TEX2023: Efficient coding and processing for perception and action

Report of Contributions

Contribution ID: **4** Type: **Long talk**

Understanding the influences of context on efficient sensory coding

Thursday, July 6, 2023 2:15 PM (50 minutes)

Neural representations of sensory stimuli are modulated by a variety of contextual factors, such as information on other stimuli present in the environment, the novelty or familiarity of the sensory inputs, and behavioral goals. Despite decades of attention in systems neuroscience, many questions persist regarding how sensory codes adapt to these different variables. Here, we study this problem in the olfactory system, which combines the advantages of being highly compact, allowing us to develop solvable theoretical models, and highly conserved, allowing us to derive general principles that are testable in relatively simple animal models (such as the locust or the fly) but are widely applicable across animal species, from insects to vertebrates. We use an approach based on the information-theoretic premise that optimal codes strive to maximize the overall entropy (decodability) of neural representations while minimizing neural costs. A novel feature of our theory is that it incorporates contextual feedback: this allows us to predict how optimal odor representations are modulated by top-down signals that represent the overall multi-sensory environment. Our predictions include adaptation to familiar stimuli, background suppression, novelty detection, olfactory illusions, contrast enhancement and pattern separation, and the amplification or reversal of these effects based on different odor-context associations. We also show that emerging optimal solutions can be implemented at the level of neural circuits through neuroplasticity. This result reconnects our theoretical findings to biologically plausible processes, thus bridging normative and mechanistic levels of analysis Our theory is biologically interpretable, is generalizable to other sensory systems and establishes a conceptual foundation for studying sensory coding associated with behavior.

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Presenter: TAVONI, Gaia (Washington University in St. Louis)

Session Classification: Invited talk

Contribution ID: **5** Type: **Short talk**

Adaptation of rats to a volatile hidden Markov model for reward collection

Tuesday, July 4, 2023 3:10 PM (30 minutes)

In an environment where sensory evidence indicates reward location, while a non-sensory, hidden probabilistic structure simultaneously imposes reward location likelihood, how will the two information channels interact in the brain? We developed a two-alternative forced-choice foraging task, where matching the probabilistic environment promotes reward collection. Rats initiate each trial at a central nose-poke. Then they withdraw and select the right or left reward spout based on the estimated likelihood of a reward being on that side. We manipulated the probability (p) of the baited side on trial n being the same as on trial n-1, following a Markov model with two states (right/left). Informed gambling can optimize gains. Two conditions, p=0.8 and p=0.2, were tested in separate daily sessions. Rats learned to align their left/right transition likelihood according to p. To maximize rewards, rats developed a "win-stick lose-switch"strategy for p=0.8 and the opposite strategy, "win-switch lose-stick", for p=0.2. While the after-win behavior was fully optimal ("win-stick"for p=0.8 and "win-switch"for p=0.2), the after-lose behavior was less consistent, suggesting that rewarded trials provided stronger confirmation of strategy than did non-rewarded trials. Reaction times provided evidence of the subjects'awareness of the correct strategy: in both conditions, rats were faster –commonly taken as a sign of confidence –when they responded by employing the optimal strategy. When p is changed within a testing session, the rats flexibly adapt. Combining this foraging task with an overlapping perceptual task will shed light on the merging of congruent or incongruent forces in decision making.

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Presenter: RAVERA, Maria (SISSA)

Session Classification: Short talk

Contribution ID: **7** Type: **Long talk**

A theory of adaptive sensory coding in dynamic environments

Wednesday, July 5, 2023 12:00 PM (50 minutes)

Our thinking about sensory systems has been shaped by two dominant theoretical frameworks: probabilistic inference and efficient coding. Probabilistic inference specifies optimal strategies for learning about relevant properties of the environment from local and ambiguous sensory signals. Efficient coding provides a normative approach to study encoding of natural stimuli in resource-constrained sensory systems. By emphasising different aspects of information processing they provide complementary approaches to study sensory computations. In this talk, I will discuss our attempts to bring them together by identifying general principles that underlie the resource-efficient sensory coding for accurate perceptual inferences in changing environments. This synthesis enables us to build theories of neural coding in dynamic scenarios, where sensory systems have to continuously infer the changes of the relevant properties of the world. I'll demonstrate how our theory can account for attentional dynamics in the visual cortex and identify fundamental trade-offs in efficient sensory adaptation. Towards the end, I'll take a step back and discuss briefly how can we rigorously compare predictions of normative theories to complex experimental data.

