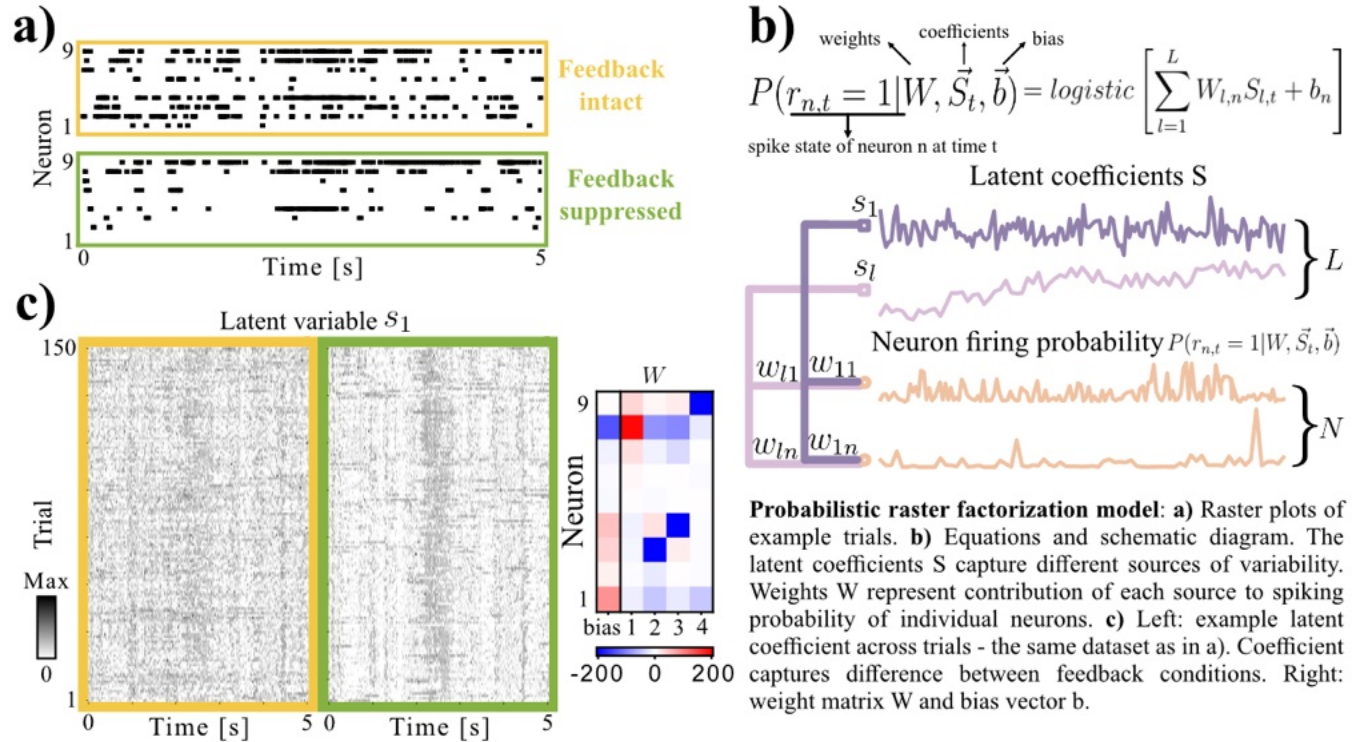
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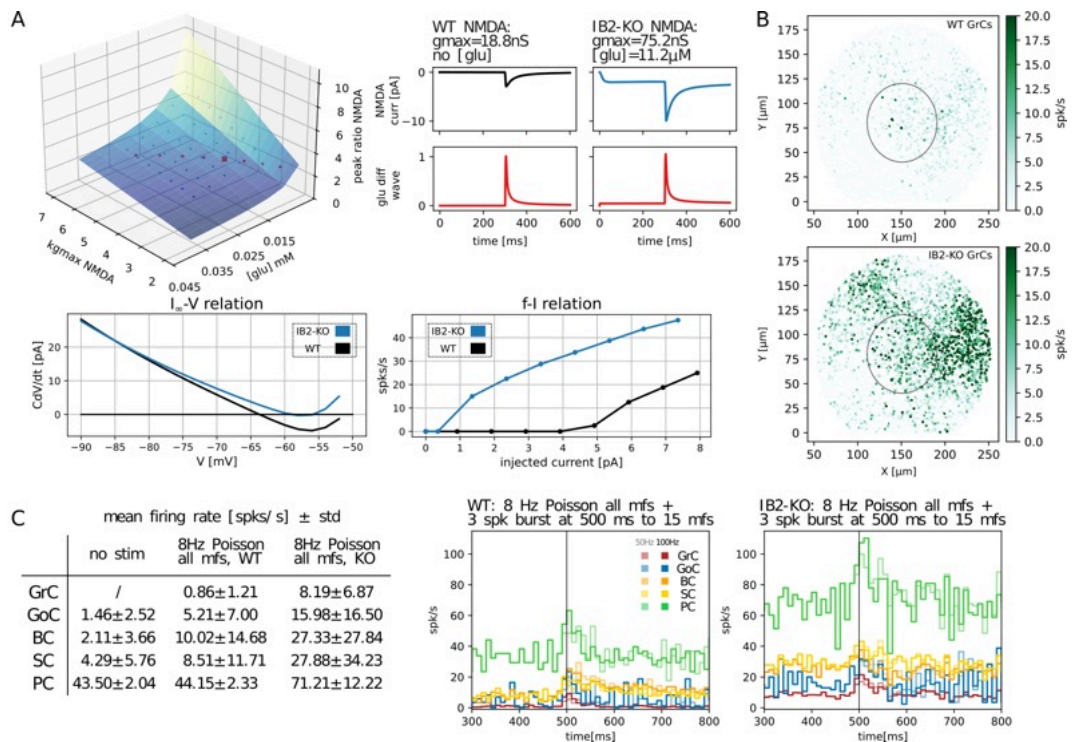
The role of feedback in sensory systems remains a major puzzle in neuroscience. Classical computational theories such as hierarchical predictive coding or hierarchical inference postulate abstract normative goals for the role of feedback connections. However, predictions derived from these theories are typically specified at the level of individual neurons. Whether feedback shapes collective properties of neural populations and how such changes may impact encoding of sensory signals remains unknown.

