

THIRTY-SECOND ANNUAL INTERDISCIPLINARY CONFERENCE
Teton Village, Jackson Hole, Wyoming
February 4 - February 9, 2007
Organizer: George Sperling, University of California, Irvine

ABSTRACTS

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John Antrobus
CUNY

Fast, Accurate Recognition: Utility and Context: Repetition Priming with Visual Words
Authors: J. Antrobus, M. Duff, Y. Shono, B. Sundaram, R. Farahani, & S. Numanbayraktaroglu

In forced-choice recognition decisions, where forced-choice alternative words are presented after the degraded, masked target, target representation is continuously modified throughout the recognition interval resulting in unpredictable and biased loss of target information. A neurocognitive attractor model suggests how prefrontal and parietal cortical structures learn to collaborate to facilitate recognition of the forced-choice and target words in the lateral occipital and fusiform cortices. Recognition criteria change with available target information: recognition continues until the expected increase in accuracy no longer offsets processing cost.

Recognition bias effects of repetition priming may be attributed to cortical-hippocampal system structures that temporarily bias cortical word representations. The effect extends to letter noise, but is too weak to affect subletter noise, so that priming bias is limited to similar forced-choice alternatives.

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Randolph Blake
Vanderbilt University

Psychoacoustics of a Chilling Sound

Psychologists are fascinated by situations in which the irrational nature of the human mind is revealed. One such instance occurs in the case of hearing: There's no obvious reason why the sound of fingernails scraped over a chalkboard should evoke an emotional reaction in people, but it does and in nearly all of us. What is it about that innocent sound that gives it an emotional charge? As a first step toward answering this question, I created filtered versions of this acoustic event and had listeners rate each version in terms of its aversive quality. I predicted that this sound's shrillness could be chalked up to the high frequency components in the acoustic signal produced by this grating action, but this proved incorrect: it is the mid-range frequencies, not the high frequencies, that make people cringe. In fact, the sound produced by dragging your fingernails over a chalkboard closely resembles the shrill warning cries vocalized by frightened chimpanzees. Is it possible that we cringe because we unconsciously feel frightened?

Ken Britten
UC Davis

Neural Mechanisms of Optic Flow Processing and the Perception of Self-Motion

Gibson proposed in 1950 that moving animals use "optic flow" to guide their locomotion. Both computational and psychophysical work has characterized how observers might represent and utilize such information, and it is quite a tractable problem compared to some higher-level visual tasks such as object recognition. A well-studied group of cortical areas in the primate brain contains neuronal signals well-suited for the analysis of such large-scale motion signals, and a number of labs are working on how such signals represent self-motion and support visually guided behavior. My laboratory has been using a combination of approaches to understand these mechanisms, including psychophysics, electrical microstimulation, and single-unit recording. I will describe experiments relating activity in cortical areas MST and VIP to the perception of heading and present a surprisingly simple account of how neuronal signals can remain stable in the presence of smooth pursuit eye movements. I will also describe recent work in which we seek to understand the cues supporting visually guided steering behavior.

Tom Busey
Indiana University

On the Nature of Privileged Visual Stimuli: An Interaction Between Noise and Inversion Authors: B. Schneider, J. DeLong, & T. Busey

In four experiments we examine the neural correlates of the interaction between upright faces, inverted faces, and visual noise. In Experiment 1, we examine a component termed the N170 for upright and inverted faces presented with and without noise. Results show a smaller amplitude for inverted faces than upright faces when presented in noise, while the reverse is true without noise. In Experiment 2, we show that the amplitude reversal is robust for full faces but not eyes alone across all noise levels. In Experiment 3, we vary contrast to see if this reversal is a result of degrading a face. We observe no reversal effects. Thus, across conditions, adding noise to full faces is a sufficient condition for the N170 reversal. In Experiment 4, we delay the onsets of the faces presented in noise. We replicate the smaller N170 for inverted faces at no delay, but observe partial recovery of the N170 for inverted faces at longer delays. We propose a model in which noise interacts with the neuronal processing properties of inverted faces more so than upright faces and extend this to other domains of visual expertise.

