Replay as a basis for backpropagation through time in the brain

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How biological neural networks can learn sequences (e.g., episodic memory) remains a puzzle for the neuroscience community. Brain areas critical for episodic learning (e.g., the hippocampus) are characterized by recurrent connectivity and frequent offline replay events. The function of the replay events remains unknown, with various
proposal for a role in planning or memory consolidation. The recurrent connectivity, computational simulations show, enables sequence learning when combined with a suitable learning algorithm such as Backpropagation through time (BPTT). The original BPTT algorithm is considered biologically implausible. Biologically plausible variants of BPTT have been proposed previously, but those variants use online approximations of BPTT and underperform compared to the original BPTT.
We present a different solution that uses offline-replay to support sequence learning in a recurrent neural network. This new Reversible Recurrent Neural Network (R2N2) model uses two RNNs (a consolidator and a cache) to form a system that learns in both one-shot and statistical manners. R2N2 is biologically plausible in that it uses only locally available information (i.e., no synthetic memory store), attributes a functional significance to hippocampal replay events, and outperforms other biologically plausible variants of BPTT. We demonstrate the functioning of R2N2 using benchmark tests from computer science and simulate the rodent delayed alternation T-maze task.

The coordinated behavior of perception and action is based on the same distorted representation of 3D space.

Fulvio Domini
Brown University

The dual-visual-stream theory of perception and action posits the existence of an accurate vision-for-action system immune to distortions commonly affecting the perceptual system. In this talk I argue that both perception and action are based on the same 3D representation, which in general does not mirror physical reality. Instead of being distinct I propose that perception and action form a coordinated system: Perception informs action about the state of the world and, in turn, action shapes perception by signaling when it is faulty. This integrated approach is quite distinct from most investigations on perception and motor control. On the one hand, while motor errors have been studied extensively in the sensorimotor adaptation field, researchers have overlooked how perception actually affects these errors. Indeed, I'll show that the visual space is systematically distorted and that these distortions clearly surface in our actions. Remarkably the arising motor errors produce motor adjustments on a trial-by-trial basis. On the other hand, studies exploring alterations of visual percepts following visuomotor interactions have neglected the causal role of error signals. Here, I will also show that persisting sensory errors signals cause a modification of 3D perception. In summary, contrary to the dual-visual-stream theory, my approach regards perception and action as two sides of the same coin expressing a currency which is not metric accuracy.

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Deep Learning Models Fail to Capture the Holistic Nature of Human Shape Perception

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Deep convolutional neural networks (DCNNs) trained to classify objects have reached human levels of performance and are predictive of brain response in both human and non-human primates. But do these networks fully capture how the brain recognizes objects? One hallmark of human object perception is sensitivity to the Gestalt (configural organization) of an object's shape. To test whether state-of-the-art DCNN models capture this sensitivity, we created a dataset of animal silhouettes that provide shape but not colour or texture cues and used these to measure both human and DCNN ability to discriminate animal category based upon shape cues alone. To assess sensitivity to Gestalt, we created two variants of these stimuli that disrupt the configuration of the object while preserving local features. We found that while human performance was impacted by this disruption, DCNN performance was not, revealing an insensitivity to object Gestalt. While prior work has suggested that DCNNs can be made more brain-like by training them to upweight shape cues relative to colour and texture cues or by incorporating recurrent or attentional (transformer) computations, we found that none of these interventions led to configural shape perception. Instead, we hypothesize that human sensitivity to Gestalt arises from a broader set of learning objectives beyond recognition.

Ecological factors shape quantitative decision-making in coyotes

Kerry Jordan
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Much research has focused on the development and evolution of cognition in the realm of numerical knowledge in human and non-human animals but often fails to take into account ecological realities that, over time, may influence and constrain cognitive abilities in real-life decision-making. Cognitive abilities such as enumerating and timing are central to many psychological and ecological models of behavior, yet our knowledge of how these are affected by environmental fluctuations remains incomplete. Our research bridges the gap between basic cognitive research and ecological decision-making. We used coyotes (Canis latrans) as a model animal system to study decision-making about quantities in foraging tasks, testing a large number of animals across their four biological seasons to examine effects of ecological factors such as breeding status and environmental risk on quantitative performance. Results show that coyotes, similar to other species, spatially discount food rewards while foraging. The degree to which coyotes are sensitive to the risk of obtaining the larger food reward, however, depended on the season in which they completed the foraging task, the presence of unfamiliar humans, and the presence of conspecifics. Although it is more readily evident that seasonal variations drive many differences in nonhuman animal behavior and cognition (e.g., hibernation, breeding, food resource availability), it may be useful in the future to extend this work to humans; such questions remain relatively unexplored in many realms of enumeration, timing, and spatial thinking.