Presenter: MLYNARSKI, Wiktor (IST / LMU Muenchen)

Session Classification: Invited talk

Contribution ID: **8** Type: **Long talk**

Biologically plausible solutions for spiking networks with efficient coding

Tuesday, July 4, 2023 11:00 AM (50 minutes)

Understanding how the dynamics of neural networks is shaped by the computations they perform is a fundamental question in neuroscience. Recently, the framework of efficient coding proposed a theory of how spiking neural networks can compute low-dimensional stimulus signals with high efficiency. Efficient spiking networks are based on time-dependent minimization of a loss function related to information coding with spikes. To inform the understanding of the function and dynamics of biological networks in the brain, however, the mathematical models have to be informed by biology and obey the same constraints as biological networks. Currently, spiking network models of efficient coding have been extended to include some features of biological plausibility, such as architectures with excitatory and inhibitory neurons. However, biological realism of efficient coding theories is still limited to simple cases and does not include single neuron and network properties that are known to be key in biological circuits. Here, we revisit the theory of efficient coding with spikes to develop spiking neural networks that are closer to biological circuits. Namely, we find a biologically plausible spiking model realizing efficient coding in the case of a generalized leaky integrate-and- fire network with excitatory and inhibitory units, equipped with fast and slow synaptic currents, local homeostatic currents such as spike-triggered adaptation, hyperpolarization-activated rebound current, heterogeneous firing thresholds and resets, heterogeneous postsynaptic potentials, and structured, low-rank connectivity. We show how the complexity of E-E connectivity matrix shapes network responses.

Presenter: KOREN, Veronika

Session Classification: Invited talk

Contribution ID: **9** Type: **Long talk**

Contextual modulation of communication processing in bats

Thursday, July 6, 2023 11:50 AM (50 minutes)

Bats are auditory specialists, processing acoustic signals to guide their behaviors, including prey tracking, navigation and communication. In this talk I will provide a brief overview of my previous work related to how bats analyze and process signals for action-selection; and I will focus on communication signals, the line of research of my current lab. There is strong evidence that context plays a role in the processing of acoustic signals. Yet, the circuits and mechanisms that govern this process are still not fully understood. Bats emit a wide array of communication calls, including food claiming calls, aggressive calls and appeasement calls. Previously, we showed that there are selective neurons for communication and echolocation calls in the inferior colliculus (IC) of bats passively listening to sound playbacks. Now, we developed a novel competitive foraging task to explore the role of behavioral context in auditory responses to social calls. With this approach, we recorded neural population responses from the IC of freely interacting bats. Our data show that bats spend a significant amount of time engaging in interactive social behaviors and emitting communication calls as
they compete for food. Furthermore, analysis of our neural recordings from the IC show stronger population responses to individual calls during behaviorally aggressive events. These results indicate that behavioral context plays a role in the modulation of neuronal population responses to social vocalizations in the bat IC.

Presenter: SALLES, Angeles

Session Classification: Invited talk

Contribution ID: **10** Type: **Long talk**

Efficient coding of texture images in the mouse visual cortex

Wednesday, July 5, 2023 3:00 PM (50 minutes)

The neural mechanisms underlying natural vision remain poorly understood. Here, we examined the processing of a class of natural images—textures—across mid-level visual areas in the mouse ventral cortical stream. First, we established that mice are capable of perceptually distinguishing between different textures and simpler stimuli matched for spectral content. Then, using GCaMP imaging, we found that the secondary visual area (LM) showed a greater selectivity for the higher-order statistics of textures compared to the primary visual area (V1). We also found that textures were encoded in neural activity subspaces whose relative distances correlated with the statistical complexity of the images and with the mice's ability to discriminate between them. These dependencies were more pronounced in LM, where the texture-related subspaces were more tightly clustered, enabling better stimulus decoding. Our results provide insights into the neural underpinnings of texture vision and demonstrate a link between stimulus statistics, neural representations, and perceptual sensitivity, indicative of efficient coding computations.

Presenter: BENUCCI, Andrea

Session Classification: Invited talk

Contribution ID: **11** Type: **Long talk**

Mapping the world around us: A topology-preserved schema of space that supports goal-directed navigation

Thursday, July 6, 2023 11:00 AM (50 minutes)