Bruce Cumming

Laboratory of Sensorimotor Research, NEI

Subspace Mapping to Investigate the Origin of Choice Probability

Authors: B. Cumming & H. Nienborg

Simultaneous use of single unit recording and threshold psychophysics has revealed correlations between perceptual choice and firing rate that cannot be explained by the visual stimulus (Choice Probability, CP). Quantitative modeling studies have explained the observed magnitudes with a bottom-up scheme, in which CP reflects an effect of random fluctuations in firing rate upon choice. In order to test this interpretation further, we measured CP using a stimulus which simultaneously allowed the use of subspace mapping to measure stimulus-driven responses. Two monkeys performed a disparity identification task while we recorded the activity of disparity selective neurons in V2. The stimulus was a random dot stereogram in which the disparity was chosen at random (from a discrete distribution) for each 10ms video frame. Signal was added by increasing the probability with which one disparity was presented on a given frame. Calculating the mean response following one video frame, for each disparity, yields disparity response functions (disparity subspace maps). These were calculated separately according to the choice reported at the end of the trial. Trials (with no net signal) on which animals report the preferred disparity have higher mean firing rates. Comparing the subspace maps reveals that a substantial component of this is produced by an increase in the gain of the neuronal response to disparity. We have been unable to generate such large gain changes in simulations in which the pooled response of a neuronal population determines choice. These gain changes resemble the effects of spatial or feature-based attention that have been reported by others. This suggests that a significant component of the CP in this task reflects a top-down process.

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Peter Dixon
University of Alberta

Memory-Based Action

The common view in cognitive science is that action is computed: First, an intention is formed; then, a suitable sequence of motor actions is planned using some form of means-ends analysis; and finally, computations based on feedback loops and servomechanisms are used to control the required movements. In this talk, I develop a different perspective: Detailed movement trajectories are simply retrieved from a large store of actions carried out previously in similar circumstances. The problem for the actor is thus not one of computing movement details, but rather one of framing a suitably precise memory cue that will serve to retrieve an appropriate action. This perspective unifies a wide range of different episodic retrieval accounts of repetition and priming phenomena. Evidence is provided from a range of different tasks in which an actor must select among several different, but equally correct, actions to achieve a given goal.

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Barbara Doshier
UC Irvine

Object Attention: Mechanisms and Dependencies

Limitations of attention sometimes occur for processing multiple attributes of separate objects, but not for multiple attributes of a single object. Object attention has been shown to have effects in high external noise, reflecting external noise exclusion (Han, Doshier & Lu, 2003, Psych. Sci.). Here, we evaluate the evidence for object attention effects in both external noise exclusion and stimulus enhancement, the susceptibility of object attention effects to practice and individual variation, and the role of judgment dissimilarity or judgment framing in the robustness of these effects. We document the relevance of all of these factors in object attention limitations.

James Elder
York University

A Geometric Model of V1 Neural Selectivity

Authors: J. H. Elder, S. J. D. Prince, S. V. David, & J. Gallant

We aim to predict physiological measurements of the neural responses of macaque V1 cells to natural image stimuli. Standard reverse correlation techniques assume neurons to be linear in the pixel domain. However, a majority of V1 neurons are known to exhibit strong spatial nonlinearities that cannot be characterized in this way (Theunissen et al, 2001). Here we propose a simple geometric model of V1 receptive fields that captures both linear and nonlinear properties in a unified way. The key hypothesis is that a V1 neuron is linear not over image pixels, but over the tangent bundle of the image patch within the cell's receptive field. We test this hypothesis against a database of V1 cell responses to natural image stimuli (Vinje and Gallant, 2000). To estimate the model for each neuron, image patches are transformed into a sampled vector bundle representation, and neural responses are regressed against the vector coefficients. We demonstrate how the resulting geometric models capture properties of simple and complex cells in a unified way, and provide an intuitive method for expressing and visualizing both linear and nonlinear neural behaviour.

Randy Gallistel
Rutgers University

Using Information Theory to Better Understand Associative Learning

Using Shannon's theory of information to quantify the information that a conditioned stimulus (CS) conveys regarding the timing of the next unconditioned stimulus (US) gives a parameter-free, quantitatively rigorous account of background conditioning, blocking, overshadowing and relative validity, while also giving for the first time an empirically valid specification and

quantification of the notion of temporal pairing.

David Heeger
New York University

Visual and Motor Adaptation in the Human Mirror System
Authors: I. Dinstein, U. Hasson, N. Rubin, & D. J. Heeger

The human brain is believed to contain "mirror neurons" that specialize in action imitation and understanding. Mirror neurons, as first characterized by single-cell recordings in the macaque monkey brain, respond selectively to particular movements whether executed or observed. The human mirror system, however, has been identified using different functional criteria that did not include movement selectivity. We used an fMRI adaptation protocol to assess movement-selectivity, measuring cortical activity while subjects played the rock-paper-scissors game against a videotaped opponent. Two previously proposed human mirror areas (ventral premotor cortex and anterior intraparietal sulcus), as well as two additional areas (superior intraparietal sulcus and an area within lateral occipital cortex), exhibited both visual and motor adaptation, responding less to repeatedly observed and to repeatedly executed movements than to nonrepeated movements. These results provide clear evidence for movement-selectivity in four cortical areas that are candidates for the human mirror system.

