UK Neural Computation 2024

Programme

July 9-10th 2024

University of Sheffield, UK

Schedule

All talks are in the Diamond Lecture Theatre 5
All food and drink will be served in Diamond Basement area
Poster sessions are in Diamond Basement area

Tuesday 9th		
11:45 – 12:50	Registration & lunch	Lunch at 12
12:50 – 13:00	Welcome	
	Session 1	Chair: Stuart Wilson
13:00 – 13:30	Rasmus Petersen	The function of sensory cortex during natural behaviour
13:30 – 14:00	Huiling Tan	Adaptive DBS for Movement Disorders – from basic neuroscience to translation
14:00 – 14:30	Valentin Schmutz*	High-dimensional population activity from low-dimensional population dynamics: an exactly solvable model
14:30 – 15:00	Coffee	
	Session 2	Chair: Mark Humphries
15:00 – 15:30	Dan Goodman	From neural mechanism to function
15:30 – 16:00	Samuel Eckmann*	A neural circuit model for inhibition-stabilized memory encoding and retrieval
16:00 – 16:30	Eleni Vasilaki	Fundamental Elements in Decision-Making: Insights from a Reinforcement Learning Model
16:30 – 18:30	Posters A & reception	

* Selected talk from abstracts

Wednesday 10th		
	Session 3	Chair: Hazem Toutounji
9:30 – 10:00	Rui Ponte Costa	Back to the present: self-supervised learning in cortical layers
10:00 – 10:30	Emma Scholey*	The explore/exploit trade-off drives variation in patch foraging decisions
10:30 – 11:00	Tim O'Leary	Data-driven neural dynamics
11:00 – 11:30	Coffee	
	Session 4	Chair: Alekhya Mandali
11:30 – 12:00	Yulia Timofeeva	Computational modelling of neurotransmitter release
12:00 – 12:30	Isabel M. Cornacchia*	An efficient coding theory for cortical connectivity
12:30 – 13:00	Andrew Adamatzky	Fungal neuroscience
13:00 – 14:00	Lunch	*Overlaps with start of poster session*
13:30 – 15:30	Posters B & coffee	
	Session 5	Chair: Hannes Saal
15:30 – 16:00	Geoff Goodhill	Decoding the development of behavior and neural circuits in zebrafish
16:00 – 16:30	Mark van Rossum	Energy efficient learning in neural networks
16:30 – 17:15	Randy Bruno (Keynote)	Cortical layers in context & learning
17:15 - 17:30	Closing remarks	

Organisers' note

Welcome to UK Neural Computation 2024!

Back in 2019 the time seemed ripe to launch a national meeting for the UK community working on the computational side of neuroscience, be it experimental or theoretical. Our community was thriving, with major investments and recruitment at institutions across the UK; the AI explosion was driving new approaches to understanding the brain; and the ever-present climate crisis driving a greater awareness of our carbon footprint, for which a strong local meeting is one small way to reduce it.

The inaugural UK Neural Computation meeting in 2019 at the University of Nottingham was a wonderful, buzzing event, drawing attendees from across the UK. Now, post-pandemic, we're delighted to bring you the belated sequel.

Our programme showcases the breadth and depth of UK computational work, from the single synapse and single neuron, through ensembles, networks, and circuits, up to the large-scale networks in the human brain. And, borrowing a fine COSYNE tradition, the first evening's poster session is accompanied by a drinks reception to encourage relaxed, convivial scientific discussion.

Hope you enjoy it!

Mark Humphries (Nottingham) on behalf of the organisers:

Hannes Saal (Sheffield)

Stuart Wilson (Sheffield)

Alekhya Mandahli (Sheffield)

Hazem Toutounji (Sheffield)

Thanks

The conference organisers would like to thank:

The School of Psychology, University of Sheffield (www.sheffield.ac.uk/psychology) for financial and administrative support.

The panel members who kindly agreed to speak at our ECR days: Dr Chris Martin, Dr Claudia von Bastian, Claire Sykes, Daniel Camilleri, Dr Mahnaz Arvaneh, Dr Mike Mangan, Dr Ruth Corps and Prof Su Li.

Sponsors

We are grateful for the support of the following:

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Contents

Talk abstracts

Tuesday 9th

Rasmus Petersen

The function of sensory cortex during natural behaviour

The purpose of sensory systems is to guide behaviour. Yet the bulk of our knowledge of sensory systems comes from experiments on anaesthetised animals where the motor systems are disengaged, and the textbook view of primary sensory cortex is that its function is feedforward sensory processing. Our data challenge this view. We are investigating the function of somatosensory cortex in freely moving mice whilst they explore objects by touch in the dark. We combine electrophysiological recording of the activity of neurons in the whisker primary somatosensory cortex (wS1) with video-based 3D reconstruction of mouse body posture. As expected of wS1 neurons, we find that whisker-object touch is a good predictor of firing rate. Surprisingly, however, sensorimotor variables describing the orientation of the head or non-rigid motion of the body explain substantial firing rate variance beyond that accounted for by touch. These results challenge the classic feedforward sensory processing framework and suggest that the natural function of primary sensory areas of the brain is more closely tied to action than has previously been appreciated.

Huiling Tan

Adaptive DBS for Movement Disorders – from basic neuroscience to translation

Electrical brain stimulation offers unprecedented temporal and spatial precision in interacting with the brain. Although continuous high frequency deep brain stimulation (DBS) is already affording major therapeutic benefits for movement disorders, there is vast scope for improving and extending this to provide adaptive and tailored interventions.

Here I will share a few projects demonstrating how we take the advantage of the research opportunity of measuring invasive brain signals from human patients to: 1) better understand the mechanism of DBS and the pathophysiology of movement control and movement disorders; 2) develop and test invasive Brain Computer Interfaces (BCIs) for adaptive DBS for movement disorders; 3) design and test new translational neuroscience research tools with improved performance for simultaneous stimulation and sensing required for bi-directional BCIs and adaptive DBS.

We argue that by better understand the underlying circuit pathophysiology and the mechanism of deep brain stimulation, by designing better tools for simultaneous sensing and stimulation, we can interact with neural dynamics from moment-to-moment as necessary to reverse or ameliorate dysfunctional brain activity, while at the same time preserving or facilitating brain activities important for normal function. This bi-directional BCI based DBS can provide adaptive and tailored intervention with increased efficacy and reduced side effects.

Valentin Schmutz

High-dimensional population activity from low-dimensional population dynamics: an exactly solvable model

Large-scale recordings of neuronal activity have revealed that spontaneous population activity in cortex is high-dimensional, in the sense that neuronal firing rates do not strictly lie in a finite-dimensional linear subspace (Stringer et al. Science 2019; Manley et al. Neuron 2024). These findings are apparently at odds with the view that neural population dynamics approximate low-dimensional dynamical systems to implement computations (Vyas et al. Annu. Rev. Neurosci. 2020).

In this theoretical work, we study the exact mean-field limit of random low-rank recurrent neural networks (RNNs). We prove that large RNNs with effective low-dimensional population dynamics can produce power-law eigenspectra when PCA is applied to the neurons' firing rates. While the co-occurrence of effective low-dimensional population dynamics and high-dimensional population activity may seem paradoxical, the exactly solvable model we propose offers a transparent explanation for this apparent paradox.

First, we prove that, in the mean-field limit, the dynamics of random low-rank RNNs can be exactly reduced to a low-dimensional system of simple differential equations (despite the nonlinearity of the transfer function). Importantly, the effective low-dimensional dynamics are expressed in terms of latent variables that are projections of the neurons' membrane potentials. Setting the model such that the effective dynamics produces a limit cycle, we then show that the PCA eigenspectrum of the neuron's firing rates, which has a closed-form expression, has a power-law decay which depends on the nonlinearity of the transfer function.

This model explains how population dynamics can be low-dimensional in the space of membrane potentials and, simultaneously, high-dimensional in the space of firing rates (because of the nonlinear transfer function), reconciling two seemingly opposing views on dimensionality in systems neuroscience.

Dan Goodman

From neural mechanism to function

What is the role of theoretical or computational work in neuroscience? In this talk, I will discuss how I think that techniques from machine learning can let us relate neural mechanisms to functions, illustrated with some examples from our recent research. In brief, theory lets us answer "what if" questions that would have been impossible to answer using experiments alone. Machine learning specifically gets us close to being able to answer "how well could the brain function if" questions that allow us to get at the computational role of particular neural mechanisms. Critically, this approach to theory is different to the ones that have often been suggested for computational neuroscience: fitting data, predicting data, letting us carry out "in silico" experiments. In summary, I will argue that if you want to understand what the functional role of a neural mechanism is, computational theory is essential, and that thinking of theory in this way lets us do it better. The research I will discuss includes: (1) How the heterogeneity of neurons allows the brain to solve sensory tasks with temporally rich structure. (2) How the structural modularity of the brain is not sufficient to guarantee functional modularity. (3) How neural nonlinearities are critical to extract temporally structured multimodal information.

Samuel Eckmann

A neural circuit model for inhibition-stabilized memory encoding and retrieval

The hippocampus plays a central role in memory formation and retrieval. To avoid deleterious interference between stored and ongoing experience, theoretical considerations require a separation between phases of memory encoding and recall within the same neural circuit, putatively controlled by hippocampal theta oscillations. However, the neural mechanisms subserving this separation remain unknown. Classical models either remain mute about these mechanisms or assume neuromodulatory interactions that are in conflict with biologically realistic timescales of synaptic modulation (Hasselmo & Stern, 2014). In addition, computational models of memory recall typically do not consider inhibitory neurons at all, or only for stabilizing the network globally. In contrast, recent experiments suggest that structured inhibitory connections are crucial for memory retrieval. Here, we develop an excitatory-inhibitory network model with structured connectivity between units conforming to a canonical circuit motif, the inhibition-stabilized supralinear network (Ahmadian & Miller, 2021). This network naturally gives rise to a separation between phases that are ideal for either the recall or the storage of memories, solely determined by the input strength of an external memory cue. For weak input, the cued memory is recalled and neurons are strongly stabilized by inhibition. For strong input, the external cue is encoded, while inhibition stabilization is paradoxically weaker. Our model only requires a Hebbian and an anti-Hebbian form of local synapse-type-specific competitive learning (Eckmann et al., 2024) that respectively store the positive and negative parts of the pattern covariance matrix. The resulting recurrent connectivity is highly structured and consistent with Dale's law. In summary, we present a model of hippocampal memory recall that meets key biological constraints and reveals a novel mechanism for alternating between storage and recall within the same circuit.