A rhythmic theory of visuo-selective attention in the primate brain

Sabine Kastner
Princeton University

The selection of information from cluttered sensory environments is one of the most fundamental cognitive operations performed by the primate brain. Classic studies of spatial attention assume that its neural and behavioral effects were continuous over time. In my talk, I will challenge this notion. First, I will present behavioral evidence from humans and non-human primates that spatial attention leads to alternating periods of heightened or diminished perceptual sensitivity, even when sustained at a particular location in the visual field. Second, I will discuss the neural basis of these rhythmic fluctuations showing results from intracranial recordings in human epilepsy patients and non-human primates. A dynamic interplay within the frontoparietal attention network and between frontoparietal cortex and thalamus accounts for the rhythmic properties of spatial attention. We use this evidence to propose a novel model for selective attention that incorporates its rhythmic properties.

The importance of causal inference in multisensory learning

Mike Landy
NYU

In estimation scenarios involving multiple cues, it has often been found that cues are integrated optimally, that is, cue are averaged and more reliable cues are given more weight. However, if the cues derive from separate sources, they should not be integrated. Thus, optimal integration involves a process of causal inference, using the cues themselves to determine the probability they came from a common source. In theory, this inference depends on the measurements, their respective reliabilities, and the prior probability that cue pairs derive from a common source. The inference of a common source will be stronger if the discrepancy between the measurements is small relative to their reliabilities and if the prior probability of a common cause is high. I will describe two experiments using auditory and visual cues to location in which we show that causal inference plays a role in learning. In the first, participants were exposed to a sequence of discrepant cues (e.g., visual displaced to the right of auditory) and we measured the ventriloquist aftereffect: the degree to which unisensory cues were perceived after learning as displaced toward the previously displaced discrepant cue. In the second experiment, participants experienced a session in which either all cue pairs were congruent (intended to increase the probability of a common source) or were all discrepant in space and time (to decrease that probability). In both cases, model comparison indicates the crucial role of causal inference in multisensory learning. In both cases, there were strong, qualitative individual differences as well.

Learning dynamics in visual cortex

Christopher C. Pack
McGill University, Montreal

Much previous research has focused on the relationship between neural activity and perceptual decisions. One principle that emerges from this work is that the brain relies on a fixed, feedforward architecture: Visual stimuli activate specific clusters of neurons in the cortex, and these neurons project to higher-order brain regions responsible for generating the corresponding percept.
In this talk, I will present evidence that this connection between neural activity and perceptual decisions is profoundly shaped by experience. Specifically, I will discuss the well-known correlations between neural activity and perceptual decisions, focusing on areas MT and V4 of non-human primates. I will show that such correlations are not necessarily causal, as chemical inactivation of the same neurons often has no influence on perceptual decisions. More importantly, the causal nature of this interaction can be shaped by training, and this plasticity appears to depend on both feedforward and feedback influences. These influences can change dramatically over the course of extended training regimens, but similar effects can also be observed with rapid learning that occurs more naturally over the course of a few minutes. Overall, these findings indicate that cortical domains with different stimulus selectivity can be wired flexibly into or out of the circuitry that supports perceptual decisions.

Traveling salesman, insight problems and scientific discovery

Zyg Pizlo
UC Irvine

The talk focuses on insightful problem solving and on scientific discovery as the most sophisticated form of insight. I will review several classical insight problems and will offer a conjecture that symmetry of the representation is what is common to all of them. Next, I will describe two phenomena from visual perception, 3D shape reconstruction and figure-ground organization, which also critically depend on symmetry of visual representation. This way, 3D vision can be considered the most elementary, but at the same time, ubiquitous form of insightful problem solving. In the third part of the talk, I will discuss the fundamental role symmetry plays in mathematics and physics including formulation of the Natural Laws. If time allows, I will conclude by describing how humans solve combinatorial optimization problems.

SARS CoV-2, Myocarditis, and the Big Ten Cardiac Registry

Nicholas Port
Indiana University

Beginning in July 2020, collegiate sports medicine departments began to notice high rates of cardiac complications in student athletes who had contracted SARS-CoV-2 and were returning to campus for Fall competitions. Over the next few months this observation transformed into a large cardiac study involving all 13 schools at the Big Ten. Several thousand cardiac MRI's later, the Big Ten Cardiac Registry has become the largest cardiac MRI study in history and is poised to change the field of cardiology forever. It has also garnered plenty of controversy.

Clinical Perspectives on Neuro-Ophthalmic Emergencies

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Two neuro-ophthalmic emergencies are presented as case reports to examine how the current neuro-ophthalmic literature can be applied to clinical care in an evidence-based medical decision-making process.