Holly Jimison
Oregon Health and Science University

Embedded Assessment of Verbal Fluency in a Computer Games Environment
Authors: H. Jimison, M. Pavel, P. Bissel, J. McKanna, & K. Wild

Cognitive performance is a key health concern of elders who are at risk for cognitive decline. Maintaining cognitive health is often the most important factor in being able to age in place. However, in standard clinical practice, cognitive screenings are usually performed only at advanced age or if there are already patient or family concerns about cognitive dysfunction. These screening tests, such as the Mini-Mental State Exam, the Kokmen Short Test of Mental Status, and the Memory Impairment Screen, can be performed in a physician's office but are fairly coarse and not particularly useful for the early detection of problems. More complete neuropsychological batteries can be performed to obtain more sensitive diagnostic information, but they are extremely expensive and time-consuming for screening purposes. To address this issue, we have developed an inexpensive approach to embedding elements of standard neuropsychological tests into computer games that are enjoyable for elders to play on a routine basis. Verbal fluency is one such test that has been shown to be predictive of future cognitive decline. This test is focused on semantic processing and recall from long-term memory. The test procedure requires the participants to recall as many words as possible within a fixed time period, given a specific semantic category or one or more phonemic constraints. We have

developed word games on a computer to assess metrics that are comparable to verbal fluency. The frequent measurement of indices of verbal fluency from computer game play on our research system allows us to track within-subject trends over time. This offers the possibility of detecting cognitive changes at an earlier point in time. Additionally, within-subject trends are less susceptible to biases due to educational level, language proficiency, and cultural background.

Peter Latham
University College London

Optimal Decision Making: Random Dots Revisited

Zhong-Lin Lu
USC

Covert Attention Enhances Stimuli & Excludes External Noise in Early Visual Areas

Using external noise analysis and a theoretical framework based on the perceptual template model, we have recently concluded that covert spatial attention operates via two independent mechanisms: (1) excluding external noise/distractors in the target region, and (2) enhancing stimulus in the target location. External noise exclusion is only effective in the presence of large amounts of external noise. Stimulus enhancement only benefits performance in zero or low external noise conditions. In two separate studies, we used BOLD fMRI measurements to investigate the neural mechanisms of covert attention in early visual areas in zero and high external noise. BOLD contrast response functions in retinotopically defined V1, V2, V3, V3a, and V4v areas of the human visual cortex were obtained in these studies. In zero external noise, the impact of attention depended critically on stimulus contrast in all five cortical areas: It is much greater in low stimulus contrast regimes; it diminishes and becomes absent in high stimulus contrast conditions. The impact of attention can be modelled as increased spontaneous activity and amplified stimulus contrast. In high external noise, attention modulated the BOLD contrast response functions differently in different cortical areas. In V1 and V2, attention reduced the BOLD responses relative to the unattended condition when the signal contrast was low, and increased the BOLD responses when the signal contrast was high. In the other cortical areas, attention didn't alter the magnitude of the BOLD responses when the signal contrast was low but increased the BOLD responses when the signal contrast was high. We concluded that (1) in zero external noise, attention simultaneously increases the contrast gain and spontaneous activity of the visual system and therefore the ability of the perceptual system to detect weak signals at the expense of sacrificing its dynamic range; and (2) in high external noise, attention improves visual performance via external noise exclusion by sharpening the perceptual templates in early visual areas.

Ken Malmberg
University of South Florida

Towards an Understanding of Individual Differences in Episodic Memory

There is considerable variability in the level of performance of memory tasks both between and within populations of individuals. A fundamental question is whether and to what degree this variability reflects random versus systematic influences. To the extent that systematic influences are responsible for some of the variability, moreover, to what degree is performance influenced by structural versus strategic influences? In this talk, I will present a theory in which memory tasks can be performed in multiple ways. The strategy adopted is the one that the subject believes will achieve a desired level of accuracy in the shortest amount of time. To better understand the sources of variability in memory performance, I will describe how associative recognition performance is affected by different structural and strategic factors.

Jeff Mulligan
NASA Ames Research Center

Oculomotor Mechanisms Revealed by the Delayed Feedback Paradigm

Recent research results suggest the existence of two distinct mechanisms controlling oculomotor tracking of moving stimuli. A fast, "reflexive" mechanism responds to a subset of visual stimuli, drives vertical vergence, and responds to unattended stimuli, while a much slower, "voluntary" mechanism responds to any visible stimulus but does not drive vertical vergence. Here we probe these mechanisms using the delayed feedback paradigm, introduced by Goldreich, Krauzlis and Lissberger (1992) in experiments with monkeys. In this paradigm, the visual effect of an eye movement is artificially delayed by slaving the position of a target to signals from an eye-tracker. Delayed visual feedback results in oscillatory eye movements, with the period of oscillation varying linearly with the artificial delay. Extrapolating the period-vs-delay function to its x-intercept allows estimation of the internal delay, while the slope of the function is indicative of the control mechanism. Using a dual-Purkinje image eye-tracker equipped with stimulus deflectors, we have applied the delayed feedback paradigm to humans. Results for a variety of stimuli favoring both reflexive and voluntary mechanisms will be presented.