Eleni Vasilaki

Fundamental Elements in Decision-Making: Insights from a Reinforcement Learning Model

We hypothesise that decision-making involves three core elements: the perception of time, the processing of information across multiple timescales, and the maximisation of rewards. Utilising these principles, we developed a simple reinforcement learning model trained on a moving dots-like coherence task. Our findings reveal three distinct signatures: (1) Signal neutrality, where the model demonstrates insensitivity to signal coherence right before making a decision; (2) Scalar property, where response times vary significantly across different signal coherences, yet maintain a consistent distribution shape; and (3) Collapsing boundaries, where the decision boundary dynamically adjusts over time, aligning with theoretical optimality. Our results propose an alternative explanation for signal neutrality: it emerges from the processing of information on multiple timescales and is integral to the decision-making process, rather than being a mere component of motor planning.

Wednesday 10th

Rui Ponte Costa

Back to the present: self-supervised learning in cortical layers

The neocortex constructs a rich internal representation of the world, but the underlying circuitry and computational principles remain unclear. Inspired by self-supervised learning algorithms, we introduce a computational theory wherein layer 2/3 (L2/3) learns to predict incoming sensory stimuli by comparing previous sensory inputs, relayed via layer 4, with current thalamic inputs arriving at layer 5 (L5). We demonstrate that our model accurately predicts sensory information in context-dependent temporal tasks, and that its predictions are robust to noisy and occluded sensory input. Additionally, our model generates layer-specific sparsity and latent representations, consistent with experimental observations. Next, using a sensorimotor task, we show that the model's L2/3 and L5 prediction errors mirror mismatch responses observed in awake, behaving mice. In summary, our findings suggest that the multi-layered neocortex empowers the brain with self-supervised predictive learning.

Emma Scholey

The explore/exploit trade-off drives variation in patch foraging decisions

Foraging decisions require the individual to choose between harvesting current resources or seeking better options elsewhere. Optimal foraging behaviour, as described by the marginal value theorem, assumes we make deterministic choices. Yet we know that animals and humans make stochastic choices due to a variety of drivers, such as random exploration or general sensory/decision noise. It is unclear what drives stochastic choice in foraging, and what these drivers predict about foraging behaviour and its variability. Here, we study a model of stay-or-leave choice in patch foraging to understand the drivers of stochastic choice. Across three datasets involving different task structures, we find that both human and animal leaving times are best explained by reward-dependent exploration in different environments. We further show that our model makes counter-intuitive predictions about variability in patch leaving times. Critically, the decay of patch reward rate influences variability predictions. In patches with exponentially decaying reward, variability is stable across different patches and environments, despite different levels of exploration in each environment. In linearly decaying patches, our model instead predicts lower variability in poorer environments. We show that these counter-intuitive predictions are verified in all three datasets. These results suggest a necessary role for the explore/exploit trade-off in foraging decisions.

Timothy O'Leary

Data-driven neural dynamics

From decades of work across species we have learned that the internal dynamics of neurons is often extremely rich, and in many cases essential for the wider function of neural circuits, and the survival of an animal. This inconvenient truth is both a source of inspiration for theories of neural computation and an obstacle to building predictive, data driven models of neural circuits with "the right level" of detail. I will describe work we are doing to build such models and ultimately use them to control the activity of living neural circuits in real time.

Yulia Timofeeva

Computational modelling of neurotransmitter release

Synaptic transmission provides the basis for neuronal communication. When an action potential propagates through the axonal arbour, it activates voltage-gated Ca2+ channels located in the vicinity of release-ready synaptic vesicles docked at the presynaptic active zone. Ca2+ ions enter the presynaptic terminal and activate the vesicular Ca2+ sensor, thereby triggering neurotransmitter release. This whole process occurs on a timescale of a few milliseconds. In addition to fast, synchronous release, which keeps pace with action potentials, many synapses also exhibit delayed asynchronous release that persists for tens to hundreds of milliseconds. In this talk I will demonstrate how experimentally constrained computational modelling of underlying biological processes can complement laboratory studies (using electrophysiology and imaging techniques) and provide insights into the mechanisms of synaptic transmission.

Isabel M. Cornacchia

An efficient coding theory for cortical connectivity

Cortical circuits transform sensory inputs into distributed neural firing patterns via the interactions of excitatory and inhibitory cell types. However, the principles relating cortical connectivity to efficient sensory codes are poorly understood. Two fundamental properties of cortical connectivity shape representations of sensory stimuli: 1) neurons with shared stimulus preferences connect more strongly than those with disparate preferences (stimulus-specific connectivity), and 2) excitatory and inhibitory synaptic inputs to each neuron are co-tuned and approximately equal (E-I balance). A substantial literature of circuit models endowed with these properties have provided mechanistic explanations for various phenomena observed experimentally in visual cortex, such as contrast-invariant tuning curves and cross-orientation suppression. However, a normative, first principles explanation for cortical connectivity and the response properties it generates is currently lacking.

Here, we asked whether these properties could emerge from an efficient coding objective. We developed a method to adjust the recurrent weights of an E-I network to maximise the Fisher information of the response for a given input ensemble. Networks optimised to encode stimulus orientation at varying contrasts exhibit stimulus-specific connectivity and co-tuned E/I synaptic currents. Excitatory connectivity selectively amplifies input patterns, while recurrent inhibition maintains dynamical stability, and although the network was not directly incentivised to encode stimulus contrast, both E and I cells exhibited contrast-invariant tuning curves. Finally, although the network was optimised to encode a single stimulus orientation, the network exhibited cross-orientation suppression for simultaneously presented orientations. Taken together, we show that fundamental features of cortical circuit connectivity, dynamics and response properties can be accounted for by an efficient coding principle.

Andy Adamtzky

Fungal neuroscience

Fungi produce neuron-like action potential spikes. We explore fungal neuroscience, showing fungi's ability to process information like neural networks. We introduce fungal neuromorphic electronics using mycelium, highlighting their capacity to change impedance and generate spikes. These circuits can be used in materials, wearables, or as standalone sensors. The presentation covers fungal electronics, computing, and language. In fungal electronics, we discuss memristors and oscillators. Memristors in *P. ostreatus* show memristive properties under voltage sweeps. Fungal oscillators use mycelium resistance fluctuations. Fungal blocks distinguish weight changes via spikes. Optical and chemical sensors respond to stimuli with unique electrical patterns. Fungal computing uses electrical analog and voltage spike methods. Models and experiments use threshold voltages for logical values. Fungal colonies maintain integrity through cytoplasmic flow and mycelium tip coordination, enabling computations via electrical potential waves. Fungal language is based on electrical potential oscillations in fungi. Analyzing activity in various fungi, we find spikes grouped into words. These patterns resemble human languages. We analyze fungal language complexity, advancing our understanding of its syntax.

Geoff Goodhill

Decoding the development of behavior and neural circuits in zebrafish

Zebrafish larvae display complex behaviors from an early age and possess a naturally transparent physiology, enabling the optical recording of whole-brain activity at the resolution of individual neurons. These unique characteristics make zebrafish ideal for investigating the computational principles governing neural circuit development. I will discuss our latest research on the physical and neural constraints that shape the development of hunting behavior in zebrafish.

Mark van Rossum

Energy efficient learning in neural networks

The brain is one of the most energy intense organs. Some of this energy is used for neural information processing, however, fruit fly experiments have shown that also learning is metabolically costly. First we will present estimates of this cost, introduce a general model of this cost, and compare it to costs in computers. Next, we turn to a supervised artificial network setting and explore a number of strategies that can save energy need for plasticity, either by modifying the cost function, by restricting plasticity, or by using less costly transient forms of plasticity. Finally, we will discuss adaptive strategies and possible relevance for biological learning.

Randy Bruno

Cortical Layers in Context & Learning

Perception, decision making, and movement deeply involve cortical circuitry, which has a stereotyped architecture repeated across the entire surface of the brain. In this talk, I will discuss our investigations of how the different cortical layers contribute to behavior. I will show how modern optogenetic and traditional lesion manipulations can lead to opposing conclusions about the necessity of a brain structure, layer, or cell type. We have developed novel cortex-dependent tasks for the rodent whisker system in which we manipulate and record the layers to test their functions. By combining array recordings and modeling in these tasks, we are additionally able to disentangle the contributions of sensory, motor, choice, and reward signals to the activity of individual neurons. We find that task context can reweight this mixture so dramatically that the most fundamental features of cortex, such as topography, disappear. Imaging of apical tuft dendrites during animal training suggest that cortical layer 1 may be a key substrate by which learning reconfigures sensory cortex according to task context.

Posters at a glance

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2. Faster building of cognitive maps in real-time with core knowledge and closed-loop behaviours
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3. Revisiting the role of synaptic plasticity and network dynamics for fast learning in spiking neural networks
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4. Multiple locomotion modes emerge from reconfigurations of neural population dynamics in Aplysia
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5. Are Brain Oscillations Emergent?
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6. Training SNNs for speech recognition with exact gradients in GeNN
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7. Diving into space: emerging and disappearing shared dimensions in neuronal activity under the influence of psychedelics.
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8. On Temporal Interference Stimulation
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11. Unsupervised learning of EEG signatures of multisensory processing in Autism and Schizophrenia
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12. The cortical 'tape measure': learning tactile distance estimation using Convolutional Neural Networks
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13. Prior probability biases perceptual choices by modulating the accumulation rate, rather than the baseline, of decision evidence

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14. Bootstrapping the auditory space map via an innate circuit

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Nammazi A, Shahraki A, Balougias T, Toumaian M, Smyrnis N, Delis I.

17. Synaptic strength fluctuations from a model of stochastic gene expression in neurons

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18. Topological maps maximise information while minimising complexity

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21. Dendritic spine neck as a control mechanism for the rules of synaptic plasticity

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22. Simulating single-unit and population responses of plantar cutaneous afferents during balance and gait

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1. A mechanistic model investigating iTBS Effects and TMS Data in Individuals with Tourette's and Healthy Controls
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2. Altered neural population coding of sensory stimuli in early development in a mouse model of Fragile-X Syndrome
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3. Neural manifold discovery via dynamical systems
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4. Adversarial-inspired autoencoder framework for salient sensory feature extraction
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5. Towards Reliable Spike Sorting: Interpretable Automated Curation for Spike Sorting Outputs
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6. Neuromodulation of the mediodorsal nucleus during MRgFUS thalamotomy demonstrates a causal role in reward learning
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7. Efficiency and reliability in biological neural networks
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8. clODE - a computational library for large-scale, rapid ODE simulation on modest hardware
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9. Application of Non-linear Mixed Effects Modeling in Computational Neuroscience
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11. Learning dynamics in the PFC can be explained by an external controller
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15. Neuromorphic approach to texture representation invariant to scanning speed and contact force

Iskarous MM, Chaudhry Z, Li F, Bello S, Sankar S, Thakor NV

16. Supramodal decision formation network identified in parietal and frontal lobes

Asadpour A, Steinemann N, Kalou K, Kelly SP, O'Connell RG, Wong-Lin KF

17. Dissecting muscle synergies in the task space

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18. What Are Autapses Good for?