Successful goal-directed navigation requires estimating one's current position in the environment, representing the future goal location, and maintaining a map that preserves the topological relationship between positions. In addition, we often need to implement similar navigational strategies in a continuously changing environment, thereby necessitating certain invariance in the underlying spatial maps. Previous research has identified neurons in the hippocampus and parahippocampal cortices that fire specifically when an animal visits a particular location, implying the presence of a spatial map in the brain. However, this map specifically encodes the current position but not the future goal location of an animal and is largely context-dependent, whereby changing the room or shape of the arena results in a new map orthogonal to the previous one. These observations raise the question, are there other spatial mapping systems in the brain that fulfil the cognitive requirements necessary for goal-directed navigation?
Using a goal-directed navigation task in an arena with multiple reward locations, we observed that neurons in the orbitofrontal cortex (OFC) exhibit distinct firing patterns depending on the animal' s goal location, and this goal-specific OFC activity originates even before the onset of the journey. Further, the difference in the ensemble firing patterns representing two target locations is proportional to the distance between these locations in physical space, implying the preservation of spatial topology. Finally, carrying out the task across different spatial contexts revealed that the mapping of target locations in the OFC is largely preserved and that the maps formed in two different contexts occupy similar neural subspaces and could be aligned by a linear transformation. Taken together, the OFC forms a topology-preserved schema of spatial locations that is used to represent the future spatial goal. Our results point to the OFC as a potentially crucial brain region for planning context-invariant goal-directed navigational strategies.

Presenter: BASU, Raunak

Session Classification: Invited talk

Contribution ID: **12** Type: **Long talk**

Principles of representation learning in deep sensory networks

Tuesday, July 4, 2023 9:40 AM (50 minutes)

Discriminating distinct objects and concepts from sensory stimuli is essential for survival. Our brains perform this processing in deep sensory networks shaped through plasticity. However, our understanding of the underlying plasticity mechanisms is still limited. First, I will present recent work on Latent Predictive Learning (LPL), a plausible normative theory of representation learning based on predicting future sensory inputs. I will show that LPL allows sensory networks to disentangle object representations while accounting for essential plasticity experiments.
Second, I will discuss recent ideas on how biological neural networks could solve the credit assignment problem, thereby improving representation learning in deep biological networks.

Presenter: ZENKE, Friedemann

Session Classification: Invited talk

Contribution ID: **13** Type: **Long talk**

The unreasonable recalcitrance of human vision to theoretical domestication

Wednesday, July 5, 2023 2:10 PM (50 minutes)

We can view cortex from two fundamentally different perspectives: a powerful device for performing optimal inference, or an assembly of biological components not built for achieving statistical optimality. The former approach is attractive thanks to its elegance and potentially wide applicability, however the basic facts of human pattern vision do not support it. Instead, they indicate that the idiosyncratic behaviour produced by visual cortex is largely dictated by its hardware components. The output of these components can be steered towards optimality by our cognitive apparatus, but only to a marginal extent. We conclude that current theories of visually-guided behaviour are at best inadequate, and we turn to neural networks in an attempt to establish whether the idiosyncratic character of human vision may be learnt from a larger repertoire of functional constraints, such as the statistics of the natural environment. We challenge deep convolutional networks with the same stimuli/tasks used with human observers and apply equivalent characterization of the stimulus–response coupling. For shallow depth of behavioural characterization, some variants of network-architecture/training-protocol produce human-like trends; however, more articulate empirical descriptors expose glaring discrepancies. Our results urge caution in assessing whether neural networks do or do not capture human behavior: ultimately, our ability to assess "success"in this area can only be as good as afforded by the depth of behavioral characterization against which the network is evaluated. More generally, our results provide a compelling demonstration of how far we still are from securing an adequate computational account of even the most basic operations carried out by human vision.

Presenter: NERI, Peter

Session Classification: Invited talk

Contribution ID: **14** Type: **Long talk**

Optimal coding of offer values in orbitofrontal cortex: Theoretical predictions and experimental tests

Thursday, July 6, 2023 10:00 AM (50 minutes)

A binary economic choice entails the computation and comparison of two offer values. When monkeys chose between different goods, two groups of neurons in orbitofrontal cortex (OFC) encode the two offer values. Importantly, experiments using electrical stimulation demonstrated a causal relationship between the activity of offer value cells and choices. Given a value range, the tuning curves of offer value cells are quasi-linear and independent of the distribution of the offers. The gain of the tuning curves (i.e., the slope of the encoding) is inversely proportional to the value range (range adaptation). In previous work, we developed a theory of optimal coding for offer values (Rustichini et al, 2017). The central concept is that the encoding of offer values is optimal if tuning curves ensure maximal expected payoff (i.e., maximum chosen value). The theory is based on a linear decision model, where choices are determined by the difference between the activity of the two groups of offer value cells. The theory indicates that quasi-linear tuning curves are optimal only if the two value ranges are equal and the joint distribution of offer values is uniform within the relevant domain of offers. (Since this condition is not satisfied in our experiments, quasi-linearity can be viewed as an inflexible trait of the tuning functions, presumably advantageous in an evolutionary perspective.) The theory also demonstrates that, for linear tuning curves, range adaptation ensures maximal expected payoff. Finally, indicating with A and B the two offered goods, with ΔVA and ΔVB the two value ranges, and with JA and JB the efficacy of synapses for which offer value A and offer value B cells are pre-synaptic, the theory predicts the relation JA/JB = ΔVA/ΔVB. We have now generalized this prediction for a decision model that (a) includes the other groups of neurons identified in OFC (encoding the chosen good and the chosen value) and (b) is fully connected. We have also tested the prediction using estimates for the synaptic efficacies derived from network inference analysis (Ising model) applied to populations of 20-120 neurons recorded simultaneously. Preliminary results based on a limited data set support the theoretical prediction. This finding validates the theory and supports the understanding that offer value cells in OFC are optimally tuned for economic choices.