Anthony Norcia
Smith-Kettlewell Eye Research Institute

Periodic Visual Stimuli Lead to Anticipatory EEG Responses in Prefrontal and Occipital Cortex: Results from EEG Source Imaging

Authors: A. M. Norcia, A. R. Wade, M. W. Pettet, V. Vildavski, & G. Appelbaum

Detecting temporal and spatial regularities in the environment is a fundamental aspect of visual perception in the adult and related processes are important in driving the assembly of the visual system during development. At the most basic level, detection of environmental regularities involves feature selectivity and a means of modifying responses and connectivity as a result of previous experience. In normal adults, feature selectivity is well established, but can be modified over both long and short time scales through sensory adaptation and perceptual learning. Here we show evidence of a form of sensory learning: anticipatory responding cued by temporal regularity using a combination of EEG source-imaging and functional MRI techniques.

One example of anticipatory responding comes from a texture segmentation experiment in which a series of 9 disks was periodically introduced and then withdrawn from an otherwise uniform background. Both the disks and the background were comprised of dynamic one-dimensional random textures (similar to a barcode) that were updated at 30 Hz. In one block of trials, the circular disks segmented from the background when their texture orientation was changed by 90 deg (orientation-defined form). In another block, the disks segmented on the basis of a misalignment cue, rather than an orientation cue. The stimuli alternated between uniform and segmented over a total cycle time of 1 sec (500ms "on," 500ms "off"). As control stimuli, we used independent textures in the figure and background region. The controls were otherwise identical to the test stimuli in every respect within the figure and background regions. The only difference was that the disks were always segmented from the background, because their texture never blended into the background.

Whole-head EEG was collected over 128 channels and evoked activity was localized using a cortically constrained minimum-norm inverse. The minimum-norm technique provides a map of current density on the cortical surface where it can be related to retinotopically and functionally defined areas obtained from separate fMRI scans.

The appearance of the segmented figures elicits a well-formed positive-negative-positive response complex that is similar to that evoked by the appearance of conventional stimuli and that is similar for the alignment-defined figures and orientation-defined figures. When we compared the responses from the control conditions (disks always segmented) with those evoked by the appearance and disappearance of the disks, we found that the figure-appearance response begins to deviate from baseline well before the onset of the disks from the uniform background. At this time, prefrontal cortex is active, as is occipital cortex. The occipital activity is maximal in lateral occipital cortex. The lateral occipital regions that are active prior to the onset of the segmented figures are also the areas that are most active post-segmentation onset (200 and 215 msec), but at this time prefrontal cortex activity is reduced. A similar response pattern was also observed with illusory contour stimuli, e.g. anticipatory responses were recorded in prefrontal cortex and in lateral occipital areas that would later show activity specific to the presence of a figure.

Our results are consistent with a memory-based, top-down modulation of occipital cortex by prefrontal areas. Just as attention can be directed to points in space, periodic stimuli may also allow attention to be allocated to points in time, in this case to time points in the future of sequences that are temporally predictable. The primary targets of this modulatory effect appear to be the areas of lateral occipital cortex that will subsequently process the figural aspects of the stimulus.

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Tatiana Pasternak
University of Rochester

Response Demands Modulate Prefrontal Cortex Neurons

Responses of neurons in the prefrontal cortex (PFC) have been shown to reflect the properties of behaviorally relevant sensory information, including visual motion. Recent work has revealed that PFC neurons exhibit direction selective (DS) responses to visual motion used in a delayed match-to-sample task (Zaksas & Pasternak, J. Neuroscience 2006). As the PFC neurons have been implicated in executive control of behavior, we asked whether the directionality of these responses is preserved when the monkeys are asked to ignore stimulus direction and attend to stimulus speed. We recorded from PFC neurons during the working memory task with identical stimuli but two alternative task demands. In one block of trials, the monkeys were required to discriminate direction, and in the other block, the speed of motion. We found that when stimulus direction was not the relevant stimulus feature, DS responses to visual motion, although present during both tasks, were weaker and emerged relatively late. In many cells attenuation of DS resulted from a decreased response to the preferred direction. However, in a subset of cells, weaker DS resulted from an increased response to the antipreferred direction, suggesting active release from the inhibition characteristic of direction selectivity in visual neurons. During the passive fixation task, direction selectivity was also drastically attenuated, with the majority of cells showing a reduction in the response to the preferred direction with little change in the response to the antipreferred direction. Our results suggest the presence of a dynamic gating mechanism by which the prefrontal cortex can modulate stimulus-induced activity in the context of current task demands.