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20. An attractor decision network model accounts for sequential sampling from memory in nonhuman primates

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Poster Abstracts

Poster session A (Tuesday 9th)

1. Towards Continuous Action Representations in Models of the Basal Ganglia

Bartlett ME, Furlong PM, Stewart TC, Orchard J

Evidence suggests the Basal Ganglia (BG) is involved in the initiation, execution, and termination of both discrete action units or sequences, and continuous-valued action kinematics, e.g. action vigor. However, existing computational models of the BG have yet to incorporate representations of continuous-valued action spaces. The discrete action assumptions that underpin modern BG models would result in either an untenable growth in model size, or an implausible discretization of the action space, if applied to continuous domains. We propose to address this using Vector Symbolic Algebras (VSAs) combined with Semantic Pointers (SPs). SPs are high-dimensional vector embeddings of discrete and continuous data that can be realised in neural networks (NNs). VSAs provide operations on those vectors that can be implemented in NNs. We apply a restricted subset of Plate's Holographic Reduced Representation VSA, creating SPs that have compositional structure.

Importantly, we can use SPs to encode both discrete and continuous actions without increasing the dimensionality of the representation. Here, we encode action spaces by representing each available action as an SP, weighting it by its salience, and combining the weighted SPs via superposition. This process is dimensionality preserving, avoiding the problem encountered by localist models of needing to grow to accommodate more actions.

For continuous action spaces, we extend this method to representing salience as unnormalized distributions over a continuous range of actions. We adopt this representation for several models of BG function, including Attractor and Accumulator models, posing the BG as a clean-up memory that takes our representations as input and produces vectors that more closely resemble SPs encoding single actions – the action with the highest salience.

We will examine the predictions made by each model when selecting from continuous action spaces and compare against behavioural data.

2. Faster building of cognitive maps in real-time with core knowledge and closed-loop behaviours

Lafratta G, Porr B, Chandler C, Miller A

In autonomous navigation, an agent's knowledge of its environment is represented as sensory inputs (states) linked together by actions. A popular approach for acquiring this knowledge is reinforcement learning (RL), where learning is stereotyped, i.e. an agent learns to react to a state with the action associated with maximum reward. Model training requires many trials and occurs offline, where the agent aims to learn generalisable reflexes rather than to actively reason about its surroundings. Thus, RL agents are inefficient to train and can exhibit inflexible behaviour. Indeed, behavioural flexibility requires more powerful encoding than trained reflexes. In nature, behaviour boils down to attraction or repulsion, both of which are closed-loop behaviours (CLBs). CLBs are object-centric reflexes which react to an obstacle/target (a "disturbance"), and terminate when it is avoided/reached, or when the behaviour fails. Thus, the lifetime of CLB depends on active feedback from the environment and relies on real-time disturbance processing. By combining CLBs with "core" (i.e. innate) knowledge of physics and causality in the form of a physics engine, a robot can simulate the execution of CLB sequences and choose the best sequence as its next plan on-the-fly. CLB sequences can then be stored in a cognitive map for recall and future reasoning. In this paradigm, reasoning involves a search over the cognitive map. We propose that, with each sensor sampling event, and with the aid of a physics simulation, the initial cognitive map may be updated incrementally with observed relationships between CLBs and by growing or shrinking the state-space. This approach, demonstrated on a real robot in a target-seeking scenario, shows promise in terms of few-shot learning of and reasoning over a state-based model in real-time. The model is egocentric and requires no global localisation or data labelling, making for a resource-efficient, as well as biologically realistic, paradigm.

3. Revisiting the role of synaptic plasticity and network dynamics for fast learning in spiking neural networks

Subramoney A, Bellec G, Scherr F, Legenstein R, Maass W

Spiking neural networks are of interest, both from the perspective of modeling neural networks of the brain and for porting their fast learning capability and energy efficiency into neuromorphic hardware. However, so far, we have not been able to reproduce the brain's fast learning capabilities in spiking neural networks. Biological data suggest that a synergy of synaptic plasticity on a slow time scale with network dynamics on a faster time scale is responsible for the brain's fast learning capabilities.

In our work, we show that a suitable orchestration of this synergy between synaptic plasticity and network dynamics does, in fact, reproduce the fast learning capabilities of generic recurrent networks of spiking neurons. We do this by allowing the synaptic weights to store priors and other information that optimize the learning process. The network state quickly absorbs information from new examples using biologically realistic neurons with spike frequency adaptation. The overall recurrent spiking neural network with spike frequency adaptation optimizes the learning process through meta-learning. We demonstrate this on various tasks, including fast learning and deleting attractors, adaptation of motor control to changes in the body, and solving the Morris water maze task – a paradigm for fast learning of navigation to a new goal.

Our work points to the important role of recurrent connections in spiking networks, as these are necessary for enabling salient network dynamics. We show that the proposed synergy enables synaptic weights to encode more general information, such as priors and task structures since moment-to-moment processing of new information can be delegated to network dynamics.

4. Multiple locomotion modes emerge from reconfigurations of neural population dynamics in Aplysia

Colins Rodriguez A, Hill E, Frost W, Humphries M

While we know much about how neural circuits can generate specific movements, very little is known about how they generate and transition between multiple motor patterns. Here we examine the neural dynamics underlying the transition between classically-defined galloping and crawling in the sea slug Aplysia. Unsupervised analysis of video-tracking data revealed that both forms of rhythmic locomotion are defined by three key parameters: the animal's length, the arching of its foot, and the period of each cycle of muscle contractions driving the movement. These parameters are flexibly controlled to generate the specific mode of locomotion. Indeed, we show that the previously described galloping and crawling are not two distinct behaviours but instead correspond to the ends of a continuum of possible modes of locomotion. To understand the neural dynamics that give rise to this continuum of rhythmic locomotion modes, we imaged the population neural activity of the pedal ganglion using voltage sensitive dyes during fictive escape locomotion for up to 20 minutes. We found that population activity consistently forms a low-dimensional spiral whose parameters independently control each of the three locomotion parameters: the spiral's amplitude controls the animal's length, its orientation of rotation controls the arching of the foot, and its period controls the period of the animal's locomotion cycle. In this way, the continuum of possible locomotion modes emerges from continuous reconfigurations of the population's low-dimensional dynamics. These results suggest that flexible control of low-dimensional neural dynamics are a general principle for specifying and transitioning between multiple motor patterns.

5. Are Brain Oscillations Emergent?

Rajpal H, Mediano PAM, Rosas F, Jensen HJ

Oscillating neural activity has been studied extensively in neuronal populations to the scale of the entire human brain. The different frequency bands are implicated in performing cognitive tasks such as perception and learning [1]. Mechanistically, these oscillations are known to facilitate communication amongst large populations of neurons across the brain. Although it is hypothesized that oscillations emerge from the underlying neural activity, the strength and the nature of this emergent activity remains elusive.

Recent advances in information theory have put forward tools to quantify emergence in time-evolving systems [2]. We use these tools to quantify the emergence of gamma oscillations in Izhikevich neurons connected together in a Pyramidal inter-neuronal gamma (PING) architecture. We find that the emergent oscillatory wave statistically constrains the activity of the connected neurons. We quantify this effect using the information-theoretic measures of downward causation [2]. Furthermore, the effect is significantly positive for the bio-realistic ratio of excitatory-inhibitory (4:1) neurons in the model. The strength of downward causation was found to increase with the number of neurons in the model. Finally we test this measure of downward causation on electrophysiological recordings of neurons in the hippocampus.

1. Başar, E., et al. "Brain oscillations in perception and memory." International journal of psychophysiology 35.2-3 (2000): 95-124.

2. Rosas, Fernando E., et al. "Reconciling emergences: An information-theoretic approach to identify causal emergence in multivariate data." PLoS computational biology 16.12 (2020): e1008289.

6. Training SNNs for speech recognition with exact gradients in GeNN

Nowotny T, Knight JC

Inspired by the superior energy efficiency of biological brains, spiking neural networks (SNN) are the target computational paradigm of most emerging neuromorphic hardware. However, training SNNs has remained difficult because gradient descent is problematic due to the non-differentiable nature of spikes. Recently, the Eventprop algorithm [1] was developed to calculate the exact gradient of a loss function on an SNN in a fully event-based manner.

We have implemented Eventprop in the GeNN [2,3] framework and here, we discuss our insights from applying it to learning two speech recognition benchmarks.

GeNN was originally developed for Computational Neuroscience research but its focus on flexibility and its efficient implementation of event-based communication on GPUs allowed us to also implement the Eventprop algorithm. The implementation is highly efficient and up to 12✕ faster than Back-Propagation-Through-Time using Norse [4].

With respect to accuracy of speech recognition, we found that after a minor extension of the formalism, Eventprop reliably calculates the gradient of many loss functions but learning success depends strongly on the choice of loss function and additional mechanisms from the machine learning toolbox. In the best case, we achieved close to state-of-the-art 91.8% test accuracy on the "Spiking Heidelberg Digits" benchmark [5] and 75.2% on "Spiking Speech Commands" [6].

Taken together, our results confirm the promise of Eventprop but also demonstrate that additional aspects need to be optimised, including loss function, regularisation, augmentation and network structure.

[1] T.C. Wunderlich, C. Pehle, Sci. Rep. 11(1), p.12829, 2021

[2] E. Yavuz et al., Sci. Rep., 6(1), 18854, 2016

[3] J.C. Knight et al., Front. Neuroinf. 15, 2021

[4] C. Pehle, J.E. Pedersen https://github.com/norse/norse, 2021

[5] B. Cramer et al. IEEE TNNLS, 33(7), p.2744, 2020

[6] P. Warden, arXiv:1804.03209, 2018

7. Diving into space: emerging and disappearing shared dimensions in neuronal activity under the influence of psychedelics.

Goldschmitt D, Dearnley B, Howarth C, Berwick J, Su L, Okun M

Psychedelics (5-HT2A agonists) show great promise in treating mental disorders but their effects on neuronal population activity are not clear. Latent dimensions identified by Principal Component Analysis (PCA) capture the dynamics of this interrelated neuronal population activity. We asked whether latent dimensions emerge or disappear as a result of psychedelic administration (acute), and across other naturally occurring brain state transitions (sleep, arousal).

Contrastive PCA (cPCA) [Abid et al. (2018), Nature Comm.] was applied to spontaneous brain activity recordings in rodents before vs. after drinking a psychedelic (Neuropixels, mPFC), wakefulness vs. non-REM sleep (Ephys silicon probe, V1), and low vs. high arousal (2-photon calcium imaging, V1). We identified directions that explain considerably more variance in one brain state (target) than in the other state (background), i.e. dimensions present after drug administration but not before (emerging dimensions), or vice versa (disappearing dimensions). Contrastive directions were computed by conducting the eigenvalue decomposition on the difference between background and target covariance matrices with contrastive parameter α ($\Sigma_{diff} = \Sigma_t - \alpha \times \Sigma_b$). We analysed the variance explained by the first contrastive components in target and background data, for the entire spectrum of α.