Presenter: PADOA-SCHIOPPA, Camillo

Session Classification: Invited talk

Contribution ID: **15** Type: **Long talk**

From Bayesian neural networks to noise and inference in the brain

Tuesday, July 4, 2023 11:50 AM (50 minutes)

In this talk, I will discuss recent results in Bayesian deep learning and how they may provide a new theoretical perspective that unifies several seemingly distinct functional interpretations for the role of noise in the brain. Specifically, I will show how: (a) multiplicative noise in neural network units; (b) Bayesian inference over neural network parameters; (c) "data augmentation"; (d) robustness of the network to structured input corruptions; (e) ability to generalize to different settings – are all near-equivalent properties in (artificial) deep neural networks. In other words, noise in neural networks can simultaneously take multiple functional roles which yield increased robustness, data efficiency and generalization, all desirable properties for biological networks as well. Key points open for discussion with the audience are whether and how this proposed unified perspective can lead to actionable empirical insights and improve our understanding of information processing in the brain. The talk will build upon results from this Bayesian deep learning paper, adapted for a neuroscience audience: https://aaltopml.github.io/node-BNN-covariate-shift/

Presenter: ACERBI, Luigi

Session Classification: Invited talk

Contribution ID: **16** Type: **Long talk**

A Model of Generative Episodic Memory and its Function

Wednesday, July 5, 2023 10:00 AM (50 minutes)

Many studies have suggested that episodic memory is a generative process, but most computational models adopt a storage view. In this talk, I will first present a system level model of generative episodic memory, in which incomplete memory traces are completed by semantic information [1]. It is based on standard machine learning components, like a vector-quantized variational autoencoder (QV-VAE) and a pixel convolutional neural network (PixelCNN). The model shows similar trade-offs between attention and semantic consistency as found in psychological experiments in an episodic memory task. In a second part, I will focus on the functional role of episodic memory, because just remembering the past has little evolutionary relevance. We show that episodic memory can accelerate spatial learning in a reinforcement setting through one-shot learning and replay learning.

[1] Fayyaz, Z.; Altamimi, A.; Zoellner, C.; Klein, N.; Wolf, O. T.; Cheng, S. & Wiskott, L. A Model of Semantic Completion in Generative Episodic Memory. Neural Computation, 2022, 34, 1841–1870, https://direct.mit.edu/neco/article/34/9/1841/112383/A-Model-of-Semantic-Completion-in-Generative
[2] Zeng, X.; Diekmann, N.; Wiskott, L. & Cheng, S. Modeling the function of episodic memory in spatial learning. Frontiers in Psychology, 2023, 14, https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1160648/full

Presenter: WISKOTT, Laurenz

Session Classification: Invited talk

Contribution ID: **17** Type: **Short talk**

Are CNNs A Good Model for the rodent visual ventral stream?

Tuesday, July 4, 2023 2:35 PM (20 minutes)

Deep Convolutional Neural Networks (Deep CNNs) are currently unsurpassed as our best models of the object-recognition pathway in the visual stream of macaque monkeys. However, the extent to which these models generalize to the rodent visual ventral stream is disputed. In this talk I will recap recent attempts at using CNNs to model the rat ventral stream and present a novel, ecologically-grounded, comparison. I will stress that in the data-restricted regime of neuroscience, realistic image preprocessing is critical for meaningful comparisons and leads to the following insights: (1) mid-to-late layers in these hierarchical architectures offer the best match for several rat behaviors, (2) probing the visual strategy reveals how rats exploit visual strategies that are superior in terms of efficiency of visual clues. Finally, these findings highlight the role of CNNs as a common language to compare different biological visual systems.

Primary author: MURATORE, Paolo (SISSA)

Co-author: ZOCCOLAN, Davide

Presenter: MURATORE, Paolo (SISSA)

Session Classification: Short talk