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Misha Pavel
Oregon Health and Science University

Model-Based Assessment of Cognitive Functions from Computer Games
Authors: M. Pavel, H. Jimison, D. Williams, P. Bissel, J. McKanna, & K. Wild

Possible mitigation of prospective cognitive decline using computer games has recently been popularized as a potential approach for neuroprotection in an aging population. However, despite the fact that previous research has demonstrated that it is possible to improve the cognitive performance of elders, several studies suggested that such improvements do not generalize. One of the major impediments to the assessment of longitudinal studies is that the standard neuropsychological tests are cumbersome to administer, inherently variable, and can be applied only very infrequently. During the last couple of years, with the support of NIST/ATP to Spry Learning Co., we developed several games that address a variety of cognitive domains. Among the advantages of the game-based approach are motivation to play and the fact that even the simplest games require multiple cognitive abilities. Although the requirement of multiple cognitive functions provides an opportunity to study the participants' performance in more realistic settings, it makes it more difficult to interpret the data in terms of specific functions such

as working memory and attention. We therefore use simple computational models of basic cognitive processes and estimate the parameters to characterize the elders' performance. We will discuss lessons learned from an analysis of data from a brief pilot study of 30 subjects over 3 months. Interestingly, the analysis of the game performance has led us to consider novel experimental paradigms.

David H. Peterzell
UC San Diego

Cracking Sensory Codes Using Individual Differences: A Review and Manifesto

The careful study of variability allows researchers to extract sensory, cognitive, neural and genetic codes from data, and to discover their functional interconnections. In this review and tutorial, I provide a short history of individual differences in vision and a general framework for extracting neural structure from data. I show that variability in data is often systematic (not due to error) and meaningful. I review how I and a few others have harvested covariance and independence to a) develop computational models of structures and processes underlying human and animal vision, b) analyze and delineate the developing visual system, c) compare typical and abnormal visual systems, d) relate visual behavior, anatomy, physiology and molecular biology, and e) interrelate sensory processes and cognitive performance. My examples will come primarily from my nearly 20 years of factor-analytic research on spatiotemporal, chromatic, and attentional processing in adults and infants. Other examples will include results from modern imaging data (e.g. fMRI), and my most recent work with Ramachandran and others on individual differences in phantom limb pain treatment. Past successes in studying individual differences in vision seem to provide a roadmap for future discoveries.

Alexandre Pouget
University of Rochester

Bayesian Decisions with Probabilistic Population Codes Authors: A. Pouget, W. J. Ma, & J. Beck

The brain often faces the task of making perceptual decisions on the basis of uncertain sensory evidence, e.g. hitting a fast approaching tennis ball. This process has two stages: 1- The accumulation of evidence. What is the probability distribution over the sensory variable given all the evidence available over time? 2- The response selection. Given the probability distribution at decision time, what's the optimal response?

We show that, when neurons exhibit Poisson-like noise, both stages of the decision process can be formulated in terms of simple operations on what we call probabilistic population codes. The accumulation of evidence simply requires a temporal integration of neural activity while response selection can be done optimally through attractor dynamics. This theory works for N-choice decisions where N can take any value, as well as decisions over continuous variables. We

show that this model can fit existing psychometric and chronometric functions, and can account for neurophysiological data for binary decisions. It also makes specific predictions for other types of decisions.

John Reynolds
Salk Institute

Neural Mechanisms of Visual Attention in Macaque Area V4

Extracellular recording studies in the visual system have documented several attention-dependent changes in neuronal response, including increases in firing rate when attention is directed toward a stimulus within a neuron's receptive field. It is not known whether attentional modulation varies across different types of cortical neurons. To examine this, responses were recorded in extrastriate visual area V4 during an attention-demanding spatial attention task. Neurons were then grouped into classes according to the duration of the action potential and the burstiness of the spike train, characteristics that have been found to vary across cell classes recorded in anesthetized animals and slices using intracellular recording techniques. These intracellular recording studies find that narrow action potentials are characteristic of parvalbumin-expressing GABAergic interneurons, corresponding to a type of basket cell and the axo-axonic or chandelier cells. Surprisingly, our sample of narrow spiking cells showed the largest attention-dependent increase in firing rate. This class of cells also exhibits a significant attention-dependent reduction in the Fano factor, a measure of response variability. A second class with broad action potentials, putative burst firing pyramidal cells, shows a more moderate increase in firing rate as well as a significant reduction in the burstiness of the response with attention. Thus, attentional modulation appears to increase the firing rate of inhibitory interneurons as well as pyramidal cells, and modulates the reliability and burstiness of neurons differently across different classes of neurons.