We found robust contrastive dimensions of neuronal population activity across different brain state transitions, recording methodologies, and brain areas. However, contrastive dimensions did not explain a large amount of variance in one brain state (e.g. on par with principal component 1) and little variance in the other state (e.g. on par with a random direction) and were merely up/downregulated. These shared dimensions could emerge or disappear. After psychedelic administration, more shared dimensions disappeared, which might indicate less connectedness and information flow in the acute psychedelic state.

8. On Temporal Interference Stimulation

Ivanov B, Mandali A, Arvaneh M

Temporal Interference Stimulation (TIS), a novel noninvasive neuromodulation technique, has sparked considerable interest for its ability to stimulate deep brain areas that are typically challenging to reach without invasive procedures. This literature review poster will underscore TIS's safety and tolerability in humans, its efficacy in standard and exciting new variations currently in development.

This review discusses the outcomes of various digital and physical phantom studies and how their findings translate to in-vivo animal models and early human trials. It covers a wide range of TI applications, from breathing restoration in post-opioid overdosed mice to epilepsy treatment, emphasising its therapeutic potential and safety profile.

This poster presents a series of visual summaries to illustrate the scope and impact of TIS research. It starts with the evolution of TIS studies and their working principles. Using graphical examples, it discusses the cutting-edge variations of TIS and its applications. To summarise, this review study provides a detailed analysis of TIS from a computational perspective.

9. Neural Oscillations as a Novel Modulatory Mechanism on Decision Confidence, Speed and Accuracy: A Cortical-Column Decision Modelling Study

Azimi A, Wong-Lin KF.

Coherent oscillations across various frequency bands are hypothesised to coordinate neural activity in cognitive tasks, such as decision-making (Samaha et al., 2020). Previous studies (Samaha et al., 2017; Benwell et al., 2017) show that neural oscillations modulate perceptual decision-making and confidence levels without changing sensory detection accuracy in visual discrimination tasks. It remains unclear the computational mechanism that may instantiate these phenomena, and whether neural oscillations can influence other choice behaviour such as decision time. Here, we developed the first three-population cortical-column based decision network model with self-feedback. This model, an extension of Roach et al., 2023, includes two excitatory and one inhibitory neural populations, with inputs to both types of populations. With two cortical columns, we simulated two-alternative decision-making tasks.

We introduced sinusoidal modulation of certain frequency to both cortical columns, simulating brain oscillations. Consistent with Samaha et al., 2017, in-phase sinusoidal modulation at 12 Hz (alpha band) did not affect decision accuracy but reduced decision confidence. Altering frequency and amplitude significantly ($p<0.005$) influenced decision times without affecting accuracy ($p=0.5$), suggesting a novel mechanism beyond standard speed-accuracy trade-off. Interestingly, anti-phase modulations were associated with increased decision confidence, but decreased decision accuracy and decision time ($p < 0.005$). These findings extend across various phase lags. The work suggests that small phase lag oscillations equally modulate competing neural populations to promote higher decision uncertainty yet faster decisions without affecting accuracy. In contrast, more anti-phase like oscillations provide swinging momentum towards choice options, facilitating faster decisions and reducing decision uncertainty, albeit a higher chance of changing minds towards error choices.

10. A unified model of retinotectal map development

James SS, Wilson SP

The axons of retinal ganglion cells form an ordered map of the retina in the optic tectum. Surgical and genetic experiments have revealed several key mechanisms that contribute to retinotectal map development, and computational modelling studies have demonstrated how maps can be shaped by their interactions. Models derived from Sperry's classic chemoaffinity theory can reproduce retinotopy, and Gierer later showed how an extension to include competition between growing axons could also account for a subset of the disordered maps that have resulted from surgical manipulation. Further extensions have each accounted for additional datapoints, but none has been able to explain the full range of maps observed experimentally. Here we present a unified model of retinotectal development, assuming only local interactions between growing axons, which can account for the full range of maps resulting from surgical manipulation. This model extends the 'potential functions' of Gierer's original to describe self-organisation across a 2D cortical sheet, and it represents a coordination of axonal growth by orthogonal pairs of opposing ligand gradients in the tectum and corresponding receptor gradients in the retina. In addition, we present progress towards accounting for the full range of maps that have resulted from genetic manipulation, by incorporating a mechanistic description of receptor ligand interactions.

11. Unsupervised learning of EEG signatures of multisensory processing in Autism and Schizophrenia

Shahraki A * ,Balougias T *, Toumaian M, Smyrnis N , Delis I

Multisensory integration (MSI) is the capacity to combine information from multiple senses, such as vision and audition, leading to improvements in behavioural performance, such as faster responses (Frassinetti et al., 2002). This process can be affected in individuals with developmental or mental disorders (Williams et al., 2010, Ainsworth et al., 2021). In this study, we aimed to characterise the neural correlates of multisensory integration in neurodivergent populations.

A total of 32 controls (CN), 23 Autism Spectrum Disorder (ASD), and 35 Schizophrenia (SZ) individuals were instructed to respond as quickly as possible to Auditory (A), Visual (V), Audio-visual (AV), or no (catch – C) cues while their electroencephalograms (EEG) were recorded (Toumaian et al., 2024). Significant reaction time (RT) effects were observed for both population and sensory condition ($p < 0.01$), with CN displaying the fastest responses, followed by ASD and SZ. Faster responses in AV condition indicated multisensory benefits for all three populations.

Then, to characterise EEG representations of audiovisual processing, we employed a recent algorithm extending tensor decompositions to uncover higher-dimensional latent structure thus capturing task-relevant covariability in few components across individuals (slice-TCA, Pellegrino, Stein, & Cayco-Gajic, 2024).

We thus identified three main components describing channel covariations: a) A parietal component indicating an AV enhancement 300-500ms post-stimulus, b) a left-lateralised central component representing early auditory processing, which is also amplified in AV for all 3 groups, and c) an occipital component representing audiovisual amplifications of visual representations, which are magnified in the ASD group. Overall, we show that our subspace identification approach extracts spatiotemporal EEG representations that are shared between experimental conditions and populations but can also quantify their differences.

12. The cortical 'tape measure': learning tactile distance estimation using Convolutional Neural Networks

Edmondson LR, Longo MR, Saal HP

Early studies of tactile perception found that perceptual judgments of the distance between two points touching the skin varied between body parts with high tactile innervation and those with lower innervation. Perceptual anisotropies also occur within body regions; for example, estimates across the back of the hand are close to veridical, but along the length of hand, they tend to be underestimated. One proposed reason for these variations is differences in receptive field (RF) size and structure. The well-known conceptual pixel model posits that the skin is represented by cortical representation units or 'pixels', each with its own RF. Distance is calculated by counting non-active pixels between activated ones. However, how the pixel model could be implemented neurally remains unclear.

To address this question, we asked how a neural network, if free to learn receptive fields (RFs), might approach the distance estimation task. We trained a convolutional neural network to calculate the distance between two stimulation points, mimicking the hierarchical processing within the somatosensory pathway through convolutional filters, which act like RFs. Training the model on two-point stimuli of varying distances, we found that the total activation in the final layer correlated with distance estimation values, such that higher activity indicated higher distance estimates. Early convolution layers were involved in denoising and standardising stimulus size differences, while later layers computed the distance. Our study of the learned RFs revealed that both excitation and inhibition were necessary to solve the task. Biases incorporated into the model could be accounted for in the distance computation regardless of orientation or distance of the stimuli, primarily through variations in RFs. This approach provides insights into the mechanisms of tactile distance estimation and the role of receptive field geometry in perceptual tasks.

13. Prior probability biases perceptual choices by modulating the accumulation rate, rather than the baseline, of decision evidence

Diaz JA, Pisauro MA, Delis I, Philiastides, MG

The prior probability of an upcoming stimulus has been shown to influence the formation of perceptual decisions. Computationally these effects have typically been attributed to changes in the starting point (i.e. baseline) of evidence accumulation in sequential sampling models. More recently, it has also been proposed that prior probability might additionally lead to changes in the rate of evidence accumulation. In this study, we introduce a neurally-informed behavioural modelling approach to understand whether prior probability influences the starting point, the rate of evidence accumulation or both. To this end, we employ a well-established visual object categorization task for which two neural components underpinning participants' choices have been characterised using single-trial analysis of the electroencephalogram. These components are reliable measures of trial-by-trial variability in the quality of the relevant decision evidence, which we use to constrain the estimation of a hierarchical drift diffusion model of perceptual choice. We find that, unlike previous computational accounts, constraining the model with the endogenous variability in the relevant decision evidence, results in prior probability effects being explained primarily by changes in the rate of evidence accumulation rather than changes in the starting point or a combination of both. Ultimately, our neurally-informed modelling approach helps disambiguate the mechanistic effect of prior probability on perceptual decision formation, suggesting that prior probability biases primarily the interpretation of sensory evidence towards the most likely stimulus.

14. Bootstrapping the auditory space map via an innate circuit

Chu Yang, Luk Wayne, Goodman Dan

The ability to accurately localize sound sources is crucial for human and other animals. A critical question is: how does the brain calibrate its space map in response to changes to acoustic cues during a lifetime (e.g. in development, aging)? Currently we still lack a comprehensive understanding. Existing models have focused on supervised learning, in which the auditory system is calibrated by exactly matching the feedback signal from the precise visual system. But such cross-sensory calibration is not always feasible. For example, it is unclear how to calibrate if sounds come from directions outside the visual field, or how do congenitally blind people develop equivalent or in some cases superior auditory localization skills. Thus, the questions arise: are there alternative mechanisms beside supervised learning? Can the auditory system efficiently calibrate itself without precise cross-sensory feedback? To address these questions, we propose various self-calibration mechanisms using only simple uni-sensory neural components, such as a circuit composed of ipsilateral excitation and contralateral inhibition that can only distinguish left from right(e.g. circuits for the lateral superior olive). At first glance, it seems unlikely that such a noisy and much less precise circuit can be sufficient to calibrate the needed map. But surprisingly, results show that a precise map can be bootstrapped from that simple circuit alone, without exact external feedback. This finding suggests an unexpected role of innate circuits for self-calibration within the auditory system. It also reveals a broader diversity of potential learning mechanisms than previously assumed. Numerous questions about these mechanisms remain open for future research. Answers to such questions may shed light on general learning mechanisms in sensory systems and help with clinical practices for development and rehabilitation.