Here we tackle these questions directly by studying the population coding of natural stimuli in the dorsolateral lateral geniculate nucleus (dLGN) of behaving mice. Extracellular electrophysiological recordings were performed in the mouse dLGN, while corticothalamic feedback from primary visual cortex was optogenetically suppressed.

To understand how cortical feedback impacts population codes in dLGN, we derived a statistical model of population activity: probabilistic raster factorization. The model identifies correlated activity patterns at the resolution of individual spikes and assigns different sources of correlated fluctuations to individual latent variables. In this way it conveniently parameterizes sources of variability in population responses - stimulus changes, fluctuations of behavioral state and the presence of feedback.

Analysis of learned latent variables revealed that within-trial and between-trial variability of population activity is higher with feedback intact. At the same time, the dynamics of feedback modulation depend on the behavioral state of the animal. These results challenge the classical computational theories of feedback in sensory coding and suggest that its role may be much more nuanced and adaptive than expected.





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Contextual modulation of neural activity in the Superior Colliculus and its behavioural impact

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The superior colliculus (SC) is a midbrain structure in the mammalian brain that receives direct input from the retina and other early sensory circuits. SC output signals can induce survival-critical behavioral responses to specific visual stimuli like those typically associated with potential threats. The SC is understood to work as a saliency detector and as an integrator for multiple streams of sensory information, yet most experimental studies focus solely on individual cell tuning properties. Ongoing work has shown that contextual information (such as the amount of environmental light) can modulate the behavioural output, however the neural processing underlying these changes is still not well understood. Here we analyze the neural activity in head-fixed Neuropixels recordings from various transgenic mice. The animals were exposed to a set of fear-inducing visual stimuli under varying ambient light conditions and had freedom to move, escape, or freeze in response. We developed statistical models with the goal of disentangling stimulus coding, its modulation by the environmental context or genetic background, and its effects on behavior across the neural population in the SC and pre-motor areas. Preliminary results indicate the existence of neural subpopulations in SC with opposite modulation by environmental light levels. This suggests that contextual information can act on very early elements of the visuo-motor circuits to flexibly adjust behavior.

Energy - Neuromodulation for Restriction:
Structure, Resilience

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Energy efficiency standards have been implemented in the United States and other countries. These standards are designed to reduce energy consumption and greenhouse gas emissions. The standards are based on the energy efficiency of buildings and appliances. The standards are designed to be flexible and to allow for innovation. The standards are designed to be cost-effective. The standards are designed to be easy to implement. The standards are designed to be enforceable. The standards are designed to be transparent. The standards are designed to be fair. The standards are designed to be effective. The standards are designed to be sustainable. The standards are designed to be resilient. The standards are designed to be inclusive. The standards are designed to be equitable. The standards are designed to be just. The standards are designed to be fair. The standards are designed to be effective. The standards are designed to be sustainable. The standards are designed to be resilient. The standards are designed to be inclusive. The standards are designed to be equitable. The standards are designed to be just.

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f u n c t i o n i n t r e e d u e i n e n d g e y m a n d s .

The findings suggest that educational institutions are not recognizing the learning patterns in a way that staff in schools might be able to provide the appropriate individual reorganizational interventions. The coefficient of the regression model was negative, suggesting that the reorganizational computation.

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[2] Panzeri, Stefano, et al. "The structures and functions of correlations in neural population codes." *Nature Reviews Neuroscience* 23.9 (2022): 551-567.

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An interspike statistics-preserving simplified model for noisy FitzHugh-Nagumo neurons on a network

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While many relevant questions regarding the dynamical emergence of self-sustained activity and synchronization in the brain can be tackled with Dynamical Systems on Graphs, the discrete formulation of Information Theory makes these models unwieldy for the study of the information processing capabilities of realistic neuronal networks. We intend to bridge this gap by building a discrete neuron model that retains the firing statistics of a nonlinear FitzHugh-Nagumo (FHN) Neuron in the presence of white noise.

The first step in this construction entails the approximation of the neuron firing rate as a Kramers transition rate problem modulated by the time elapsed since the last event. Despite some limitations linked to parametric noise-like effects due to the non-separability of timescales, an analytical form for the Inter-Spike Interval (ISI) of the noisy FHN neuron is obtained, which, upon regression, can be discretized to define the transition rules of a binary stochastic system whose states 0 and 1 are interpreted as quiescent and firing states. By further endowing the system with a memory variable that keeps track of the time of last firing for the neuron, the binary unit is able to reproduce the ISI histogram of a FitzHugh-Nagumo neuron. (Figure 1).

We finally discuss how to move from the single neuron to a network perspective considering a loop of neurons. We obtain a partial match of dynamical behaviours with the the emerging travelling wave states obtained with noisy nonlinear models, which is interpreted in light of findings on the latter type of systems.