Paul Sajda
Columbia University

Circuitry and Classification of V1 Simple and Complex Cells

We use a large-scale neural network model of striate cortex (V1) to study the extra- and intracellular response modulations for drifting and contrast reversal grating stimuli. Specifically, we study the dependence of these modulations on the neural circuitry. We find that the frequently used ratio of the first harmonic to the mean response to classify simple and complex cells is highly insensitive to circuitry. Limited experimental sample size for the distribution of this measure makes it unsuitable for distinguishing whether or not the dichotomy of simple and complex cells originates from distinct LGN axon connectivity and/or local circuitry in V1. We show that a possible useful measure in this respect is the ratio of the intracellular second to first

harmonic response for contrast reversal gratings. This measure is highly sensitive to neural circuitry and its distribution can be sampled with sufficient accuracy from a limited amount of experimental data. Further, the distribution of this measure is qualitatively similar to that of the subfield correlation coefficient and it is more robust and easier to obtain experimentally.

Keith Schneider
University of Rochester

fMRI Attention Modulation in LGN and Superior Colliculus

Authors: K. A. Schneider & S. Kastner

Multiple visual streams arising from distinct populations of retinal ganglion cells become largely mixed in the cortex but remain segregated in subcortical nuclei. High-resolution functional magnetic resonance imaging and, recently, the application of super-resolution processing techniques have permitted the detailed study in humans of the internal structure of small subcortical structures such as the lateral geniculate nucleus (LGN) and superior colliculus (SC). Here we investigate the effects of sustained spatial attention. In one experiment, subjects fixated and performed a difficult motion coherence task that required attention to one of the two sides of a bow-tie stimulus composed of moving dot fields. As the stimulus slowly rotated in the visual field, the attended and unattended sides of the stimulus passed through the receptive fields of LGN and SC neurons, and the attentional modulation was evident in the difference in the hemodynamic response to the two stimuli. In the second experiment, the bow-tie stimulus was composed of transient objects that differed in color and shape. The subjects' equally difficult task in this experiment was to detect particular feature conjunctions that appeared in one side of the stimulus. The results show that both the LGN and SC are modulated by attention, the SC remarkably so, likely including both the superficial and deeper layers. No variation throughout the structure of the LGN or dependence on contrast sensitivity was noted that would suggest any differential modulation between the magnocellular and parvocellular layers. The strength of attentional modulation in both the LGN and SC was found to be independent of whether the task involved motion coherence or feature conjunctions, which is consistent with a purely spatial mechanism of attention.

Michael Shadlen
University of Washington and Howard Hughes Medical Institute

A Neural Mechanism for Decision-Making

With little sophistication, the spike rates from sensory neurons can be used to approximate useful statistics for decision-making. In the context of deciding between two sensory hypotheses, a simple difference in spike rate between sensory neurons with opposite selectivity is proportional to the log likelihood ratio in favor of one sensory interpretation over another. I will describe neural recording and stimulation experiments that demonstrate the use of such a

difference during decision-making in a 2-alternative direction discrimination task. The accumulation of this difference to threshold (a.k.a. the bound) explains the speed and accuracy of simple decisions. A new probabilistic classification task, similar to the weather prediction task, reveals a direct representation of log probability in parietal cortex. And, if time permits, I will explain how the brain uses elapsed time to decode such probability. Interestingly, the neural computations that underlie such decision-making were anticipated during WWII by Alan Turing and Abraham Wald. Turing applied this tool to break the German navy's Enigma cipher, while Wald invented the field of sequential analysis. In addition to mathematical elegance and winning wars, our experiments suggest that this computational strategy may lie at the core of higher brain function.

Shihab Shamma
University of Maryland

Representation of Speech in Primary Auditory Cortex

Animal behavioral studies suggest that the neural mechanisms underlying speech perception are based upon the common mammalian mechanisms of auditory processing. In order to explore the contributions of innate auditory versus learned mechanisms to the neural encoding of speech, an important step is to determine the representation of phonemes in the auditory cortex of naive nonhuman animals. In this study we examined the responses of single neurons in the primary auditory cortex of naive awake ferrets to various American-English phonemes in the TIMIT corpus. The Timit corpus is a widely used continuous speech database spoken by multiple male and female speakers which includes a time-aligned phonetic transcription. Speech samples from Timit were chosen to represent a diversity of male and female speakers. We presented these stimuli to head-restrained awake ferrets and recorded the responses of 80 primary auditory cortical neurons. For analysis, we segmented the continuous speech samples into sequences of phonemes, which represent the smallest significant units of speech. We characterized the response properties of each neuron as the average peri-stimulus time histogram response to each phoneme (across multiple exemplars of the same phoneme). We then computed the extent to which these phonemes are distinguishable based on these neural responses. Across the population of A1 neurons, we observed distinct patterns of phoneme selectivity that may provide a bottom-up neural basis for low-level phoneme discrimination. Finally, we also computed a distance matrix between all phoneme pairs, and compared it to the well-known analogous confusion matrix measured in humans. This comparison provides insight into the relationship between the neural representation and perception of speech sounds and other complex natural stimuli.