15. Fast and slow synaptic plasticity enables concurrent control and learning

Bicknell BA, Latham PE

Natural intelligence is rooted in the ability to adapt on multiple timescales. Indeed, this is critical for survival; animals must be able to form lifelong memories, but also react rapidly to disturbances and maintain stable brain activity. Much of this is driven by synaptic plasticity, which exhibits a comparable range of dynamics. To understand the brain, it is therefore imperative to identify its many interacting plasticity rules. Towards this goal, here we develop a normative theory of synaptic plasticity that explains how the output of a neuron can be optimized through concurrent fast and slow mechanisms. We consider a general task in which a neuron must modify its synapses in order to drive a downstream process to match a time-varying target. By framing synaptic plasticity as a stochastic control problem, we derive a biologically plausible update rule that dramatically outperforms classical gradient-based approaches. In this, fast synaptic weight changes greedily correct downstream errors, while slow synaptic weight changes implement statistically optimal learning. Applied in a cerebellar microcircuit, the theory explains widely observed features of spiking behavior and plasticity, and makes novel experimental predictions.

16. Deep Learning Application to EEG Reveals Sensory Processing Differences in Autism and Schizophrenia.

Nammazi A, Shahraki A, Balougias T, Toumaian M, Smyrnis N, Delis I.

Understanding multisensory processing complexity and its implications for neurodiversity is of significant interest in neuroscience (Li et al., 2022). The emergence of new deep learning (DL) models facilitates the extraction and visualization of neural features (Roy et al., 2019) This aids in the detection of intricate patterns embedded in noise within EEG data, associated with specific populations and/or experimental conditions. Here we harness the power of DL to explore the neural signatures of multi-sensory (Uni-)integration and their differences in individuals with Autism Spectrum Disorder (ASD) and Schizophrenia (SCZ).

We collected EEG data from 23 individuals with ASD, 35 Schizophrenia, and 32 Controls. Participants responded to audio (A), visual (V), and audiovisual (AV) stimuli. To detect sensory processing differences between ASD and schizophrenia, we used Convolutional Neural Networks (CNN) for classification and interpretive feature analysis (Aellen et al., 2021; Lawhern et al., 2016).

We started by comparing EEG responses in the multisensory condition (AV) across the three groups. We found that three populations could be reliably discriminated (77% accuracy for SCZ vs. ASD, 75% for ASD vs. CN, and 70% for SCZ vs. CN). Next, we assessed neural gains from multisensory processing by comparing EEG responses between multisensory (AV) and unisensory (A and V) stimuli within each group. AV to V classification achieved the highest accuracy in CN (62.7%), with similar accuracies in ASD (61.9%) and SCZ (61%). Comparing AV and A stimuli, CN showed 63% accuracy, while ASD and SCZ achieved 62% and 56%, respectively. Overall, our results suggest that CNN applications to EEG data can uncover spatiotemporal components of neural processing that discriminate neurodiverse populations.

In future work, we intend to identify the discriminating EEG features, assess their interpretability, and explore novel visualization techniques to determine potential group variations.

17. Synaptic strength fluctuations from a model of stochastic gene expression in neurons

Senkevich O, Veltz R, O'Donnell C

Recent experimental results suggest that synapses fluctuate in size on time scales of hours-days, even in the absence of electrical activity. Understanding these fluctuations will be critical for understanding how information is stored in the brain. However the source and general properties of these fluctuations are unknown. In this study, we show how such fluctuations can be explained by a simple stochastic model of gene expression in a single neuron that includes gene activation/deactivation, mRNA production/degradation and transport, and protein production/degradation and transport.

We characterised this model both analytically and via detailed numerical simulations and found several interesting phenomena: 1) synaptic protein fluctuations were highly correlated, both spatially – across different neuronal compartments - and across time; 2) there are multiple timescales of fluctuations, with different spatial eigenmodes corresponding to different processes in the model; 3) the apparent magnitude and correlation of the synaptic fluctuations strongly depend on the observation timescale; 4) due to resource sharing, synapses show heterosynaptic plasticity -- plasticity at one synapse causes knock-on plasticity in its dendritic neighbours. Overall, this work provides evidence that stochastic gene expression may be the dominant driver of synaptic strength fluctuations in neurons and makes several concrete predictions for future experiments.

18. Topological maps maximise information while minimising complexity

Mendini N, Mangan M, Wilson SP

The primary cortical areas of most mammalian species contain topological feature maps, wherein similar stimulus features are represented by the selective activation of nearby neurons. For example, primary visual cortices typically contain topological maps of visual edge orientation. However, despite the evidence that evolution has favoured topology in most species, we still lack a clear explanation for the possible functional role of map topology. Traditional accounts based on wiring minimisation are incomplete, explaining how topology can reduce metabolic costs, but only after first assuming a functional role of like-tuned connectivity. Here, we suggest that the functional role of topology is to minimise metabolic costs by preserving a high mutual information between a stimulus and its encoding, while minimising the spatial complexity of the neural code. Using simulations of orientation map development, we show that topological maps can be considered optima in the trade-off between the mutual information and the spectral entropy of a neural code. Further, we show that by reducing spatial complexity, topological maps allow wiring costs to be minimised by sparse lateral connectivity, without compromising the encoding. In addition, we show how these trade-offs between efficient coding and efficient wiring can account for species differences in the organisation of cortical feature maps.

19. Brain connectome-based reservoir computing

McAllister J, Wade J, Houghton C, O'Donnell C

Reservoir computing is a computational framework where a fixed recurrent neural network, called the reservoir, is used to process input signals and perform computations. Reservoirs have rich dynamics allowing complex non-linear transformations of the input, but, since learning is restricted to the output layer they do not have the costly, and biologically unrealistic, training associated with deep neural networks. It is not known how the connectivity of reservoir nodes affects task performance (Inubushi et al., 2021; Dale et al., 2021). In particular it is unclear whether reservoirs must be fine-tuned as task-specific, or can be constructed in a task-generic way.

It is possible we can build good specific and multi-task reservoirs using the connectivity of real brains (Damicelli et al., 2022) and advance NeuroAI. We test this using connectomes of C. elegans and drosophila larva mushroom body (Cook et al., 2019; Eichler et al. 2017). We analysed graph theoretic and spectral characteristics of these connectomes and compared the performance of reservoirs with these properties to equivalent randomly-initialised reservoirs. Performance was tested on three conceptually different computational tasks: working memory, perceptual decision making, and chaotic time-series prediction. The working memory task measures the degree to which the reservoir can reproduce sequential random input data after time delay; the perceptual decision making task tests the capacity to process motion data and discern direction; and the time series prediction task measures how long the reservoir can accurately predict the Lorenz system from a given time point. There are significant performance differences between random reservoirs and connectomes, and also between the two connectomes in specific tasks. The performative, structural, and spectral distinctions show how connectivities are related to specific task performances, and highlight qualities that may underlie potential multi-task reservoirs.

20. Machine learning for detecting effector dependent and independent neural signals in perceptual decision-making

Umesh Kumar Naik Mudavath, Abdoreza Asadpour, Shaik Rafi Ahamed, and KongFatt Wong-Lin

In human perceptual decision-making studies, decision neural signals from neuroimaging data are often entangled with effector information associated with motor movement. A recent study using intracranial electroencephalography (iEEG) data (Gherman et al., 2024) revealed effector-independent evidence accumulation dynamics of neural sources in multiple human brain regions. The experiment involved visual discrimination of the direction of random-dot stimuli, and participants responded either with a speeded button press (BP) (N = 24), or vocally (V), after a randomized delay (N = 12). Subsets of iEEG contacts were systematically selected from high-frequency activity (70-170 Hz) based on several hypothesis-driven criteria. Here, we used more objective data-driven machine learning (ML) to identify subsets of iEEG data (N = 10 for each response type). First, we used linear time warping on iEEG data based on individual trial reaction time into 1-second window, averaging over all trials. We then used a novel convolutional autoencoder ML model to extract key time points. Next, we fed these extracted time points to an ensemble ML classifier to evaluate its discriminative performance on V vs BP response across all task difficulties (high or low coherence). Using LightGBM classifier (Guolin Ke et al., 2017) with 5-fold cross-validation, we obtained the highest area under the ROC curve (AUC) of 0.81. Our upcoming work will employ perturbation analysis to identify top-ranked contacts, and ML to identify contacts with effector-independent evidence accumulation and their neural dynamics.

21. Dendritic spine neck as a control mechanism for the rules of synaptic plasticity

Gupta R, O'Donnell C.

Dendritic spines host the majority of glutamatergic excitatory synapses in the brain. A narrow spine neck connects the synapse with its parent dendrite, and acts to biochemically compartmentalise the synapse. However, spine neck shape and molecular makeup is highly heterogeneous and plastic. The functional purpose of this neck heterogeneity is unknown - we propose its role is to regulate the rules of synaptic plasticity. We addressed this problem with data-constrained biophysical computational model of AMPA receptor (AMPAR) trafficking and intracellular signalling of synaptic enzymes Ca^{2+}/calmodulin-dependent kinase II (CaMKII) and calcineurin, in hippocampal CA1 neurons. We first fit the model to reproduce published data on single-synapse long-term potentiation (LTP), then explored the effects of neck morphology and molecular restriction of membrane diffusion. We found that spine neck properties control synaptic LTP by regulating the balance between AMPAR and calcineurin escape from the spine. Surprisingly, our model predicts that LTP is largest for wide and long spine necks. We also modelled activity-dependent neck plasticity. Plastic increases in spine-dendrite coupling reduced LTP by allowing more AMPA receptors to diffuse away from the synapse. Surprisingly, neck plasticity that decreases spine-dendrite coupling can also reduce LTP by trapping calcineurin, which dephosphorylates AMPARs. Further simulations with dynamic spine necks showed the importance of the exact timescale of neck plasticity, relative to AMPAR and enzyme diffusion and phosphorylation dynamics. These results suggest a new mechanistic and experimentally-testable theory for how spine necks regulate synaptic plasticity induction.

22. Simulating single-unit and population responses of plantar cutaneous afferents during balance and gait

Cleland LD, Howe EE, McSweeney LP, Nester C, Hollands K, Reeves J, Strzalkowski NDJ, Bent LR, Saal HP.