Papilledema is swelling of the optic nerve head due to elevated intracranial pressure. Patients may be asymptomatic, or they may present with one or more of a plethora of symptoms. These symptoms include nausea, vomiting, pulsatile tinnitus, horizontal diplopia, transient visual obscurations, morning headaches, and positional headaches. Any number of pathologies that occupy intracranial space, increase cerebrospinal fluid production, or reduce cerebrospinal fluid outflow may result in increased intracranial pressure. Diagnostic testing can include an emergency magnetic resonance imaging (MRI), computerized tomography (CT) scan, and/or a lumbar puncture (LP). Treatment of papilledema targets the underlying cause of the increased intracranial pressure, and is guided by the current neuro-ophthalmic literature.

An ocular motor nerve palsy is the weakening of a motor nerve that innervates one or more of the extra ocular muscles. Symptoms may include double vision, blurry vision, difficulty focusing, dizziness, and a droopy eyelid. A variety of local and systemic conditions can cause motor nerve weakness. Investigations can include blood work, an MRI and/or a CT scan. The application of the current neuro-ophthalmic literature is examined, as inappropriate management can have life threatening consequences.

Neocortical intrinsic traveling waves (iTWs) gate perception in behaving primates

John Reynolds
Salk Institute

Perceptual sensitivity varies from moment to moment. One potential source of this variability is spontaneous fluctuations in cortical activity that can travel as waves. These intrinsic traveling waves (iTWs) have been reported during anaesthesia, but it is not known whether they have a role during waking perception. Here, using newly developed analytic techniques to characterize the moment-to-moment dynamics of noisy multielectrode data, we identify spontaneous waves of activity in the extrastriate visual cortex of awake, behaving marmosets (Callithrix jacchus). In monkeys trained to detect faint visual targets, the timing and position of spontaneous traveling waves before target onset predicted the magnitude of target-evoked activity and the likelihood of target detection. iTWs with statistics matching those we observe in vivo emerge naturally as a general property of large-scale computational model with topographically-organized connectivity and conduction delays relevant to biological scales. By modulating local network state, iTWs can shape responses to incoming inputs as observed in vivo. The traveling waves that occur in the model are sparse, with only a small fraction of neurons participating in any individual wave. Consequently, they do not induce measurable spike correlations and remain consistent with locally asynchronous irregular states.

Stress during development: Perceptual auditory deficits and neural correlates

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Critical developmental periods for neural plasticity have been best described in sensory cortices. Sensory deprivation and altered experience during these periods of heightened plasticity impair sensory perception. Mechanistically, this arises from alterations in neural mechanisms involving inhibitory neurons, trophic factors, and perineuronal nets in primary sensory cortices. These mechanisms are similarly altered by early-life stress (ELS) in higher neural regions involved with cognition (e.g, frontal cortex, amygdala, and hippocampus). Indeed, ELS is well known to affect cognitive processes involving these regions, including learning, attention, and memory. Yet whether ELS also affects sensory regions and perception is surprisingly unexplored.

To examine the effects of ELS on auditory perception, we have developed a model of early-life stress in the Mongolian gerbil, a well-established model for auditory processing. Our data indicate that ELS impairs the behavioral detection of rapid changes in sounds critical for accurate speech perception. This is accompanied by reduced responses to these sounds in both the auditory periphery and auditory cortex, along with reduced inhibition in cortex. We are systematically investigating the mechanisms underlying these deficits. These ELS effects on auditory responses presumably degrade the fidelity of sensory representations available to higher regions affected by ELS, and could contribute to known ELS-induced cognitive problems.

Toward "reading" and "writing" topographic neural population codes in the primate cortex

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Abstract: A long-term goal of sensory neuroscience is to understand the nature of the neural code in sensory cortex. To demonstrate this understanding, we need to show that we can (1) "read" the code – i.e., use neural signals from a subject's cortex to outperform the subject in a demanding perceptual task and to account for the variability in the subject's perceptual decisions, and (2) "write" the code – i.e., substitute sensory stimulation with artificially evoked, perceptually equivalent, neural responses.
Distributed representations and topography are two key properties of primate sensory cortex. For example, in primary visual cortex (V1), the most localized stimulus can activate millions of V1 neurons that are distributed over multiple mm2, and neurons that are similarly tuned are clustered together at the sub-mm scale and form several overlaid topographic maps. The distributed and topographic nature of V1's representations raises the possibility that in some visual tasks, the neural code in V1 operates at the topographic scale. If this were the case, then the fundamental unit of information would be clusters of similarly tuned neurons (e.g., orientation columns) rather than individual neurons, and to account for the subjects' performance, it would be necessary and sufficient to consider the summed activity of the thousands of neurons within each cluster.
A major goal of my lab's research is to test the topographic population code hypothesis. In this presentation, I will discuss studies that indirectly test the topographic population code hypothesis, and describe our progress toward developing a bi-directional, read-write, optical-genetic toolbox for directly testing this hypothesis in behaving macaques.