Steve Shevell
University of Chicago

And The Beat Goes On: Bono's Theory of Induced Temporal Modulation
Authors: S. K. Shevell & A. D. D'Antona

The color of a light depends on the context in which it appears, and this context can vary over time. Slow changes in background chromaticity (say, from red to green) induce counterphase temporal variation (from green to red) within a physically constant central test field but only if the temporal frequency of the surround is 3 Hz or less (De Valois, Webster, De Valois, & Lingelbach, Vision Research, 1986). At a higher surround frequency, the surround itself is perceived to vary in time but the central test appears steady (that is, no induced temporal modulation). De Valois et al. (1986) posited a cortical low-pass filter acting on neural signals that mediate chromatic induction. We replicated the classical 1986 results but found also that superimposing two surround frequencies, each of which alone induces no temporal modulation (e.g., 5.0 and 6.25 Hz), causes clear perceived temporal modulation within the test. With superimposed surround frequencies $F1$ and $F2$, the perceived modulation was at the difference (or "beat") frequency $|F1-F2|$. The measurements implicate a neural nonlinearity that results in a distortion product at the difference frequency, with later low-pass filtering that passes only the low frequency beat $|F1-F2|$. As the visionary Sonny Bono crooned in 1967, the beat does indeed go on.

Richard Shiffrin
Indiana University

How Predictive Information Affects Object Identification
Authors: C. Weidemann, D. Huber, & R. Shiffrin

We use short time visual priming (prime word followed by a brief and masked target word, followed by two choices) to investigate visual object identification. In previous research we showed that priming could be changed from positive to negative by changing prime durations (attention) from short to long. We presented a ROUSE model to explain such results: Features from primes join the target percept, and then cannot be distinguished from features produced by the target. The system that evaluates evidence to form object identification deals with this source confusion by discounting evidence from features known to have been in primes. Short primes produce too little discounting (causing positive priming) and long primes produce too much discounting (causing negative priming).

In the present research, we included conditions in which the primes strongly predicted the correct choice. Although both intuition and previous research in other tasks suggest that such predictive information would or could be used to improve performance, this did not occur. The direction and strength of the predictive information did, however, strongly affect performance in other ways, ways that were consistent with the assumption that diagnostic information affected the rate of discounting. The ROUSE model with this addition predicted the complex pattern of results from four studies quite accurately. Although the predictive information could have been used to improve performance (e.g. through use of sophisticated guessing), it appears that the task of object (i.e. word) identification instead causes the visual system to adapt implicitly.

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George Sperling
University of California, Irvine

A Functional Architecture for Visual Attention: Application to Visual Spatial
Attention

Authors: G. Sperling, I. Scofield, & A. Hsu

Visual attention can be directed to instants in time, locations in space, and to specific features. A functional architecture for attention allocation is described and is illustrated for the special case of allocating attention to a specific location or locations. We use a linear systems approach. First, we measure an observer's ability to distribute his or her attention sinusoidally in space as per Gobell, Tseng, & Sperling (Vision Research, 2004, 19, 1273-1296). These sinusoidal data then enable us to make accurate, parameter-free predictions of the same observer's ability to distribute spatial attention in arbitrarily complex requested patterns, i.e. to attend to various locations arbitrarily arranged in space. A basic search task is used throughout. Observers view a 150 msec exposure of an array of 144 disks arranged in a jittered 12x12 array. Observers must find a target (a larger disk in one of 72 attended locations) among the remaining smaller disks (distractors). To force an observer to confine attention to the 72 attended locations, 10 false targets (large disks) are distributed in the 72 unattended locations. In Experiment 1, the 72 attended locations constitute a grating of alternating columns (or rows). Spatial frequency 1 is 6 attended columns adjacent to 6 unattended columns, AAAAAA,UUUUUU. SF2 is AAA, UUU,AAA,UUU; SF3 is AA,UU,AA,UU,AA,UU; and SF4 is A,U,A,U,A,U,A,U,A,U,A,U. In Experiment 2, the 72 attended locations are defined by 8 arbitrarily placed 3x3 blocks among the 144 locations. In Experiment 3, the 72 attended locations are defined by 18 arbitrarily placed 2x2 blocks. From the data of Experiment 1, we derived a spatial acuity function and an attentional modulation transfer function that enabled accurate predictions of performance in each of the 144 locations of Experiment 2, and approximate predictions in Experiment 3 where the extreme complexity of the required distribution of attention itself became a new limiting factor. The attentional model enables predictions of performance in all the less extreme configurations of spatial attention that have been previously studied.