The foot sole is the primary interface between the body and environment, carrying information about the surface upon which we are standing or walking on, and contributing to balance maintenance. Existing research into the responses of tactile afferents at the foot sole has focused on low-force stimuli close to threshold. However, such stimuli are not reflective of those experienced by the foot sole during everyday behaviour and current recording techniques do not allow for population responses to dynamic stimuli to be investigated, limiting the generalisability of experimental results to real-world behaviour. To fill this gap, we presented novel stimuli with load profiles comparable to those experienced during gait, with forces of up to 35 N/cm2, and recorded afferent responses using microneurography. Afferent responses to high force stimuli could not be predicted from vibrations alone, with slowly adapting receptors responding strongly to high force data. We used the responses recorded to both low force vibration and high force ramp stimuli to fit a computational model of foot sole cutaneous afferents and simulated tactile responses from a population of afferents across the foot sole to spatiotemporal pressure patterns during balance and gait. Simulated population responses are especially sensitive to changes in pressure experienced by the foot sole, which are experienced frequently when swaying or during the gait cycle. As a consequence, the spatial profile of the population responses, and its peak activity, will not always coincide with the area where pressure is highest on the foot. Combining experimental and computational methods affords the opportunity to provide new-found insight into the combination of single afferent responses to population responses, and thus role that tactile feedback plays during natural behaviours, such as standing balance and gait.

Poster session B (Wednesday 10th)

1. A mechanistic model investigating iTBS Effects and TMS Data in Individuals with Tourette's and Healthy Controls

Angelica Pozzi

Tourette's Syndrome is a common neurological disorder characterized by motor and vocal tics, and it is particularly prevalent among children. Although tic severity often decreases with age, many adults continue to experience significant symptoms. Recent advances have shown that median nerve stimulation can effectively reduce the frequency and severity of tics. Furthermore, studies employing Transcranial Magnetic Stimulation (TMS) have shown significant differences between individuals with Tourette's compared to healthy controls, regarding the mean amplitude and coefficient of variation of motor-evoked potentials in response to stimuli.

The objective of this work is to develop a mechanistic model to explore TMS and Intermittent Theta Burst Stimulation (iTBS) data, aiming to provide new perspectives on these interventions' underlying mechanisms and on neurophysiological differences between Tourette's and healthy individuals.

Our model employs connected binary threshold units to represent the neuronal firing activity of both excitatory and inhibitory neurons. Variability within each subject is accounted for by introducing noise into the firing threshold. We employ a mean-field approach to obtain an expression for the global mean network activity, representing the fraction of firing neurons in the long term, as a function of the input current. Interpreting the normalized motor evoked potential in the experimental data as the proportion of neurons recruited, we fit our model to this data, with changes in the model fit before and after iTBS and between patients and controls providing a potential biomarker to differentiate between the groups.

These findings could provide new perspectives on exploring the neurophysiological characteristics of Tourette's and new insights into the potential effects of iTBS and its implications for neurostimulation strategies.

2. Altered neural population coding of sensory stimuli in early development in a mouse model of Fragile-X Syndrome

Mizusaki BEP, Kourdougli N, Suresh A, Houghton C, Portera-Cailliau C, O'Donnell C

Alterations in sensory processing are a common symptom of neurodevelopmental disorders like Autism Spectrum Disorder (ASD). However, their biological mechanisms are not understood. We studied a mouse model (Fmr1 knock out) of Fragile X Syndrome, the most common single-gene cause of ASD. Neural population activity in layer 2/3 primary somatosensory cortex was imaged in vivo by 2-photon microscopy of GCaMP6s in lightly anaesthetised animals. Neuronal development was monitored through longitudinal recordings first at P14 and then P19, book-ending a critical window of development for layer 2/3. As sensory input, mice whiskers were bundled and vibrated at either 5 or 10 Hz. Spontaneous activity in KO mice showed both higher within-individual heterogeneity of neuronal firing rates and higher between-individual heterogeneity of population firing statistics, than WT mice. Using a decoder we found that KO neural activity was harder to distinguish between spontaneous vs stimulus-evoked. It appeared that, during rest, KOs activity was more similar to a stimulated state. This agreed with single cell level coding properties: WT P14 displayed more statistically significant stimulus-responsive neurons than KO. However, at a population level WT mice at P14 showed greater trial-to-trial noise covariance, specifically in the directions of separation between two different stimuli (5 Hz and 10 Hz), relative to KO P14 and WT P19. These stimulus-aligned noise correlations dropped with age from P14 to P19 for WT but were unseen in KO animals even at P14. Overall, our results suggest an altered developmental trajectory of cortical neural population coding in Fragile-X model mice: refinement of stimulus representations is either 1) reduced, or 2) shifted earlier in development.

3. Neural manifold discovery via dynamical systems

Pellegrino A, Cornacchia I, Chadwick A

Recent studies have proposed that neural circuits have a task manifold: i.e., a subset of the neural state-space to which neural activity is confined as an animal performs a task. Thus, discovering and characterising these manifolds and their associated dynamics from experimental data can shed light on the neural computations unfolding within the brain during various cognitive tasks. Yet, common manifold discovery methods often do not take into account that neural data is generated by an underlying dynamical system. To address this, we first mathematically derive a general class of manifolds that neural dynamics can implement. Building on these results, we introduce a dynamical systems-based dimensionality reduction method for neural population data: Manifold Discovery via Dynamical Systems (MDDS).

To illustrate the usefulness of our method, we apply MDDS to two large-scale neural datasets. First, on electrophysiological population recordings of the macaque motor and premotor cortex during a reach task, we show that MDDS uncovers a manifold with task-relevant geometry, such that trajectories within this manifold were strongly correlated with the behaviour without the need to perform any decoding. Second, on two-photon imaging of the visual cortex during perceptual learning, we show that MDDS can be used to disentangle variability in the data due to changes in manifold geometry as a result of learning from variability due to the task condition within a fixed manifold. Finally, we validate our results by applying our method to data generated from RNN models of those tasks. Overall, our framework offers a link between the geometric and dynamical perspectives on population activity, and provides a generative model to uncover task manifolds from neural data.

4. Adversarial-inspired autoencoder framework for salient sensory feature extraction

Horvathova G, Goodman DFM

The natural world is full of noise, but the brain's capacity for information transmission is severely limited. Therefore, discarding irrelevant information contained in sensory inputs while retaining salient features that are related to the input label, is key to survival. What are the salient features? And what are the underlying feature selection mechanisms?

It is thought that the brain may implement information bottlenecks, which aim to optimise the trade-off between compression and preservation of salient information. However, information bottlenecks are notoriously difficult to implement due to the intractability of mutual information in high dimensions. In recent years, progress has been made by framing the estimation of mutual information as a minmax optimisation problem in an adversarial setting. Building on this, we propose a novel adversarial-inspired autoencoder framework, the objective of which is to compress data such that it can be accurately classified but cannot be fully reconstructed.

We validated the efficiency of the framework on coloured MNIST digits and the CIFAR10 dataset, and our results show that it learns to discard irrelevant information, such as colour, while retaining salient information tied to the semantic label of the image. Additionally, the framework appears to perform figure-ground separation without explicit training, suggesting that it may mimic salient feature extraction in the early visual pathway.

Our findings suggest the framework may find potential use in generating new, testable hypotheses about the salient features underlying noise-robust sensory information processing.

5. Towards Reliable Spike Sorting: Interpretable Automated Curation for Spike Sorting Outputs

Greene R, Hennig M

Modern extracellular probes can capture precise activity of thousands of neurons in the brain simultaneously. While this offers exciting opportunities to understand the neural mechanisms underpinning cognitive processes in health and disease, the analysis of the resulting data sets is challenging. Specifically, for many applications it is desirable to obtain the precise spiking activity of single neurons. This requires de-mixing of signals with a process called spike sorting. Numerous algorithms exist for this purpose, but they all have weaknesses that prevent using their outputs directly without quality control. A common strategy to improve spike sorter outputs is manual curation, which is feasible for small recording devices. Yet this process is subject to operator bias and is unmanageable for more modern devices which produce very large quantities of data. Despite the increasing demand for automated curation methods, few exist. A possible solution is offered by a number of post-hoc computed quality metrics, which aim to indicate how well separated a putative neuron is. Currently however there are no validated guidelines for their use in curation. Here we combine quality metrics and a recently developed consensus-based identification of true positive units to train models to predict unit isolation quality. Unlike previous approaches where manually determined thresholds were used, this method discovers appropriate weights for the metrics from data without need to provide labels. Moreover, the models exploit complementary information provided by the metrics, thus improving predictive power. We demonstrate that the performance of this method is competitive with manual curation by examining simulated datasets from a recent benchmarking study as well as recordings from different systems including tetrodes and Neuropixels arrays. Overall, we show that it is possible to achieve interpretable, automated curation using quality metrics using simple, interpretable models.

6. Neuromodulation of the mediodorsal nucleus during MRgFUS thalamotomy demonstrates a causal role in reward learning

Gilmour W, Mackenzie G, Barnard I, Macfarlane J, Khan S, Kanodia A, Canty M, Littlechild T, Marshall V, Newman E, Farah J, Radon M, Marcerollo A, Steele D, Gilbertson T

Introduction: Evidence from basic neuroscience increasingly supports a specific role for the Medial Dorsal (MD) thalamic nucleus influencing decisions that guide reward-based learning. As common clinical syndromes of impulsivity, apathy and executive dysfunction can be explained by abnormal reward-learning across multiple clinical groups. Neuromodulation target MD nucleus may represent a potential future therapeutic intervention for disorders of cognitive control.

Methods: Thirty-five patient's undergoing MRgFUS thalamotomy for Essential Tremor targeted at ventral intermediate nucleus (Vim) performed pre-and post-operative (<24 hours) cognitive testing using the 4-armed restless bandit task. Outcome measures of task performance included probability of choosing the most rewarding bandit (Prew) and choice perseveration (Pstay). In 23 patients, post-operative masks of (< 24 hours) oedema extension into the MD nucleus were used to analyse the relationship with cortical functional connectivity and it's influence on decision making.

Results: Post-thalamotomy, patients used a greater proportion of perseverative choices (Pstay) pre:0.67±0.07, post; 0.75±0.0.05, rmANOVA, F = 11.05, p<0.001). Task performance indexed by choices to the best bandit (Prew) was unaffected by thalamotomy (rmANOVA, F = 3.02, p=0.07). Cortical functional connectivity with thalamotomy oedema extension into the MD nucleus predicted the extent to which the thalamotomy increased Pstay in individual patients (rho = 0.64, p=0.001).

Conclusion: MRgFUS thalamotomy can be used as an opportunity to study cognitive thalamic nuclear function. An experimental design for intra-operative thermal neuromodulation is proposed to causally map the different contributions of the thalamic nuclei to cognitive control.

7. Efficiency and reliability in biological neural networks

Egas Santander D, Pokorny C, Ecker A, Lazovskis J, Santoro M, Smith JP, Hess K, Levi R, Reimann MW

Neurons in a neural circuit exhibit astonishing diversity in terms of the numbers and targets of their synaptic connections and the statistics of their spiking activity. We hypothesize that this diversity is the result of an underlying tension in the neural code between reliability – highly correlated activity across trials on the single neuron level – and efficiency – highly uncorrelated activity between neurons within a trial. Specifically, certain architectures of connectivity foster efficient activity while others foster the opposite, i.e., robust activity. Both coexist in a neural circuit, leading to the observed long-tailed and highly diverse distributions of connectivity and activity metrics, and allowing the robust subpopulations to promote the reliability of the network as a whole.