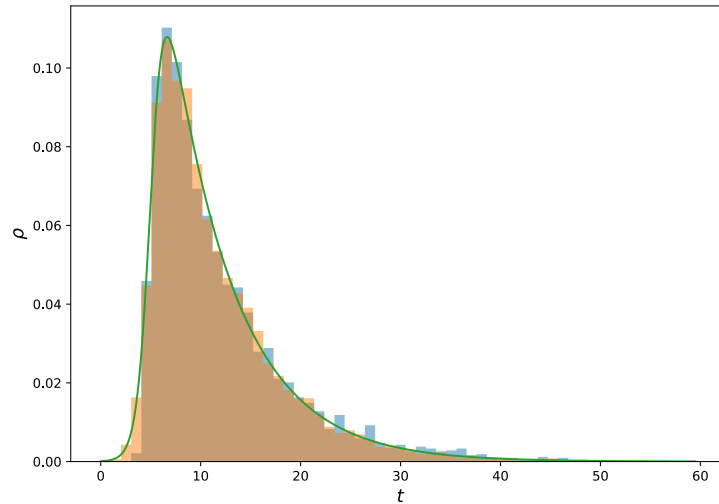


Figure 1: Comparison of the ISI distribution of a noisy FitzHugh-Nagumo neuron (blue shade region), simplified model (orange shade). The solid green line shows the analytical distribution function with parameter values obtained from regression.

Generative random latent features models and statistics of natural images

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Complex, high-dimensional data are often analyzed by grouping their constituent units into components, sometimes referred to as latent features, which afford physical or biological interpretation. However, *a priori* many different types of latent features and data decompositions can be defined, and one typically uses a trial and error approach to determine a decomposition that is natural to the system and its data. Principled understanding of which decomposition is appropriate for a given dataset is needed. In this work, we take a step in this direction and argue that sample-sample correlations carry important information to this effect. We construct a generative random latent feature matrix model of high-dimensional data based on linear mixing of latent features. As a key ingredient, we allow for statistical dependence between the mixing coefficients. We argue that, with only two parameters (latent dimensionality and the structure of the statistical dependence), the resulting model captures characteristic properties found in many types of natural data. Specifically, the model can produce (overlapping) clusters, sparse mixing, and constrained (non-negative) mixing. We describe typical correlations and eigenvalue distributions of each pattern. Finally, we fit the model on correlation patterns in a benchmark natural images dataset and find a good match between the data and the sparse mixing regime of our model. This is in line with the well-known sparse coding structure in natural images, arguing that our approach identifies a correct latent decomposition of these data. We believe that our work will deliver similar insights for other diverse datasets.

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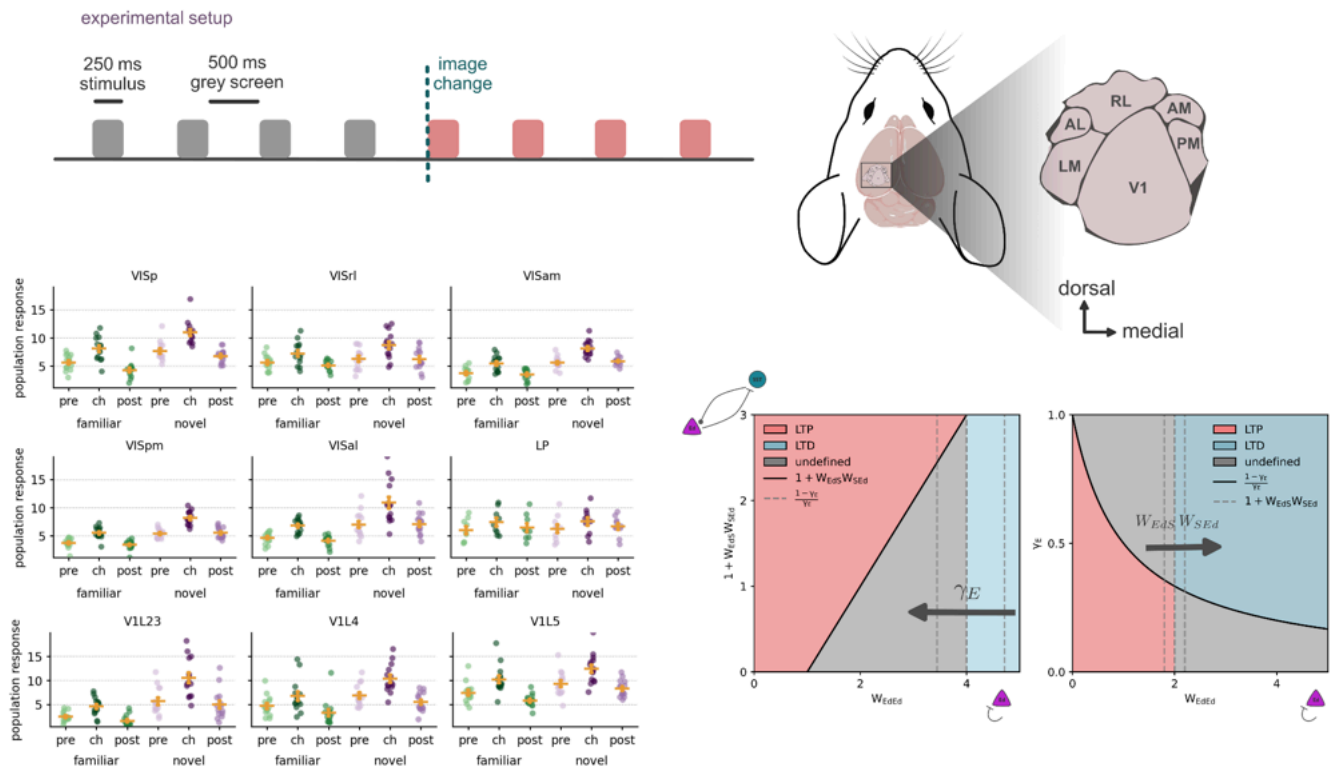
Title:

Identifying plasticity mechanisms underlying context-dependent neural responses in cortical circuits

Summary:

Biological circuits rapidly adapt to sensory stimuli through experience and ongoing learning in a non-trivial manner. Extensive experimental evidence indicates that neural circuits operate in distinct processing modes based on contextual information characterised by differential responses to the same stimuli. In early sensory cortices, different neuronal subtypes are thought to have specialized functional roles in controlling sensory information flow through the cortical hierarchy. Specifically, in mouse primary visual cortex (V1), populations of pyramidal and vasoactive-intestinal-peptide-expressing (VIP) cells show pronounced responses to novel and unexpected visual stimuli, while they rapidly adapt to elicit moderate responses to familiar or expected ones. However, the exact plasticity and circuit mechanisms that establish these distinct responses are not fully characterised.

Here, we analysed electrophysiological recordings from visual cortex and adjacent visual areas of mice performing a sequential visual discrimination task that establishes contextual stimulus expectations. Our analyses identified distinct inter-area communication patterns based on stimulus condition, suggesting selective, context-driven information routing to V1. To characterise the circuit design constraints and synaptic plasticity mechanisms that explain our empirical findings, we developed a data-constrained recurrent neural network model with three inhibitory interneuron subtypes. Using linear response theory on a mean-field approximation of the model, we derived the necessary circuit conditions on population interactions to replicate the experimentally observed responses. Our work provides a mechanistic explanation of how cortical circuits adjust their activity in response to contextual cues and stimulus expectations.



Modeling connectome structure using avalanche-based models with Hebbian learning on hierarchical modular networks

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Brain studies mainly focus on the anatomical wiring of the brain and its topological qualities to ascertain the exact relationship between anatomical structure and function. In this study, we examine the weighted degree distributions of representative large connectomes. We find that the behavior of the node strength (weighted degree) distribution varies according to the scale under consideration. The distributions exhibit power-law behavior on a global scale, with an approximately universal exponent near 3. However, this tendency deviates at the local level as the node strength distributions follow the log-normal distribution suggestive of underlying random multiplicative processes which support non-locality of learning in a brain near the critical state. Furthermore, to gain insight on the dynamics that led to this observed scale-free behavior of the global weight distributions of connectomes, we impose an avalanche-based model with Hebbian learning over Hierarchical modular network (HMN) architecture to simulate the dynamic process of reinforcement [weakening] of preferred [unused] pathways. HMNs recover key features of neuronal activity, making them good representative baseline structures for modeling cortical activity. Via targeted link creation and/or reinforcement for dynamically activated sites in a sandpile-like avalanche, and a random weakening and/or pruning during stasis times, we recover edge weight distributions that closely resemble the empirical connectome edge weight distributions.