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The Time-Order Error in the Context of a Theory of Global Psychophysics
Authors: R. Steingrímsson & R. D. Luce

In four empirical articles, Steingrímsson and Luce (e.g. in press) have evaluated aspects of theories due to Luce (2004) on global psychophysics of intensity. Considerable support has been found in both audition and vision for the representations. In current efforts, we are extending both the theoretical and empirical work in a variety of ways. Among these is an understanding

and account for what is often called the time-order-error (TOE). In loudness when a tone, x , is presented and a second tone, z , is adjusted to match x in loudness (with all intensities in dB), the TOE may be expressed as $\epsilon_{2,dB} = z(x)_{dB} - x_{dB}$. The subscript of 2 refers to its being the second tone in the sequence being adjusted; an equivalent expression obtains $\epsilon_{1,dB}$. We note first that both the magnitude of the TOE and the direction (sign on the ϵ 's) varies with intensity. Second, from Luce's model we derive two linear expressions and explore their fit to two matching procedures: free adjustment of one intensity to match a standard, and a 2IFC staircase procedure. We discuss marked differences between the two procedures and implications for their use in various experimental paradigms.

Luce, R. D. (2004). Symmetric and asymmetric matching of joint presentations. *Psychological Review*, 111, 446-454.

Steingrimsón, R., & Luce, R. D. (in press). Empirical evaluation of a model of global psychophysical judgments: IV. Forms for the weighting function. *Journal of Mathematical Psychology*.

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Multisensory Adaptation to Temporal Asynchrony
Authors: D. Whitaker, J. Heron, J. V. H. Hanson, & P. V. McGraw

In a typical multisensory temporal order judgement (TOJ), observers are asked which of two stimuli appeared first - "light" or "sound." It has been shown that prolonged adaptation to a suprathreshold asynchrony (e.g. "light" well before "sound") results in a previously synchronous test pairing being perceived in the opposite direction ("sound" before "light"). It has been suggested that this effect is peculiar to audiovisual pairings, since these arise naturally in the world around us from distant events, due to the differential velocity of sound and light (consider the "flash" then "bang" of an exploding firework). We confirm that, if observers are allowed to adapt to the naturally-occurring temporal asynchrony of physically synchronous distant audiovisual events, then via a process of adaptation, perceived synchrony tends to be maintained. In the absence of adaptation (and contrary to several high-profile reports), our observers are categorically unable to maintain perceived synchrony of audiovisual events as a function of observer-source distance. With regard to specificity of the effects to audiovisual asynchrony, it should be noted that the effects also occur for the adaptation condition "sound" well before "light" - a situation which never occurs naturally. Furthermore, we demonstrate similar asynchrony adaptation effects for audio-somatosensory and visual-somatosensory pairings.

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Equisalience Function Analysis
Authors: C. E. Wright & C. Chubb

Equisalience function analysis (EFA) combines an experimental design and a data analysis procedure to investigate basic questions about human functional architecture in the areas of cognition and perception by testing hypotheses about whether cognitive processes have similar access to different sorts of information in the sensory input stream. This talk provides an introduction to the method and describes our research using it to study the ventral-dorsal streams of visual processing. Results from that research help identify three functionally separate streams of visual processing: one that describes and characterizes objects, one that localizes objects in allocentric space and is involved in movement planning, and one that mediates online control of aimed movements to objects. Although EFA does not allow localization of functional streams, the research of others (e.g., Milner & Goodale, 1995; Creem & Proffitt, 2001; Glover & Dixon, 2002) suggests that these functional streams might correspond to those hypothesized in the temporal lobe, the inferior parietal lobule, and the superior parietal lobule, respectively.

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Probabilistic Search 1.0: A New Theory of Visual Search
Authors: L. Zhang & G. Cottrell

Visual search has been extensively researched in recent decades. Numerous psychological experiments have provided abundant data. Among others, two well accepted phenomena are that bottom-up saliency attracts attention and that knowledge of the target affects attention. A number of theories and models have been developed to address how these two factors interact, and computational implementations of saliency maps have shown some agreement with human data. However, so far, no research has asked the fundamental question: "What is the goal of the computation?" In this proposal, we begin to address this question. We will start from an intuitive assumption concerning the goal of the visual system, and develop a probabilistic framework that describes the calculation the system should perform. Within this framework, we propose a model of saliency, why it made its way into the organism over evolution, and how top-down information is used in visual search. Also, the "pop out" of single-feature targets and the "serial search" of targets defined by a conjunction of features falls out naturally from this framework. Then we will show that, within this framework, it is easy to collapse the dichotomy of so called "parallel search" versus "serial search." This notion has been active for more than three decades. Although it has been challenged by more recent experiment results, no other satisfactory alternative explanations have been able to displace this dichotomy. Here we will show that, without the assumption of two separate processes, our framework accounts for the observations. The putative mechanisms of "parallel processing" and "serial processing" are two sides of one probabilistic coin, and there is a continuum between the two. We will also qualitatively discuss some other observations that are easily accounted for by our framework.

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