To test this hypothesis we developed a notion of the complexity of the connectivity of a subpopulation and used it to analyze several openly available connectomes, revealing that they all exhibited wide complexity distributions. Using co-registered functional data and simulations of a morphologically detailed network model, we found that low complexity sub-networks were indeed characterized by efficient spiking activity, and high complexity subnetworks by reliable but inefficient activity. Moreover, for neurons in cortical input layers, the focus was on increasing reliability and for output layers on increasing efficiency. To progress from describing correlations to establishing causation, we manipulated the connectivity in a biologically realistic model and showed that complex subnetworks indeed promote the reliability of the network as a whole. Our results improve our understanding of the neural code, demonstrating that the code itself is as diverse as the neuronal connectivity and activity, and must be understood in the context of the efficiency/reliability tradeoff.

8. clODE - a computational library for large-scale, rapid ODE simulation on modest hardware

Byttner W, Fletcher PA, Wedgwood K, Tabak J

We present clODE, a highly-parallel ODE computational library that can build ODE solution databases in seconds, letting researchers rapidly iterate over parameter ranges and model equations. By utilising GPUs and on-the-fly feature computation, the library creates highly memory-efficient representations of ODE solution spaces, letting researchers evaluate millions of parameter vectors, even with modest hardware like consumer laptops and Google Colab. It is cross-platform and runs on Linux, Mac and Windows, lets users write dynamical systems in Python or OpenCL and supports XPPAUT files.

clODE lets users find parameter regions giving rise to particular dynamics and can vary multiple parameters simultaneously to find nonlinear parameter relationships. We illustrate this by showing how nonlinear parameter relationships regulate cytosolic calcium levels in pituitary lactotroph models. We further illustrate how users can select the dynamics that interest them, like particular spiking frequencies, and then find parameters that create those dynamics. The resulting parameters can then be validated against experimental data to build better computational models by rapidly iterating parameter ranges or equations. clODE can even be used to simulate systems in near-real-time to predict the effects of injecting currents in voltage patch-clamped (in-vitro) cells during an ongoing experiment.

9. Application of Non-linear Mixed Effects Modeling in Computational Neuroscience

Linkevicius D, Chadwick A, Stefan MI, Sterratt DC

Neural data is heterogeneous and contains sources of variability beyond experimental control. This inter-subject variability is a significant challenge when fitting models, as it necessitates individual level nuisance variables (random effects) to account for it. We use non-linear mixed effects (NLME) models which are common in other fields (Lee, 2022 Mathematics 10:898), but seldom applied in computational neuroscience, to deal with the nuisance variables.

Pumas.jl and DeepPumas.jl (Rackauskas et al. 2020, bioRxiv, https://doi.org/10.1101/2020.11.28.402297) NLME modeling frameworks allowed us to successfully tackle two computational neuroscience problems. The first problem is evaluation and comparison of published Calmodulin (CaM) models using the temporal response of calcium-sensitive fluorescent dyes in a CaM solution in response to calcium uncaging (Faas et al. 2011, Nat Neurosci 14:301). Here a crucial nuisance variable, the laser uncaging strength, affects subsequent model dynamics and parameter fitting. The second problem is modeling of ion channel data from Rajnish et al. (2019, Front Cell Neurosci 13:358). This dataset contains many nuisance parameters, such as levels of channel expression, temperature and seal strength, which affect the current conducted by ion channels.

We show that the published parameters of 6 different CaM models give a sub-optimal fit (by up to 50%) compared to parameters we found using NLME modeling. We also found that the model with the most degrees of freedom (Byrne et al. 2009, J Comput Neurosci, 27:621) - independent CaM lobes and non-cooperative binding -- fit the data best. Moreover, early results, that include replacement of classical voltage-dependent Hodgkin-Huxley rate functions by neural networks, suggest that NLME modeling can fit ion channel data much better than shown in Rajnish et al. Our results demonstrate that NLME may facilitate finding robust solutions to many modeling problems in computational neuroscience.

10. Overcoming Connectome Reconstruction Challenges with Image-to-Image Translation of Electron Micrographs

Mohinta S, Correia A, Corrales M, Galvez PG, Cardona A

It remains unclear how behaviour and cognition emerge from neuron-neuron interactions. By studying neural wiring diagrams (connectomes), at synapse resolution, we can begin to unravel these fundamental structure-function relationships. However, mapping even a modest nervous system, such as that of a Drosophila larva containing ~10,000 neurons, demands ~10 person-years of manual effort (Winding et al. Science 2023). Automation, therefore, is necessary, albeit fraught with challenges. While recent advances in machine learning (ML)-based neuron segmentation and synapse detection have sped up reconstruction of connectomes from volume Electron Microscopy (vEM), many models fail to generalise to new, unseen vEM due to variability in noise levels, artefacts, or staining techniques. Moreover, creating representative ground-truth to effectively capture the inherent heterogeneity in any new vEM for training these supervised ML models is extremely tedious.

We propose leveraging image-to-image (im2im) translation to bridge the gap (differences stemming from variations in staining and imaging protocols) between training and unseen test vEM data quality, which standard data augmentation, transfer learning or regularisation methods alone fail to overcome. Specifically, we employ generative adversarial networks (CycleGAN, Zhu et al. ICCV 2017) and diffusion models (SynDiff, Ozbey et al. arxiv 2022) adapted for EM. By training state-of-the-art models on diverse synthetic data, we demonstrate that integrating im2im translation with common image preprocessing significantly improves model generalisability on unseen vEM (Adapted Rand Error ~0.05, Precision ~0.95, Recall ~0.94). But solely relying on data augmentation or transfer learning proves insufficient (ARand Error >~0.1, Recall ~0.6-0.89). In summary, our work promises few-shot generalisation to new data with minimal errors even in limited ground-truth availability settings, expediting downstream connectomic-neuroscience research.

11. Learning dynamics in the PFC can be explained by an external controller

Wójcik MJ, Pemberton J, Costa RP

The prefrontal cortex (PFC) exhibits a remarkable capacity to employ two distinct strategies when engaging in cognitive tasks. Upon encountering a novel task, it leverages high-dimensional representations, well positioned for rapid linear decoding. However, with growing task familiarity, the PFC transitions to employing generalisable low-dimensional neural codes. Through a system-level modelling approach, we propose that these two strategies can operate harmoniously at different timescales, ensuring a shift from high-to-low dimensional representations. Specifically, we introduce a controller-based framework in which: (i) on a faster timescale control signals drive recurrent networks to generate task-encoding but relatively unstructured, high-dimensional representations, which is then followed by (ii) a slower optimisation of recurrent connections and consequently more structured, low-dimensional representations. We validate these predictions by analysing PFC neural dynamics at fast and slow learning scales in non-human primates that were trained to learn a complex cognitive task from scratch. In summary, our results suggest a learning-dependent control of prefrontal dynamics via a separate brain-region for high-to-low representational switching. Conceptually, this multi-phase learning approach can be associated to theories of consolidation in the brain, in which task knowledge may be eventually stored in local cortical circuits to improve generalisation and metabolic cost.

12. Representation learning in continuous time with Hebbian plasticity

Reis Aguiar H, Hennig M

The brain computes internal representations by applying highly recurrent dynamics to feed-forward input. Such dynamics may be viewed as analogous to the inference step in latent variables models, where one usually follows the gradient of the latent posterior distribution until a stable state is reached. At the stable state, when this gradient has approximately zero norm, a parameter optimization step can be applied to slightly increase the likelihood of the current sample under the model. Here we suggest that this procedure, which closely matches the expectation-maximization (EM) algorithm, can be implemented in a network with lateral inhibition and Hebbian plasticity, leading such network to learn factorised representations of the input data. For instance, when trained on natural images this network learns an encoding in terms of edges, similar to the one found in the visual cortex. However, in its pure form, this neural EM-like procedure requires carefully timing the plasticity so that it is only applied at the stable state, which precludes the use of ongoing Hebbian synaptic plasticity. Here we show a modification of Hebbian plasticity that allows factorized representation learning without waiting for recurrent dynamics to settle. We achieve this by adding separate dynamics that restrict plasticity events to periods of high postsynaptic activity. Overall, we show how fundamental representation learning capabilities can be achieved in recurrent neuronal networks through biologically plausible mechanisms.

13. Dynamical properties and mechanisms of metastability: a perspective in neuroscience

Rossi Kalel L., Budzinski Roberto C., Medeiros Everton S., Boaretto Bruno R. R., Muller Lyle, Feudel Ulrike

Metastability, characterized by a variability of regimes in time, is a ubiquitous type of neural dynamics. It has been formulated in many different ways in the neuroscience literature, however, which may cause some confusion. In this Perspective, we discuss metastability from the point of view of dynamical systems theory. We extract from the literature a very simple but general definition through the concept of metastable regimes as long-lived but transient epochs of activity with unique dynamical properties. This definition serves as an umbrella term that encompasses formulations from other works, and readily connects to concepts from dynamical systems theory. This allows us to examine general dynamical properties of metastable regimes, propose in a didactic manner several dynamics-based mechanisms that generate them, and discuss a theoretical tool to characterize them quantitatively. This perspective leads to insights that help to address issues debated in the literature and also suggest pathways for future research.

14. Spatiotemporal characterisation of multisensory perceptual learning in the human brain

Birmpas K, Bolam JW, Diaz JA, Jiang Z, Astill SL, Philiastides MG, Delis I

Converging evidence from neuroimaging and theoretical modelling in perceptual decision-making suggests that perceptual learning involves changes in neural signatures across the decision-processing timeline. Here to dissect the constituent processes and test their dependence on the available sensory information, we designed a multisensory two forced-choice learning task. 22 participants categorised noisy visual (V), auditory (A) or audiovisual (AV) stimuli of faces and cars, while undergoing a simultaneous 64-channel Electroencephalography (EEG) recording. To probe effects of learning, the experiment was conducted over three days. Statistical analysis using ANOVA revealed that choice accuracy was lower on the first day of experiments, while reaction times kept decreasing over days. Single-trial multivariate Linear Discriminant Analysis (LDA) of the EEG detected temporally specific components distinguishing the first and last day of the experiment, encoding modality-specific (V, A, AV) and stimulus-specific (face, car) differences in both 'early' (sensory) and 'late' (decision) evidence processing. Importantly, a stimulus and sensory modality-agnostic signal of learning was identified, demonstrating a generalised multimodal enhancement in decision-making. Time-frequency analysis indicated the alpha-band power as a key differentiator across days, even prior to stimulus presentation, implying a difference in attention modulation accompanying perceptual learning. A cognitive modelling approach employing a Hierarchical Drift Diffusion model (HDDM) revealed an increase in the rate of evidence accumulation (drift rate) across all modalities over days. Preliminary findings from a neurally-informed HDDM suggest that day-by-day alpha power modulations were predictive of drift rate increases with learning. Overall, this study proposes a theoretical and experimental framework for interrogating the spatiotemporal dynamics of multisensory learning.