Enhancement of memory storage capacity in recurrent neural networks through synaptic tagging and capture

Nahid Safari Lemjiri, Zahra Heidari Shali, Arash Golmohammadi, Christian Tetzlaff, Jannik Luboeinski

Life expectancy is continuously increasing, and with it, the demand for maintaining existing knowledge, habits, and skills. As a result, the ability to learn and store information is becoming increasingly important. In this paper, we present a novel approach to enhance the memory storage capacity of recurrent neural networks (RNNs) by using synaptic tagging and capture (STC). The STC mechanism is a biological process that allows the network to store information for a long time. We propose a modified STC mechanism that can be used to enhance the memory storage capacity of RNNs. The proposed mechanism is based on the idea of synaptic tagging and capture, which is a biological process that allows the network to store information for a long time. We propose a modified STC mechanism that can be used to enhance the memory storage capacity of RNNs. The proposed mechanism is based on the idea of synaptic tagging and capture, which is a biological process that allows the network to store information for a long time.

Here, we extend the biological model of STC to a neural network model. We show that the proposed mechanism can be used to enhance the memory storage capacity of RNNs. The proposed mechanism is based on the idea of synaptic tagging and capture, which is a biological process that allows the network to store information for a long time. We propose a modified STC mechanism that can be used to enhance the memory storage capacity of RNNs. The proposed mechanism is based on the idea of synaptic tagging and capture, which is a biological process that allows the network to store information for a long time.

Additionally, we analyze the performance of the proposed mechanism. We show that the proposed mechanism can be used to enhance the memory storage capacity of RNNs. The proposed mechanism is based on the idea of synaptic tagging and capture, which is a biological process that allows the network to store information for a long time. We propose a modified STC mechanism that can be used to enhance the memory storage capacity of RNNs. The proposed mechanism is based on the idea of synaptic tagging and capture, which is a biological process that allows the network to store information for a long time.

Testing the impact of noise correlations on stimulus decoding in a two-neuron system

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ABSTRACT .

Sensory neurons encode information about the external world through their collective spiking activity. This activity is both noisy and correlated across neurons. How correlations affect the encoded information in neural populations remains a matter of ongoing debate. Theoretical studies typically distinguish between *signal correlations*, which reflect similarities in stimulus tuning across neurons, and *noise correlations*, which arise from shared sources of noise. Understanding how the interplay between these two types of correlation influences stimulus representation remains a central challenge in computational neuroscience. Studies based on local stimulus discrimination (*Fisher Information*) have suggested that noise correlations reduce encoded information when they share the same sign as signal correlations, and are beneficial when they have opposite signs. More recent theoretical work, based on a global metric of information (*Mutual Information*), partially supports these findings but also reveals an additional regime in which strong noise correlations can be advantageous. Here, we address the problem from a decoding perspective—specifically, by reconstructing the stimulus from the noisy neural activity. We evaluate the performance of Bayesian decoding using the responses of two neurons with or without correlations. The results not only confirm the presence of the additional regime predicted with Mutual Information, but they also highlight the centrality of noise correlations in the trade-off between local and global stimulus discrimination. Moreover, we show that under certain conditions, correlated noise can enhance decoding performance even when it increases local uncertainty between stimuli (*information-limiting correlations*)—a regime considered always detrimental in the literature.

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Patterns replay and Criticality in a modular spiking neural network : comparison with MEG data

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ABSTRACT .