Representation of Mouse Vocalizations across Subdivisions of the Inferior Colliculus

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Background: The inferior colliculus (IC) is a midbrain structure that receives ascending projections from all auditory brainstem nuclei. In this study, we characterized IC neural responses to vocal communication calls to understand the information available to higher auditory centers (e.g., thalamus, cortex and amygdala). We report neuronal responses within the three main IC subdivisions to mouse ultrasonic vocalizations (USVs) and several categories of non-USV, mostly broadband calls. We address: 1) whether and how frequency tuning properties of neurons affect their vocalization responses, 2) whether factors other than frequency tuning influence vocal selectivity, 3) how frequency tuning and vocalization response properties are distributed across IC subdivisions, and 4) how these responses might differ between males and females.
Methods: We used multichannel silicon probes to extracellularly record multiunit responses in head-fixed, urethane-anesthetized adult CBA/CaJ mice (male and female, ~4-8 months of age). Frequency tuning and sound level responses were assessed using tones (4-81 kHz) and broad band noise (4-80 kHz) at 0-80 dB SPL. Recording sites were then tested for responses to both pre-recorded and synthesized syllables containing a broad range of spectral components.
Results: For both sexes, the frequency tuning distribution of IC neurons displayed a broad peak centered in the 16-20 kHz range, with a secondary peak above 40 kHz most evident in the central nucleus of the IC. At moderately high sound levels (70 dB SPL peak), most IC neurons across the tonotopic range were responsive to the non-USV calls, even those with low fundamental frequency. The response of high characteristic frequency (CF) neurons to these lower frequency calls was likely the result of stimulus energy in the low frequency tails of high-CF tuning curves. The response to both tonal and stepped USVs was, as expected, most common among neurons tuned above 32 kHz, but was also observed in some neurons with CFs well below the frequencies within these calls. These responses in low CF (< 16 kHz) neurons may result from cochlear distortion products, as proposed by Portfors and colleagues, or from very broad tuning in some of these neurons. There were several key features of these low-CF responses to USVs: 1) they occurred much more commonly in response to stepped USVs than tonal USVs such as flat or chevron calls, 2) they occurred in a larger proportion of neurons from the external (ECIC) and dorsal (DCIC) cortex than in the central nucleus, and 3) there were substantially larger percentages of these responses among females than males, especially in the DCIC and ECIC.
Conclusions: To our knowledge, this is the first report exploring responses in the mouse lemniscal and non-lemniscal IC to a broad range of vocalizations in males and females. These results provide a basis for understanding the nature of projections from the IC through the auditory thalamus to structures such as the amygdala and cortex, and how this information may be processed differently between the sexes.

Multiple salience maps, multiple uses

George Sperling
UC Irvine

Koch and Ullman (1985) proposed a 2D salience map that took features-map outputs as its input and represented the relative importance "saliency" of the features as a scalar (real number). Their computation on the map, "Winner-Take-All," was used to predict action priority. We propose that the same or a similar topographical map is used to compute centroid judgments, the center of a cloud of diverse items. A defining property of salience maps is substance indifference. For example, the centroid task requires subjects to use a mouse to indicate the center of a briefly flashed cloud of items. Subjects can do this equally well whether all the items are identical dots or composed of all different shapes and colors. Similarly, Ss can judge motion direction in successive frames in which the only thing that changes consistently is an area defined as figure, the nature of both figure and ground changing in each new frame. In a brief flash, subjects can as easily and as accurately judge the distance between two totally different objects (defined only by their difference from the background clutter) as between two identical objects. The fact that subjects can make centroid, motion direction, and distance judgments that simultaneously involve the locations of highly different items defined merely as figure versus ground implies that these computations are made on a salience map that records the presence and the location of such items but is indifferent to their substance. In motion and centroid tasks, Ss can also selectively respond to attention-selected subsets of items and ignore distracter items. Here we show that, following a single brief flash of a 24-dot cloud (8 black, 8 red, 8 green dots, all interleaved), Ss can accurately report the centroid of each color—i.e., make three centroid judgments on each trial. These data suggest two reformulations of the classical concept of a salience map: (1) That three centroid computations can occur concurrently means that all our subjects have at least three salience maps. (2) That motion direction, planar distance, and letter-shape identification judgements utilize salience maps means that salience maps are utilized much more widely than merely for a winner-take-all computation to serve priority judgments.