15. Neuromorphic approach to texture representation invariant to scanning speed and contact force

Iskarous MM, Chaudhry Z, Li F, Bello S, Sankar S, Thakor NV

Humans have an exquisite sense of touch which robotic and prosthetic systems aim to recreate. We developed algorithms to create neuron-like spiking representations of texture that are invariant to the scanning speed and contact force applied in the sensing process. The spiking representations are based on mimicking activity from slowly adapting and rapidly adapting mechanoreceptors in human skin and further processing up to the brain. The neuromorphic encoding process transforms analog sensor readings into speed and force invariant spiking representations in three sequential stages: the force invariance module (in the analog domain), the spiking activity encoding module (from analog to spiking domain), and the speed invariance module (in the spiking domain). The force invariance module and the spiking activity encoding module together create a force invariant spiking representation of texture to match biological recordings in nerve fibers. The addition of the speed invariance module creates a force and speed invariant spiking of representation of texture to match biological recordings in the cortex.

A set of sixteen textures is applied to a 3x3x2 tactile sensor array with fifteen speed-force combinations. The texture set was explicitly designed to confound with the force and speed conditions. An offline texture classification system built on the invariant representations improve accuracy and computational efficiency across texture exploration conditions. Beyond this, the invariant representations also enable the successful identification of texture in novel speed-force conditions. Finally, the speed invariance algorithm was adapted to and improved the accuracy of a real-time human-operated texture classification system. The results demonstrate that biologically inspired invariant representations enable better performing neurorobotic tactile sensing systems and in the future can be used as the basis for naturalistic sensory feedback for upper limb amputees.

16. Supramodal decision formation network identified in parietal and frontal lobes

Asadpour A, Steinemann N, Kalou K, Kelly SP, O'Connell RG, Wong-Lin KF

Perceptual decision-making involves a sequence of sensory information processing, decision formation via temporal accumulation of evidence, and if instructed, motor execution (Shadlen & Kiani, 2013). Prior studies have identified distributed neural networks activated during perceptual decision-making and have sought to distinguish brain regions dedicated to the aforementioned stages. Non-invasive human brain recording studies have identified brain signals that appear to trace evidence accumulation abstracted from the specific sensory or motor requirements of a choice (O’Connell & Kelly, 2021). However, the brain regions that generate such signals have yet to be identified. In this study, we sought to comprehensively map brain regions exhibiting supramodal activation during decision-making using functional Magnetic Resonance Imaging data and a task paradigm in which sensory and motor requirements were independently manipulated across blocks. The detection tasks involved alternations of visual contrast or audio volume changes from a baseline while we varied the need for immediate versus delayed choice reports. We acquired EEG and fMRI data across separate recording sessions.

Consistent with prior research, our preliminary results of event-related potential data from 28 participants found a centro-parietal positivity (CPP) profile with reduced average amplitude and slower mean reaction times when contrast or volume decreased. Conjunction analysis of the fMRI data in 41 participants (due to varying data availability) using SPM12 (Penny et al., 2011) revealed common brain regions in the parietal and frontal lobes and cerebellum across all tasks. These findings indicate the presence of a network for a supramodal signal abstracted from sensory encoding and motor execution. In a second step, we are exploring which of the identified activations are credible generators of the evidence accumulation signals observed in scalp EEG via fMRI-informed EEG source reconstruction.

17. Dissecting muscle synergies in the task space

O'Reilly D, Shaw W, Hilt P, de Castro Aguiar R, Astill SL, Delis I

The synergy concept is a pervasive phenomenon describing the interactions underpinning the self-organisation of living systems. The muscle synergy approach applies this concept to the problem of coordinating the many degrees-of-freedom of the human body. It suggests that the motor system is organised into functional modules comprised of muscles 'working together' towards common objectives. However, recent work has added nuance to this idea, showing how muscles can work together towards functionally different and independent task-goals also, representing crucial attributes of flexible motor behaviour. Here we probed this proposed functional neural architecture by building upon an established theoretical framework to characterise distinct types of muscle interactions, i.e. functionally similar (redundant), -complementary (synergistic), and -independent (unique), across scales.

Building on current approaches and our recent work, we introduced the Partial Information Decomposition (PID) approach to the motor control field. We integrated this approach into our framework, leveraging various statistical tools to extract low-dimensional motor components from movement data.

In applying this novel PID approach to large-scale muscle activations, we unveiled complex networks of inter- and intra-muscular interactions with distinct functional roles as well as independent muscle contributions to task performance. We showcased the approach's effectiveness by extracting hierarchical and functionally diverse motor components that were a) generalisable across participants and tasks and b) predictive of balance performance across trials and of differences in motor variability between young and older adults.

In aligning muscle synergy analysis with the forefront of understanding on human movement modularity, our findings suggest the proposed methodology can offer novel biological insights into the neural control of movement and research opportunities towards practical applications.

18. What Are Autapses Good for?

Toutounji H

An autapse is a synapse connecting the neuron to itself. Previous anatomical studies suggest that Autapses in pyramidal cells are rare, irrelevant errors in neuronal wiring. However, a recent electrophysiological study challenges showed that autapses are a common phenomenon in layer 5 pyramidal cells of the prefrontal cortex that are also functionally relevant to neural computation [1]. The study observed that autapses enhance bursting, which may suggest a role in boosting neural information transmission. In contrast, a study on aplysia demonstrated that motor-neuron autapses facilitate persistent activity in the absence of strong input [2].

To reconcile these disparate experimental observations, I augmented a simple, spiking neural model with autaptic excitation. Simulations show that for different parameter choices, the presence of an autapse either enhances bursting [1] or leads to persistent activity in absence of strong external excitation [2]. That these results conform to two different experimental observations reflects the nonarbitrary choice of parameters, based on known biophysical properties of the modelled neuron, and shows that the model can capture the neuro-computational properties of functionally specific cell types.

The model also suggests a route to chaos in single neurons. Previous studies discovered biologically implausible parameter regimes where a single neuron model is chaotic [3]. I show that staying within biologically plausible parameters, adding a delay to the autaptic current as it arrives to the soma, and applying a strong stimulation current give rise to chaos. This suggests delayed autaptic pyramidal cells may provide another source for neural variability, expanding the dynamic range of these neurons and allowing for complex neural computations.

[1] Yin L et al. (2018). Nat Commun, 9(4890).

[2] Saada R et al. (2009). Curr Biol, 19(6), 479–484.

[3] Nobukawa S et al. (2017). Sci Rep, 7(1331).

19. Recurrence in temporal multisensory processing

Anil, Swathi; Ghosh, Marcus; Goodman, Daniel F M

Animals continuously process information from multiple sensory modalities to assess their environment and guide their behaviour. For instance, a predator may use both visual and auditory cues to track its prey. To date, numerous algorithms have been developed to describe multisensory processing, including linear and nonlinear fusion. However, these algorithms treat each time step independently, and so fail to account for temporal dependencies in these signals. To address this limitation, we present a novel set of multisensory tasks that systematically introduce controlled temporal dependencies across streams of sensory signals, thereby making them more naturalistic. Our findings reveal that conventional multisensory algorithms, which do not consider temporal dependencies, perform sub-optimally on these tasks. However, these algorithms approach near-optimal performance when adapted to integrate evidence across both sensory channels and time. Furthermore, we demonstrate that recurrent artificial neural networks (RNNs) outperform algorithmic models, highlighting the importance of recurrent connections and temporal dependencies in multisensory processing. In summary, our study explores the advantages of integrating multisensory information across both channels and time and presents novel, naturalistic tasks for evaluating the significance of these processes in biological systems.

20. An attractor decision network model accounts for sequential sampling from memory in nonhuman primates

Lenfesty BL, Bhattacharyya SB, Wong-Lin KF

Perceptual decision-making tasks often involve sensory-to-motor transformation, which may not readily allow neurons encoding sensory information to be unyoked from effector-based neurons. A visual motion discrimination study on non-human primates (Shushruth et al., 2022) found neurons in the lateral intraparietal cortex (LIP) to exhibit delayed evidence-based neuronal responses, only activated upon choice target onset (for action selection/planning) after motion stimulus offset – akin to effector-like neurons yet encoding choice evidence. The LIP neurons were suggested to have recalled earlier sensory evidence from memory, but its neural mechanism remains unknown.

Here, we extended a previous mean-field attractor decision model (Wong and Wang, 2006) to allow for integration of sensory information from memory. One group of neuronal populations encodes and store sensory evidence for recall, while continuously influencing another group of effector-based neuronal populations, which were substantially activated upon cue onset for action selection/planning. The model's nonlinear nature allowed this cue to behave as a gate in activating effector-based neural populations. The latter recapitulated observed LIP neuronal activity profiles and the model produced similar choice behaviour. Crucially, the model shows the potential interplay of neural dynamics with populations that encode sensory evidence during stimulus in the absence of knowledge of motor movement, then recalling evidence via persistent neural activities.

Overall, the findings offer insight on how neurons may integrate, store, and recall information in a dynamic neural circuit, informing how sensory evidence accumulation occurs during sequential sampling from memory.

21. A mean field model for beta bursts and non-averaged neural data

Skelly B, Ross J, Byrne Á, Coombes S

Classically, neural oscillations were believed to be sustained oscillations that varied in amplitude over time due to certain tasks being performed. However, this picture was formed from trial averaged data. More recent studies investigating non-averaged data show that beta oscillations occur in so-called 'bursts,' which are transient spikes in power in the beta frequency range, rather than sustained oscillations. It has also been shown that the characteristics of these bursts vary between Parkinson's patients and healthy controls. In particular, the burst power is increased, the burst rate is reduced and the burst duration is increased in patients with Parkinson's disease (PD).

In this work, we employ a next generation neural mass model to generate bursting beta activity and study the characteristics of these bursts. By posing the model close to a Hopf bifurcation and driving it with noise, the model produces brief bursts of beta activity, as seen in real non-averaged EEG and MEG data. We use a hidden Markov model to detect the beta bursts and build a Genetic Algorithm to optimise the model parameters to fit the characteristic burst statistics of the real MEG bursting data .

Next, we perform a thorough parameter investigation to understand how the parameters and their associated mechanisms affect the burst characteristics. Using these findings, we hope to identify parameter manipulations that result in increased beta power, reduced burst rate, and increased burst durations, and as such identify potential mechanisms disrupted in PD. These results may help identify biomarkers of PD, aiding in the assessment and treatment of patients with the disease.