Healthy brains exhibit a rich dynamic repertoire with flexible and diverse spatiotemporal pattern replays across both microscopic and macroscopic scales. We hypothesize that the system must operate near a critical regime for the functional repertoire to be fully explored, and flexible dynamics to emerge. To test this hypothesis, we employ a modular Spiking Neuronal Network model, where each group of Leaky Integrate-and-Fire neurons represents a cortical region. A learning rule based on Spike-Timing-Dependent Plasticity (STDP) is used to encode patterns of activations that propagate between modules. The patterns exploit empirical information on the number of white-matter fibers between regions. The model displays two distinct dynamical regimes: an uncorrelated low-rate state and a strongly correlated state, marked by a high Order Parameter value (indicating the similarity of spontaneous activity with one of stored patterns). These regimes are separated by either a first-order or second-order phase transition, depending on the strength of global inhibition and structured connections. When the hysteresis loop shrinks, a continuous phase transition occurs, and it opens up an extended region with high order parameter fluctuations (close a Widom line with maxima of fluctuations). The model's predictions are compared with empirical data from magnetoencephalographic (MEG) recordings in healthy adults. The Levenshtein distance is used to quantify the similarity between the sequences of region activations in neural avalanches from both the empirical data and the model simulations. Notably a similar repertoire of sequence is observed in synthetic data and MEG only when the model operates within the critical extended regime.

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Quantifying (hidden) hearing loss through optimal neural codes

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Even though auditory nerve deafferentation is likely to be a primary cause of noise-induced hidden hearing loss (NIHHL), the specific link between observed physiological changes and perceptual effects of subtle acoustic trauma remains an open problem in hearing research. This work addresses this gap by using a computational framework based on normative brain theories (Młynarski et al. 2021), viewing spike-train recordings from the auditory midbrain of small mammals in terms of optimal neural coding. Specifically, we derive optimization priors for acoustic contexts defined by probability distributions of intensity (quiet, moderate and loud), for then calculating a posterior based on rate-intensity functions parameter distributions (threshold and gain) measured experimentally, associating neural recordings with the statistics of these optimal solution spaces. By contrasting the dynamics within neural coding utility, neural gain regulation, and entropy of solution spaces, the model provides a unified lens to examine neural adaptation processes in NIHHL and conductive hearing loss, crucially, being consistent that neural gain is up-regulated following loss of afferent inputs, and that such gain regulation has different and measurable consequences for the efficiency and variability of neural codes, depending on the acoustic context. The consistency of these results across groups and recent literature supports the idea that optimal coding models offer a principled starting point for understanding and measuring hearing dysfunction, departing from the clinical audiogram for which these pathologies remain hidden, quantifying them through shifts in representational capacity and information processing optimality.

Modelling Response of Brain Activity to Perturbations

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ABSTRACT

Understanding the brain's response to transcranial magnetic stimulation (TMS) is crucial for advancing both basic and clinical neuroscience. This study applies neural mass modelling to analyze TMS-evoked potentials (TEPs) through electroencephalography (EEG). Building on Momi et al. (2023) [1], who used source-localized TMS-EEG analyses to disentangle local from network dynamics, we aim to replicate and extend these findings by modelling the response from the resting state.

We adopt the whole-brain Hopf model proposed by Ponce-Alvarez and Deco (2024) [2],

$$\frac{dz_j}{dt} = (a_j + i\omega_j)z_j - |z_j|^2 z_j + g \sum_{j \neq k} C_{jk} [z_k(t + m_{jk}) - z_j(t)] + \eta_j \quad (1)$$

adapting it to EEG data [3]. Our results show that this model can reproduce resting state activity in the Fourier domain, while the TMS-evoked dynamics are accurately captured in the EEG trajectory space. This highlights the model's potential in bridging spontaneous and perturbation-driven brain activity.

Current efforts focus on integrating site-specific effective connectivity into the model, estimated for different TMS stimulation targets. This approach aims to capture how local connectivity profiles shape both spontaneous and evoked activity. By combining resting state dynamics with region-dependent effective connectivity, we aim to predict perturbation responses more accurately across stimulation sites. This direction holds promise for informing stimulation strategies and improving individualized neuromodulation protocols.

REFERENCES

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